



Proceedings of the XL CIOSTA & CIGR Section V International Conference

10 – 13 September, 2023 Évora, Portugal

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Presentation

This proceedings book results from the XL CIOSTA & CIGR Section V International Conference. Subordinated to the theme "Sustainable Socio-Technical Transition of Farming Systems", the conference took place at University of Évora, Portugal, from 11 to 13 September 2023.

This book contains the full papers of a selection of abstracts that were the base for the oral presentations and posters presented at the conference.

We would like to thank all the participants who made this conference possible with their work and presentations.

Also thanks to the sponsors and members of the scientific committee, for their important and fundamental contribution to this congress

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Using Microgreen Production to Demonstrate Plant Propagation Techniques for Agriscience Teacher Professional Development

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Abstract

To improve student performance, change in teaching practice is required and professional development is an important aspect to assure teachers are provided with occasions to learn new approaches to teach plant science. Two departments in the College of Agriculture, Forestry and Life Sciences at Clemson University in the USA collaborated to create a professional development experience for agriscience teachers using microgreens in a sterile laboratory. Microgreens are clean, bite size, tender, ready to eat raw or cook quickly and are a commodity for the restaurant industry, being added to salads and as garnishes for entrees. Ease of production, rapid growth rate, and a desirable shelf-life make microgreen production a novel crop to use to demonstrate seed germination and plant propagation processes in secondary agriscience curricula. Teachers who engage in professional development do so to learn strategies and obtain tangible ideas to apply to their daily lessons. Guskey's (2010) model of teacher change provided the theoretical framework applied to this research. Agriscience teachers were invited to attend a 3-day professional development conference, supported by the American Floral Endowment; focused on science, technology, engineering, and mathematics (STEM) concepts related to the horticultural/floricultural industry. A pre/posttest evaluation was utilized to determine participants' knowledge of plant propagation, seed germination and microgreens. After participating in the experience, 75% of participants rated their personal knowledge of microgreens to be at a moderate level compared to no previous knowledge. Participants' definitions of microgreens expanded, and they explained how the seeds were cultivated. Microgreen production is an innovative technique for agriscience teachers to use to engage students and maintain their attention and interest while teaching sexual plant propagation.

Keywords: agriscience curricula, plant science, seed germination, STEM

Introduction

At Clemson University, in South Carolina, USA, two departments in the College of Agriculture, Forestry and Life Sciences collaborated to create a professional development experience for agriscience teachers comparing microgreen production techniques in a sterile laboratory environment and a tabletop production method. Faculty in the Agricultural Sciences Department, Agricultural Education program (AGED) and Plant and Environmental Sciences (PES) department collaborated to create a special laboratory section for five AGED graduate students in the spring of 2017. The intent of the semester long (16 week) laboratory utilized experimental research focused on sexual propagation for microgreen production. The experimental research was conducted in a laboratory setting in the PES department research laboratory and compared the effects of light treatments, either light emitting diode (LED) or fluorescent lighting and utilized a clean room technique versus a tabletop method, classroom technique to harvest and monitor shelf life of the microgreens that were produced.

After conducting the experimental research focused on a comparison of light treatments, nutrient content and shelflife related to the requirements for growing microgreens for human consumption, it was determined that a tabletop production method could be used as a viable technique to demonstrate seed germination and plant propagation processes in secondary agriscience school-based agricultural education (SBAE) program curricula in the United States. AGED students conducted all aspects of the experiment and then in collaboration with AGED faculty prepared lesson plans, with a materials guide, a facility design including specifications and budget, and a 90 - minute professional development seminar for agriscience teachers. The curricular model was developed with the intent to provide an innovative example of a unit of instruction heavily concentrated in science, technology, engineering and math (STEM) for secondary agriscience teachers.

Microgreens are a clean, bite size, tender, ready to eat raw or cooked very quickly commodity for the restaurant industry, being added to salads and as garnishes for entrees (Treadwell, et al., 2020). Ease of production, rapid growth rate, and a desirable shelf-life all make microgreen production a novel crop due to these efficient factors. The brevity of time from sowing to harvest and how microgreens are utilized after harvest make them an efficient and nutritious food. "Harvesting at the first true leaf stage" results in a very young and tender plant (Treadwell, et al., 2020). Ease of production factors allow microgreens to be an innovative method to teach sexual propagation in SBAE programs. Microgreens can be harvested as early as seven to twenty-one days after being sown (Treadwell, et al., 2020), which

aligns well with teaching plant propagation in a SBAE program. Microgreens are also called "super greens or "vegetable confetti" and include plant species such as cabbage, beet, kale, kohlrabi, radish, mizuna, amaranth, swiss chard, broccoli, and mustard (Treadwell, et al., 2020).

To improve student performance, change in teaching practice is required (Guskey, 2010) and professional development is an important aspect to assure teachers are provided with occasions to learn new approaches to teach rigorous standards (Alexander, et al., 1998). Discovery of innovative methods to teach standards while enhancing the science, technology, engineering, and mathematics (STEM) concepts in the content has become paramount to increase student engagement.

Castellano, et al. (2003) outlined school reform efforts that emphasized a need for STEM concepts more typically concentrated on in academic courses to be integrated into career and technical education curricula. Despite the contractual requirements related to maintaining teaching certificates, teachers regularly choose to participate in professional development to become more effective, increase their personal competence, and improve their own professional satisfaction (Fullan, 1991,1993; Huberman, 1995). Realistically teachers who engage in professional development do so to learn strategies and obtain tangible ideas to apply to their daily lessons (Fullan & Miles, 1992). The model of teacher change (Guskey, 2010) depicted in Figure 1 provided the theoretical framework applied to the research we conducted. The goal of professional development has been, to first elicit change in teachers' classroom practices, and second to prompt change in student learning outcomes, which can then impact and evoke change in teachers' beliefs and attitudes (Guskey, 2010).



Figure 1. Model of teacher change (Guskey, 2010).

The objectives for the microgreen laboratory agriscience teacher professional development experience were for participants to be able to 1) demonstrate the process of seed preparation for the growing of microgreens, 2) discuss how to integrate a microgreens project into a school based agricultural education program, 3) design a laboratory facility to propagate microgreens and 3) provide feedback to assist in developing instructional materials for a secondary school-based agricultural education program.

Materials and Methods

Stages of Design for Agriscience Teacher Professional Development

In the first stage of designing the professional development program, 12 agriscience teachers from the state of South Carolina selected the microgreen workshop to attend during an annual teacher in-service training conducted through an interdisciplinary collaboration between the AGED program and the PES department at Clemson University in 2017. The second design stage included feedback from another 11 agriscience teachers in the state of South Carolina who participated in the microgreen laboratory professional development during the summer 2018 agriculture teacher's conference. After evaluating data collected at both microgreens professional development seminars, it was determined that there was an overwhelming interest for teachers to be able to purchase a microgreen propagation laboratory investigation kit and unit of instruction to utilize in their SBAE programs. The researchers determined it was important to take the information provided by the participants and create instructional materials to match the needs of teachers. Therefore, a laboratory investigation kit was created before the next stage of professional development was offered. The third stage of the professional development program was offered in conjunction with the STEM it Up: Everything you need to know to get your floriculture curriculum in bloom, conference in the summer of 2019.

For the STEM it Up conference, agriscience teachers from SBAE programs across the United States applied, were selected, and were invited to attend a three-day professional development conference located at Clemson University. The conference was supported by the American Floral Endowment and the content focused on science, technology, engineering, and mathematics (STEM) concepts related to the horticultural/floricultural industry and highlighted careers in the plant science industry. After a review of applications, 15 agriscience teachers from ten states in the US were



selected to participate. Students in either the AGED or PES programs conducted all aspects of the professional development and developed an agricultural STEM unit of instruction and laboratory investigation kit that included the materials needed to grow microgreens. The professional development experience demonstrated the compared effects of light treatments (LED vs. fluorescent) and utilized clean room versus the tabletop method seed propagation techniques to harvest and monitor shelf life of the microgreens.

Materials

Materials needed for the microgreens laboratory investigation included microgreen seed, mesh bags, thermometer, bleach, distilled water, detergent, 2 containers, metal pole, 3 distilled water bath containers, polyester mats, colored tape, timer, pencil, paper, long handled teaspoons, forceps/scrapers, paper towels, hair nets, face masks, gloves, binder clips, petri dishes, lab coats, and a hot plate. Required equipment included a refrigerator, sink, metal shelving unit, chains for hanging lights, light-emitting diode (LED) light, fluorescent light, safety station, worktables, and a tabletop workstation.

Pre/post Test Evaluation

A pre-test evaluation was administered on the first day of the conference. The evaluation asked why the teachers applied to participate in the conference, the career pathways they taught, how they taught sexual plant propagation in their plant science courses, what resources they utilized to teach plant propagation techniques, and how many instructional days were dedicated to teaching the subject. Participants were asked to define microgreens, use a rating of zero to ten with zero representing no knowledge of microgreens and ten indicating extensive knowledge of microgreens they self-reported their current knowledge of microgreens, and reported if they currently incorporated microgreens into classroom instruction.

On the last day of the conference, a post-test evaluation required participants to rate their new knowledge of microgreens and provide a new definition of the term. They were also asked to rate their likelihood to incorporate microgreens into their unit of instruction using the supplemental resources they received at the end of the conference.

Data Analysis

Data were analyzed using both quantitative and qualitative methods. Descriptive statistics were used to describe the population and compare pre and post test program evaluation responses of the participants before and after each stage of the professional development program. Qualitative data were analyzed and presented by direct quotes as presented from participants responses to open-ended questions and statements. Frequency counts were used to determine percentages of participants likelihood of incorporating microgreens into the curricula after the professional development experience.

Results

The first stage of the professional development focused on microgreens propagation was presented to 12 agricultural education teachers in South Carolina. This workshop demonstrated the skills derived in the experimental study conducted previously by the AGED graduate students. Agriscience teachers who participated in the seminar were overwhelmingly interested in the idea of incorporating microgreens into their SBAE programs with all but one teacher indicating they were "likely" or "very likely" to utilize the topic within their classroom when they taught plant propagation. The teachers unanimously agreed that a laboratory kit would be beneficial for teaching how to demonstrate plant propagation techniques. One teacher expressed interest because "it would be contingent upon overall cost and quantity. In the second stage of the professional development the evaluation found similar results, with all teachers choosing "likely" or "very likely" in regard to utilizing the curricula in their SBAE program. During the second stage professional development, the agriscience teachers also expressed interest in purchasing a laboratory kit with one participant specifically saying, "A 'kit' would be amazing. I find it's easier for my school to agree to order if I can purchase a 'kit' from one vendor."

Career pathways primarily taught by the participants were floriculture, horticulture, and plant systems. Prior participant knowledge on microgreens revealed they had little to no knowledge of microgreens. When asked how they currently taught sexual plant propagation, frequent responses included lecturing and using visual aids such as Microsoft PowerPoint presentations and instructional videos. Other methods reported to be used by the participants to teach sexual plant propagation concepts were described as hands on laboratory activities such as flower dissection, seed propagation, and specific propagation techniques in addition to seed identification, seed collection, germination rate tests and comparing monocot and dicot plant species. The minimum amount of instructional time participants reported teaching sexual plant reproduction was two days, while the maximum time spent was two weeks.

After participating in the conference, over 75% of the agriscience teachers rated their personal knowledge of microgreens to be at a moderate level compared to reporting no previous knowledge before the professional development experience.

Participants' definitions of microgreens expanded, and they explained how the seeds were cultivated. Specific



responses to how their knowledge developed included being able to "grow and harvest" microgreens as well as "feeling confident" they could apply the microgreen production process in the classroom when teaching their own students. Table 1 indicates agriscience teachers' change in definition of microgreens before and after the professional development experience.

Table 1. Agriscience teachers' definition of microgreens before and after a professional development experience.

Before (Pre)	After (Post)		
"Individual leaves of lettuce of other types of greens	"Tiny edible greens used for garnish and		
(Collards)"	extra flavor"		
"The cultivation of lettuce greens maybe	"Harvested the 1 st 3"-shoot +		
hydrononically"	cotyledon "		
nyeropoinceny	cotyledon.		
"I'm not sure I can confidently [define]"	" They only grow to about 3" tall and		
i milot sure i can confidenti y [define]	are ready to harvest total time 1-14 days		
	approx "		
	approx		

At the conclusion of the professional development experience, participants received a microgreens laboratory investigation kit that included curricula and resources to teach plant propagation using the same techniques they practiced learning about seed propagation. Of the responses, 77% of the agriscience teachers agreed that it was 'very likely' and other 23% reported 'likely' they would incorporate the microgreen laboratory investigation kit and resources into their plant science curricula. Table 2 shows agriscience teachers' likelihood of incorporating microgreens into curricula after participating in the professional development experience.

Table 2. Agriscience teachers' likelihood of incorporating microgreens into curricula after a professional development experience.

How likely are you to incorporate microgreens into your plant science curricula?					
Very Likely (77%)	Likely (23%)				
Best training, I have been to this year.	I would like to have the right supplies to get started.				
I have learned so much that I can use in my classroom.	It would be a good start kit to then expand on				
I am much more confident and excited to teach microgreens.	Great hands-on tool to teach students sexual propagation.				
Gives me ideas to bring back to my students	Materials are hard for me to come by, but my students would like it.				

When asked to explain why the agriscience teachers wanted to participate in a professional development opportunity focused on microgreen production, frequent responses revealed the teachers wanted to learn new and engaging ways to teach plant science concepts. Participants reported the experience would help them grow as an educator and incorporate STEM teaching methods into their curricula. Furthermore, two participants indicated "*excitement*" because the professional development content was catered specifically to plant science and finding professional development that is content specific to the horticulture career pathway was a "*very rare opportunity*". Figure 2 depicts an image of the words that were used to describe why agriscience teachers participated in a plant science specific microgreens professional development program.





Figure 2. Reasons why agriscience teachers participated in a plant science specific microgreens professional development program.

Discussion

Agriscience teachers found the microgreens professional development experience to be practical and refreshing. The participants' comments reflected that the topics and activities presented in the microgreens laboratory could be easily integrated into their SBAE curricula to enhance their students learning experience and potentially increase student engagement. Guskey's (2010) model of teacher change reflects this notion by showcasing how interlaced teaching methods and student outcomes can be. The agriscience teachers who participated in the microgreens laboratory professional development opportunities indicated there may not be enough professional development catered to specific career pathways and subjects. To improve the impact of professional development specifically for agriscience teachers the content focus seems to be an important factor they consider before choosing to engage in the experience.

The professional development experience allowed agriscience teachers to become more knowledgeable on content specific to sexual plant propagation in the plant science industry. Participants were able to explore ways to integrate inquiry-based instructional methods using STEM concepts in their curricula through experiential learning about microgreens and careers in the plant science. Microgreens are an innovative way to engage students' attention while teaching sexual plant propagation. Agriscience teachers can incorporate this novel crop into their curricula with ease and allow their students to have an inquiry-based learning experience by sowing and harvesting microgreens. An added benefit to demonstrating sexual plant propagation techniques with microgreens was the average harvest time of seven to twenty-one days which aligned with the average time the agriscience teachers reported spending on teaching sexual reproduction in their SBAE curricula.

Through this professional development, agriscience teachers expanded their knowledge, research skills and confidence in plant science to shift their instructional methods from a more traditional lecture style method to integrate STEM techniques in a laboratory environment. The professional development provided the opportunity for agriscience teachers to explore innovative methods for instruction and catered specifically to their content needs.

Conclusions

Introducing agriscience teachers to the STEM concepts embedded in the production of microgreens was beneficial. Designing professional development offered experiential learning opportunities to improve the participants' teaching effectiveness by using microgreen production to demonstrate plant propagation techniques. The experience also increased the participants' awareness of the array of careers associated within plant science and the horticulture industry. Participants were given microgreen investigation kits and instructional resources to encourage them to immediately implement their new knowledge and skills into the plant science curricula they teach. Providing a curricular resource for teachers would save them time in preparing an innovative unit of instruction. Change in teaching practices can lead to change in student learning outcomes (Guskey, 2010).

The microgreens laboratory investigation kit included a teacher's guide (lesson plans, step-by-step lab manual, videos demonstrating the procedural steps and all supplies used for the microgreen production process (seeds, Hoagland's modified basal salt solution, polyester growing mats, 1020 flats and dome trays with inserts, glass thermometers, mesh bags for seed, and measuring spoons). The teachers were also provided with resources to design a growing facility to add a STEM focused research component to the unit of instruction that was developed. Using the research component, secondary agriscience students would be able to utilize different light sources, such as LED and fluorescent, to determine which is more effective for various microgreen species cultivation practices, potentially enhancing interest in all aspects of the three-component model of agricultural education.

Because cost was a factor reported by agriscience teachers in many SBAE programs where funding was described as limited, it was a priority to keep the price of the laboratory kit as low as possible at a maximum amount of \$200 US



dollars. The microgreen laboratory investigation kits that were provided to the 15 *STEM it Up* participants during the third stage of the professional development were granted at no cost to the teachers through educational support from the American Floral Endowment. Additional research should be conducted to determine how the agriscience teachers who participated in the *STEM it Up* professional development program utilized the microgreens laboratory investigation kits in their SBAE curricula, and to determine if any changes in student learning outcomes occurred and, if changes in the teachers' beliefs and attitudes were evoked as a result (Guskey, 2010).

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Analysis of feeding operations when using a self-propelled automatic feeding system (AFS)

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Abstract

In Austria, dairy farms are predominantly run as family farms. Rising production costs and the shortage of labor increase the need for automation. Automated work aids can make a compensating contribution through reduction and flexibilization. For this case study, different feeding activities using a self-propelled feeding robot and their effects on humans were investigated according to time and ergonomics. The work element method according to Auernhammer (1975) and video analysis with Ortimzeit 6.5 software were used to determine the work time requirements. Ergonomic assessment was performed using the EAWS (Ergonomic Assessment Work Sheet) method to evaluate musculoskeletal risks for an 8 hour shift (Schaub et al. 2012). A work process simulation was performed using the ema Work Designer for temporal (using the MTM-UAS standard time method) and ergonomic analysis (according to EAWS) as well as the design of work activities (Spitzhirn et al. 2022).

For the manual feeding activities, labor time savings, compared to motorized current technology, resulted from 50 % to 84 %, depending on the cattle category and distances traveled. The machine working times behaved in a contrary manner, these were many times higher for the self-propelled feeding robot. In the manual load-accentuated post-processing activities, there were medium biomechanical risks (yellow risk area), which are to be eliminated in the medium term. The potential for optimization lies in the working time required and in load handling by reducing feed losses during distribution and in a higher feeding frequency and/or the autonomous removal of feed remains. The added value of the simulative determination of changes in working time requirements, walking distances and load handling (EAWS, EMA) lies in the efficient and cost-saving procedure.

Keywords: feeding, robotic, working time, work load, working distance

Introduction

In Austria, small to medium-sized dairy farms are managed as full-time or part-time businesses. The ongoing structural change, rising production costs and the decrease in family and external labor as well as the partly professional double workload increase the need for automation (Bundesministerium Land- und Forstwirtschaft, Regionen und Wasserwirtschaft, 2022, 68-73, Landwirtschaftskammer OÖ, 2012). Automation has already started in the dairy barn in the 1970s, with the use of concentrate feeding stations and pedometers, followed by automated milking technology and feeding.

Automatic feeding is primarily understood as the automatic mixing of basic and concentrated feed and a subsequent allocation of feed. The stage of development can range from automated feed presentation to fully automated feeding. Three stages can be distinguished, with the second stage, which includes mixer filling with concentrate and basic feed, mixing and distribution with or without postfeeding, currently being the most widely used. The work is limited to filling the storage bins for basic feed. The first stage is limited to mixing, distributing with or without replenishment, and the third stage additionally includes automated removal and transport of basic feed (cf. Haidn, 2018).

The most recent developments include self-propelled feeding robots, which automatically fill themselves with feed, mix it, transport it, present it and feed it again. They are classified as automation level II and move autonomously along the feeding tables independently of a rail (Reger et al., 2018). Their operating times and effects on the manual feeding work and its working time requirement and load have not yet been investigated in detail in cattle farming, as their use is not yet widespread in Austria due to their novelty.

Materials and Methods

For this case study, a medium-sized dairy farm by Austrian standards with 66 feeding places for cattle over 120 kg was selected, which used a self-propelled feeding robot to feed various categories of cattle in the old and new buildings.

Manual labor that occurred during autonomous feeding were post-processing manual feeding activities that the feeding robot did not perform.

The work element method according to Auernhammer (1975) and video analysis using Ortimzeit 6.5 software and modeling in PROOF (Schick, 2006) were used to determine the work time requirements of the manual activities as well as walking distances during feeding. Ergonomic assessment was performed using the EAWS (Ergonomic Assessment



Work Sheet) method to evaluate biomechanical risks for an 8 hour shift (Schaub et al. 2012). A work process simulation using the ema Work Designer was applied for temporal (using the standard time method MTM-UAS) and ergonomic analysis (according to EAWS) as well as the design of daily feeding activities in cattle farming (Spitzhirn et al. 2022).

Results and Discussion

Feeding with the self-propelled feeding robot corresponded to automation level II, in the automated filling of the ration, mixing, transporting, feeding and pushing. Manual feeding of cattle categories over 120 kg consisted of sweeping feed into the feed table, which the robot lost as part of the distribution away from the feed table, pushing the feed residues together to the end of the feed table, and shoveling the feed residues into the wheelbarrow for distribution to another cattle category or transport to the manure pile.

These postfeeding activities caused an average labor time requirement of 0.43 AKmin (labor minutes) per animal place per day (MIN: 0.29, MAX: 0.88, SD: 0.25) or 2.63 AKh (labor hours) per animal place per year (MIN: 1.77, MAX: 5.33, SD: 1.53) for cows, heifers, and calves over 120 kg, with significant differences by animal category due to differences in walking and driving distances and their group-specific numbers.

Compared to feeding with the feed mixer wagon of the size class 60 cattle (1.77 AKmin as well as 0.43 Mmin per cow and day or 10.8 Akh/cow/year as well as 2.62 Mh/cow and year) according to model calculations in PROOF (after Schick, 2006), resulted in significant savings in daily AKmin of up to 83.5%.

The machine operating times for feed component intake and distribution and robot-related service (control, programming and maintenance) were largely contrary, averaging 7.14 Mmin (machine minutes) per animal place and day or 43.5 Mh (machine hours) per animal place and year.

Autonomous service accounted for 0.28 Mmin/animal place and day or 1.7 Mh/animal place and year. These averaged 16.6 times the feed mixer truck operating hours per day for a similar cattle population. Similar results are available from Mačuhovà (2013) on the rail-guided variant with labor time requirements ranging from 2 to 7.5 Akh/cow/year, depending on the removal technique and herd size.



Figure 1. Manuel and automated feeding work in hours per cattle category place and year

These manual work tasks were predominantly gross motor activities involving load handling while feeding dairy cows, heifers and calves > 120 kg. These came about by shoveling the uneaten feed residues into the disk chest as well as by pushing and emptying the filled disk chest.

The distances covered amounted to almost one kilometer (899 m) per day and 328 km per year across all cattle categories for the actual situation of the example farm as well as of the case study.

There were biomechanical risks in the yellow risk range, which are to be eliminated in the medium term by



optimizing the technology and a different work organization.

When feeding with the feeding robot, there is a reduction in working time for humans of 61% to 87%, depending on the cattle category, herd size and walking distances covered, compared to the motorized variant (feed mixer wagon).

Based on the work process simulation, the daily manual feeding work resulted in walking distances of 899 m per day and 328 km per year. The use of the feeding robot increased the necessary machine working times many times, to about eight times over in the actual situation compared to the feed mixing truck.

By autonomously removing the feed losses parallel to autonomous feeding and/or more frequent feeding, the daily distances (in meters) with load could be reduced by an average of 52.9% for the example farm and by 32% per animal place at higher occupancy density, full occupancy. The working time requirement would be reduced by an average of a further 68.4% for the actual situation of the case study and by an average of 69.3% per animal place, as well as eliminating the critical loads according to EAWS.

Conclusions

The physical relief is similar to the rail-guided feed mixer variants as well as working time savings are significant compared to feeding with the feed mixer wagon. The optimization potential is in the labor time requirement and load handling by reducing feed losses during distribution as well as in the reduction of feed residues by more frequent feeding or in the autonomous removal of these as well as partly redistribution or composting of feed residues. A more cost-effective feeding robotics, combined with renewable electricity energy, is also desirable to enable the use on smaller farms also economically as well as sustainably.

The added value of the simulative determination of changes in working time requirements (PROOF) and load handling (EAWS, EMA) is given in the determination of working time requirements and risks, which do not have to be adapted to people and technology often time-consuming and measured, as well as through rapid derivation of the optimization scenarios time and cost-saving.

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Benefits of Adding Composted Poultry Litter to Soilless Potting Media for the Production of Woody Ornamentals

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Abstract

A common media used for woody ornamentals is a mixture of 8 parts pine bark and 1 part sand (v/v). The objective of this project was to observe the benefits of blending 20%, 40%, and 60% (v/v) of composted poultry litter (CPL) with a bark-sand mix. It was determined that the media mix that contained 20% CPL and 80% of the bark-sand mix met or exceeded the typical concentrations of P_2O_5 , K_2O , Ca, Mg, Mn, and other minor nutrients recommended for fertilizing potting media for ornamental production. Addition of 20% to 40% of CPL to the base mix also provided 64% of the available N common in fertilized media and increased the pH to the recommended range. However, increasing the blend to 60% CPL resulted in an excessively high pH. Measurements of the aeration porosity (AP), total porosity (TP), water holding capacity (WHC), and water capacity per pot (g H₂O/pot) for the four mixes indicated that bark and sand mix had mean values of TP and AP that were higher than the recommended ranges. The water capacity measurements indicated that the mixes with 20% to 60% CPL increased the water per pot at saturation by 8% to 34% as compared to pots filled with the bark-sand mix. After four days of dying the pots that contained CPL in the media contained 12% to 317% more water than pots filled with the bark-sand mix. It was concluded that adding CPL to a container mix could potentially eliminate the need for using granular fertilizer and lime to supply a base-level of fertility for potting media. Additional N fertilizer would be added to containers to meet the needs of the plants grown.

Keywords: Nutrients, Aeration Porosity, Water Holding Capacity, Horticulture, Container Production

Introduction

Success for any container grown, nursery crop, greatly depends on the chemical and physical properties of the potting media. An ideal media must be free of pests (*i.e.*, weed seeds, insects, and pathogens), heavy enough to prevent the pot from tipping over, but light enough to allow ease-of-transport. The mix should retain sufficient water to reduce the need for frequent watering but have enough porosity to allow for good drainage and to provide air for plant roots. Compost has been evaluated as an alternative to peat moss in pine bark media because it offers the advantages of supplying nutrients and improving the physical properties of the media (Robbins and Evans, 2005; Marbles et al., 2010). Disadvantages of including compost in the growing media include possible high salts and fine particle size (Robbins and Evans, 2005).

Peat moss has been a valuable component of many potting mixes since it can be mixed with a variety of materials (*i.e.*, pine bark, vermiculite, sand) to provide media with the desired porosity and consistency. However, peat moss is a non-renewable resource, and decreased availability has caused price increases in some regions of the USA (Herrera et. al, 2006). This has prompted many media manufacturers and growers to search for alternatives that will be more sustainable and cost-effective.

Screened pine bark is a common primary ingredient for soilless potting mixes in the USA (Warncke and Krauskopf, 1983; Buamscha, et al., 2007; Polomski, 2010; Marble et al., 2010). Traditionally, the advantages of pine bark were good availability and low price. It has also been shown to contain sufficient amounts of phosphorus, potassium, calcium, magnesium, zinc, iron, and boron for production of plants in containers (Warncke and Krauskopf, 1983; Buamscha, et al., 2007). The primary disadvantages of pine bark are its high bioavailable carbon content and low pH. Bioavailable carbon can cause immobilization of soluble nitrogen in the container resulting in a reduction of nitrogen that can be taken up by the plant (Marble et al., 2010; Franklin et al., 2015). Low pH, on the order of 5.0, requires addition of lime to raise media pH if plants require a pH of 6.0 or more to grow efficiently.

One of the problems with modern livestock and poultry operations is the large amount of manure generated in concentrated areas (Marble et. al, 2010). Land application of poultry litter to cropland has been the main form of manure utilization, but federal and state regulations on animal farms has caused many in the animal industries to consider composting as an alternative manure treatment option. The resulting compost product could be used to enhance soil structure and provide nutrients for fruit and vegetable production, and container ornamental production (Marbles et al., 2010). A study by Marbles et al. (2010) indicated that several types of woody ornamentals could be successfully grown using several container media made by blending composted poultry litter (CPL) with wood chips and pine bark (*Rhododendron; Buxus sempervirens* L.; *Ilex crenata* Thunb.; *Loropetalum chinese* Oliv.; *Ternstroemia gymnanthera*).



Poultry litter is a good choice as a component for making compost. It is relatively dry and can be transported to the composting facility and mixes easily with other high-carbon ingredients such as wood waste, yard waste, and crop residues. Poultry litter also has a higher concentration of major and minor plant nutrients than other types of animal manures.

Field experience and research studies have shown that compost can be a valuable addition to a potting mix resulting in improved plant growth (Herrera et al., 2007; Marble et al., 2010). However, very little information is available that relates amount of compost added to a potting mix to the chemical and physical properties of the mix. The chemical properties of interest included pH, and concentrations of major plant nutrients (organic-N, soluble-N, P, K), secondary and minor plant nutrients (Ca, Mg, S, Zn, Cu, Mn, Fe), sodium, carbon, and organic matter. The physical properties that were important in evaluating a potting media were the aeration porosity (AP), water holding capacity (WHC), total porosity (TP), and dry bulk density (BD). The ideal amount of compost to add to potting mix would be the amount that adds plant nutrients that are similar to fertilized media blends used in the nursery industry while providing enhance aeration porosity and water holding capacity to maximize plant performance.

Another media characteristic that is rarely quantified is the water capacity of a container which was defined in this study as the mass of water per pot of media (g W/pot). Addition of compost to a pine bark and sand base mix was expected to add large amounts of organic matter and was expected to enhance the amount of water contained in a pot at saturation and after drying for several days. This simple measurement was expected to provide insight into the potential to reduce irrigation by using compost as a potting media ingredient.

Four potting media mixes were formulated that contained 0%, 20%, 40%, and 60% compost on a volume basis. The base mix (0% compost) was composed of 8 parts screened pine bark (PB) and 1 part sand on a volume basis. This base mix was selected because it was a simple, low-cost mix that was commonly used for production of woody ornamentals (Polomski, 2010). The compost used in this study was obtained from a local producer and was made from a mixture of broiler breeder litter, wood waste and cotton gin waste.

The primary objective of this study was to observe the impact of blending 20%, 40%, and 60% (v/v) of composted poultry litter (CPL) to a standard bark-sand mix on the concentrations of major, secondary, and minor plant nutrients, sodium, carbon, organic matter, and key physical properties including aeration porosity, total porosity, water holding capacity, bulk density, and the water capacity (g W/pot). The secondary objective was to compare the plant nutrient and mineral composition of the three blends of CPL and base mix with the nutrient contents of the base mix blended with a commercially available slow-release granular fertilizer.

Materials and Methods

Several bags of pine bark were obtained from a potting media manufacturer located in Anderson, South Carolina. The pine bark had been screened to exclude particles greater than 6.35 mm, but it still contained more fine particles than desired. For most nursery container mixes, 70% to 80% (by volume) of the particles should be in the range of 0.61 to 9.54 mm (Robbins and Evans, 2005). The pine bark was screened again with a 2.0 mm screen to yield material with particles that ranged from 2.0 to 6.35 mm. The arithmetic mean particle size of the screened pine bark used to make the base mix in this study was 4.18 mm.

Composted poultry litter was obtained from a commercial composting operation in South Carolina. The proprietary compost recipe included broiler breeder litter, cotton gin trash, and wood shavings. Composting was carried out in open windrows and when active composting was completed, as indicated by the lack of temperature rise after turning, the windrows were covered with a porous geotextile and allowed to cure. The finished product was bagged using an in-field bagging machine. Several bags of the finished compost product were transported to Clemson University to be used in the study.

Four potting media mixes were formulated by mixing 0%, 20%, 40%, and 60% of the composted poultry litter (CPL) with a bark-sand base mix on a volume basis. The base mix was a mixture of 8 parts screened pine bark and 1 part builder's sand (Polomski, 2010). The ingredients not included, but would normally be added by a nursery producer, were lime for pH adjustment and a granular slow-release fertilizer (SF). The other three potting mixes were made by mixing 1 part CPL with 4 parts base mix (20% CPL mx), 2 parts CPL with 3 parts base mix (40% CPL mix), and 3 parts CPL with 2 parts base mix (60% CPL mix).

Chemical properties

The bags of composted poultry litter were stored in three covered, plastic storage bins. Three well-mixed, samples of compost were taken from each storage bin to provide three replicate samples for analysis. The screened pine bark was stored in a separate plastic bin and three well-mixed samples of pine bark were also collected. The volume of each of the samples was about 500 mL and each replicate sample was placed in a sealable plastic bag and transported to the Agricultural Services Laboratory at Clemson University for analysis. Each of the compost and pine bark samples were analysed to determine the concentrations of total nitrogen (TN), total ammoniacal nitrogen (TAN = NH_4 - $N + NH_3$ -N), nitrate-N (NO₃-N), total phosphorous, total potassium, calcium (Ca), magnesium (Mg), sulphur (S), zinc (Zn), copper



(Cu), manganese (Mn), iron (Fe), sodium (Na), and aluminium (Al). The total P and total K were reported as P_2O_5 and K_2O to correspond with commercial fertilizer specifications. Other characteristics measured included: moisture content (MC), total carbon content (C), organic matter content (OM), pH, electrical conductivity (EC₅), and dry bulk density.

Standard laboratory procedures were used for all analyses and details are summarized online by the laboratory director of the Agricultural Services Laboratory at Clemson University (ASL, 2023a and ASL, 2023b). The concentrations of TN and C were determined from a dried and ground sub-samples using the Elementar procedure. The TAN concentrations were measured by mixing a representative 2 g sub-sample in a flask containing 20 mL of KCl (2 M) followed by standard digestion and acid titration techniques. This method included the small amount of NH₃-N that was present in the samples. As a result, it provided a measurement of the total ammoniacal nitrogen (TAN). The NO₃-N content was determined using the cadmium reduction method for solid manures. The organic-N content (Org-N) was calculated as:

$[Org-N] = [TN] - [TAN] - [NO_3-N].$ (1)

All other elements (P, K, Ca, Mg, S, Zn, Cu, Mn, Fe, Al, and Na) were measured using ICP Mass Spectrometry (ASL, 2023b). The moisture content of all replicate samples was determined by drying a sub-sample in an oven maintained at 105 °C for 2.5 to 3 h and determining the weight of the dry matter fraction (DMF). The moisture content (%) was calculated as: MC = 100 (1-DMF). The organic matter was determined by burning a dry sample in a 360° C furnace for 2.5 h. The OM was expressed as the percent of the dry matter and was calculated as the difference between the dry weight and the ash weight divided by the dry weight. The pH was measured after mixing a 15 mL sub-sample with 15 mL of deionized water and soaking for 30 min. The pH of the resulting solution was measured using a pH analyser.

The electrical conductivity (EC₅) was determined by making a 1:5 dilution of the sample with deionized water (ASL, 2023a). After allowing the slurry to equilibrate, an electrical conductivity meter was used to measure the conductivity in mmhos cm^{-1} .

Physical properties

The physical properties included the total solids (TS), volatile solids (VS), bulk density (BD), aeration porosity (AP), water holding capacity (WHC), and total porosity (TP). The aeration porosity, water holding capacity, and total porosity were measured using a chamber that was designed for that purpose. Also, the initial, or antecedent, moisture content of the media was taken into account when determining the water holding capacity to improve precision.

Total solids (TS) and fixed solids (FS) of the compost, pine bark , and builders' sand were measured using standard oven-drying techniques (APHA, 1995). Each of three replicate samples was dried in an oven at 105 C for 24 hours. Total solids content was determined after the sample was allowed to cool in desiccator. Fixed solids content (ash) was determined by incinerating the dried solids in a furnace at 550 C for 24 hours, allowing the sample to cool, and determining the sample mass. Volatile solids were calculated as the difference between the total and fixed solids. The moisture content was calculated as 100 – TS (%). The fraction of the TS that was VS (VS/TS) was calculated from the data to describe the composition of the dry matter. A high value of VS/TS indicated the lack soil and minerals in the material and would be indicative of a soilless media ingredient (*i.e.*, pine bark). A very low value of VS/TS would indicate that a media ingredient was low in organic matter and contained mostly minerals or soil.

Bulk density

The density of the composted poultry litter, pine bark, sand, and each potting media mix was measured using a calibrated aluminium container (323 ± 1.71 mL). The density of each media ingredient or mix was determined by filling the calibrated container with a well-mixed sample, measuring the mass of the sample, and dividing the sample mass by the container volume. Three replications were performed for each material. The dry bulk density (g DM cm⁻³) was calculated as the wet bulk density (g sample cm⁻³) divided by the dry matter fraction (g DM g sample ⁻¹).

Aeration porosity, water holding capacity, total porosity

The aeration porosity, water-holding capacity and total porosity of a potting media, or individual ingredient, is typically measured and reported on a wet volume basis. The total porosity is defined as the percentage of the media that is occupied by open pores on a volume basis at saturation. The defining relationship for the total porosity (TP, %) used was (BCMA, 2015):

$$TP = (PV / MV) 100,$$
 (2)

where PV is the water added to saturate media and fill pore volume (mL), and MV is the volume of solid media and pores (mL).

The aeration porosity is defined as the percentage of saturated media which is occupied by air after completely draining water from the media by gravity. The volume of the water drained ($V_{DRAINED}$) was measured and represents the volume of the pores occupied with air at 100% water holding capacity. The aeration porosity (AP, %) was calculated as (BCMA, 2015):

$$AP = (V_{DRAINED} / MV) 100.$$
(3)

The water holding capacity is defined as the percentage of the media and pore volume that is occupied by water at



(4)

(7)

(8)

saturation. The suggested water holding capacity (WHC) equation given by BCMA (2015) was:

$$WHC = TP - AP.$$

Calculation of WHC using Eq. (1) and Eq. (2) did not account for the antecedent moisture content prior to adding water to reach saturation and fill the pore volume. To account for the antecedent moisture, the defining equation for the water holding capacity was rewritten as:

WHC =
$$(V_{TW} / MV)$$
 100. (5)

The total water volume (V_{TW}) was the amount of water contained in the media plus the amount of water required to bring the media to saturation and fill the pore volume. The total water volume was calculated based on the antecedent moisture content and the volume required to reach saturation as:

$$V_{\rm TW} = 1/\rho_{\rm w} ({\rm MC_I} / 100) \ge {\rm M_{PM}} + {\rm V_{WR}},$$
 (6)

where ρ_w is the water density (1g mL⁻¹); MC_I is the initial moisture content of media (wet basis, %); M_{PM} is the mass of potting media before adding water (g); and V_{WR} is the volume retained by media after draining (mL). The volume of water retained was defined as the difference in the volume of water added (VA_{DDED}) to fill the total pore space and the volume of water drained. The water volume retained (V_{WR}) was calculated as:

$$V_{WR} = V_{ADDED} - V_{DRAINED}$$
.

The total porosity was calculated using Eq. (3) for AP and Eq. (5) for WHC as:

TP = AP + WHC.

A test chamber was designed and constructed to facilitate the measurement of the aeration porosity, and water holding capacity. The chamber was constructed from a section of acrylic pipe with an inside diameter of 14.6 cm and a height of 8.25 cm. The bottom was a round, 0.635 cm thick piece of acrylic sheet that was chemically welded to the pipe to form a water-tight seal. Three 0.813 cm holes were drilled in the bottom of the chamber and were fitted with rubber stoppers that were flush with the inside surface of the bottom of the chamber when fully inserted. A circular piece of plastic window screen (1.27 mm openings) was placed in the bottom of the test chamber to retain the media while water was allowed to drain from the pore volume. The chamber was placed on a level metal rack that facilitated the collection of water drained from saturated potting media in a container. The chamber was calibrated to a volume of 1364,7 mL which corresponded to the volume of media contained in commonly used 15 cm diameter pots.

The test chamber was used to determine the aeration porosity and the water holding capacity of screened pine bark, the base mix (8 parts PB and 1 part sand), and the three mixes that contained 20%, 40%, and 60% CPL using the following procedure.

1. The media to be tested was placed into a large plastic container and water was added to increase the moisture content. It was determined that if extremely dry media was used the pine bark would float and it would take a prohibitively long time to saturate the media. After water was added to the media a tightly fitting cover was used to minimize evaporation between replications.

2. A large sample of the moistened potting media was removed from the storage container and the moisture content was measure using standard oven drying techniques (105 C oven for 24 h). This provided a measure of the initial or antecedent moisture content and was used in Eq. (6).

3. The test chamber was filled with media to the 1364.7 mL mark. This was the value used for media volume (MV) in Eq. (3) and (5). The chamber was dropped onto a hard surface from the height of 7.6 cm four times and additional media was added to re-fill the container to the 1364.7 mL mark. This was done to ensure consistent compaction for all replications of all four potting mixes.

4. The test chamber full of media was placed on a level rack and a plastic container was placed below the rack.

5. Water was slowly added to the media using a graduated cylinder until the solids were completely saturated and the pore volume was full. When this had been achieved, no air bubbles were present in the media and the surface of the media glistened. The total volume of water added (V_{ADDED}) was recorded and was used in Eq. (7).

6. The three rubber stoppers were removed, and water was allowed to drain from the pore space of the media until all dripping stopped (approximately 1 h per replication). The total amount of water that drained from the test chamber was measured using a graduated cylinder and was recorded. The volume drained ($V_{DRAINED}$) was used in Eq. (3) and (7) and the calculation of the AP and WHC was completed.

This procedure was followed for three replications of each of the four potting mixes as well as screened pine bark.

Chemical composition of the potting mixes

The plant nutrient, sodium, carbon, and organic matter concentrations, bulk density, and pH were measured for screen pine bark and the composted poultry litter. The only properties measured for the sand that was used to make the base mix were the moisture content and the bulk density. The pH of the sand was not measured; however, the pH of sand was about 7.0 according to the literature (FM&T, 2017). The concentrations of all the elements and compounds (% d.b.) contained in the four potting mixes were calculated using the mean values for two ingredients using the following formula:



(9)

$$[C_{j MIX}] = [(\Pi_{j1} BD_1 V_1 + \Pi_{j2} BD_2 V_2) / (BD_1 V_1 + BD_2 V_2)] \times 100,$$

where $[C_{j MIX}]$ is the concentration of nutrient C_j of the mixture of the two ingredients (% d.b.); Π_{j1} is $[C_{j1}]/100$ (g C_{j1} g DM_1^{-1}); BD₁ is the bulk density of ingredient 1 (g DM cm⁻³); V₁ is the volume of ingredient 1 (cm³); Π_{j2} is $[C_{j2}]/100$ (g C_{j2} g DM_2^{-1}); BD₂ is the bulk density of ingredient 2 (g DM cm⁻³); and V₂ is the volume of ingredient 2 (cm³).

The chemical composition of the base mix was calculated first using the concentration data and measured BD for the screened pine bark (ingredient 1) and the BD of the sand (ingredient 2). It was assumed that the sand did not contribute plant nutrients to the base mix. The volume of the pine bark was 800 cm³ (V₁) and the volume of the sand was 100 cm³ (V₂). The bulk density of the base mix was calculated based on total mass of dry matter in the mix and the total volume of the mix ($V_T = V_1 + V_2$) as:

$$BD_{MIX} = (BD_1 V_1 + BD_2 V_2) / V_T.$$
(10)

The pH and moisture content of a mix of two ingredients was calculated as a weighted average based on the volumes of the two ingredients as:

$$pH_{MIX} = pH_1 (V_1/V_T) + pH_2 (V_2/V_T)$$
, and (11)

$$MC_{MIX} = MC_1 (V_1/V_T) + MC_2 (V_2/V_T).$$
(12)

After the chemical concentrations ([C_{jMIX}]), BD_{MIX}, pH_{MIX} and MC_{MIX} of the base mix were calculated the composition of each of the three mixes that contained 20%, 40%, and 60% composted poultry litter were calculated using Eq (9) through Eq. (12) using the base mix results as the first ingredient and the data for the composted poultry litter as the second ingredient. The total volume of mix used in the calculations (V_T) was 1000 cm³. The 20% CPL mix used 800 cm³ for the pine bark (V₁) and 200 cm³ for the CPL (V₂). The volumes for the other two mixes were V₁ = 600 cm³ and V₂ = 400 cm³ for 40% CPL, and V₁ = 400 cm³ and V₂ = 600 cm³ for 60% CPL.

Comparisons of the base mix fertilized using compost with base mix fertilized using granular fertilizer

A common practice in commercial woody ornamental production is to add slow-release pellet fertilizer (SF) to large volumes of container media to provide base-levels of TN, P_2O_5 , and K_2O fertility prior to filling pots with media (Warncke and Krauskopf, 1983; Yeager et al., 2010). After planting, additional fertilizer is provided either through irrigation water or by surface application of granules to meet the specific needs of the plants being produced. Many fertilizer formulations are available, but a commonly used product contained 14% TN, 14% P_2O_5 , and 14% K_2O . Recommended fertilizer application rates for general fertilizers that provide secondary and minor plant nutrient (*e.g.*, Ca, Mg, Mn, Zn). However, pine bark often provides sufficient amounts of these nutrients (Buamscha et al., 2007; Marble et al., 2010).

Mixing CPL with the base mix used in this study was expected to provide P_2O_5 , K_2O , and many secondary nutrients that would typically be added to media via application of commercial fertilizers. The large amounts of stable organic-N provided from the CPL may provide an extremely slow-release form of N that is currently unavailable in other organic ingredients or fertilizer products. In order to compare the nutrient contents of the three mixes containing CPL with a typical fertilized media the concentrations of plant nutrients that would be achieved by blending 2 and 5 kg of slow-release fertilizer (SF) per m³ of base mix were calculated using Eq.(9) and Eq. (10) assuming a SF analysis of 8.2% NH₄-N, 5.8% NO₃-N, 14% P₂O₅, and 14% K₂O with a BD of 1.205 g/cm³ (data obtained from product specifications). This allowed comparison of the nutrient composition of the unfertilized base mix, the base mix blended with 2 kg SF m⁻³, the 20% CPL mix, the 40% CPL mix, and the 60% CPL mix. The nutrient concentrations of all six of these blends were converted to a volume basis ([VC_{j MIX}]; g C_{j MIX} m⁻³) using the following formula:

$$[VC_{jMIX}] = 1,000,000 BD_{MIX} [C_{jMIX}]/100.$$
(13)

Water capacity and water content

An experiment was performed to observe the effect of the amount of CPL used in a potting mix (0%, 20%, 40%, and 60%) on the mass of water contained per pot at saturation and after moisture was lost by evaporation over a period of four days. This was accomplished by bringing three pots of the four media mixes to saturation and then measuring the mass of water per pot, mass of DM per pot, and the water content (g W g DM^{-1}) at saturation and four days later. All the pots of media were randomly placed on a laboratory table in an air-conditioned room to provide a common thermal and convective environment for all pots.

The nominal 15 cm diameter pots selected for use in this experiment were made from plastic to eliminate loss of water through the sides of the pots. They also had only one hole in the bottom to facilitate bringing the contents of each pot to saturation and then allowing pore water to drain. A total of six pots were used for each of the four potting mixes to give a total of 24 pots for the study.

The experiment was initiated (day 0) by filling all the pots with the selected mix to a known volume (1364.7 mL) using the same compaction procedure as used to determine the aeration porosity and water holding capacity. Rubber stoppers were used to plug the whole in the bottom of the pots and water was added to bring the pot to saturation. After the pot was at full capacity, the pot was placed on a rack and the stopper was removed to allow the pore water to



completely drain. After six pots of a particular media were saturated with water three pots were selected and the entire contents were emptied onto a foil pan and weighted to determine the total mass (DM + W) per pot (g/pot). A large sample of the pot contents was used to determine the moisture content (MC, %) using standard oven drying techniques. The average of the three measurements was used to determine the mass of dry matter per pot (g DM/pot), the mass of water per pot (g W/pot), defined as water capacity, and the water content (WC, g W g DM⁻¹) for each of the potting mixes. After allowing the remaining 12 pots to air dry for four days the pot contents were analysed in the same way to determine the mass of water remaining in each pot, the mass of water that had evaporated, and the final water content and moisture content for each of the potting mixes. The results were used to determine if adding CPL to a bark-sand mix had an impact on the water capacity per pot at saturation and after four days of drying, and the mass of water evaporated over four days.

Results and Discussion

The chemical and physical properties of the screened pine bark, composted poultry litter and sand used to formulate the four potting mixes are compared in Table 1. The values shown are the means of three observations along with the standard deviations (s). The only measurements that were included for the sand were the bulk density, moisture content, and VS/TS.

	Screened		Poultry Litter	· Based		
	Pine Bark		Compost - Cl	րլ		
	Mean	S	Mean	S		
	(% d.b.)	(% d.b.)	(% d.b.)	(% d.b.)		
TAN	0.00	0.000	0.00	0.000	_	
Org-N	0.33	0.035	0.96	0.043		
NO ₃ -N	0.00	0.000	0.12	0.011		
TN	0.33	0.035	1.08	0.053		
$P_2O_5^A$	0.12	0.063	2.45	0.589		
K ₂ O ^B	0.22	0.040	0.82	0.179		
Са	0.33	0.027	4.35	0.986		
Mg	0.11	0.016	0.36	0.085		
S	0.05	0.006	0.20	0.046		
Zn	0.004	0.00003	0.02	0.0051		
Cu	0.001	0.00001	0.02	0.0043		
Mn	0.014	0.0006	0.02	0.0052		
Fe	0.298	0.0066	0.67	0.1404		
Na	0.023	0.0062	0.15	0.0383		
Al	0.380	0.005	1.19	0.209		
С	52.40	0.647	9.94	0.502		
OM	92.57	0.145	13.67	1.041		
					Sand	
					Mean	S
C:N	161:1	15.7	9.2:1	0.07	NM ^C	NM
EC₅ (mmhos cm ⁻¹)	2.56	0.182	0.71	0.254	NM	NM
рН	5.10	0.173	7.33	0.058	7.0 ^D	NM
Moisture (%)	59.4	0.38	25.6	5.14	3.7	0.328
BD (g DM cm ⁻³)	0.164	0.002	0.607	0.052	1.143	0.010
VS/TS	0.994	0.0014	0.182	0.0023	0.0028	0.0003

Table 1 Chemical and physical properties of the pine bark compost and sand used to make the four potting mixes

To convert P_2O_5 to total P divide by 2.29.

^B To convert K_2O to total K divide by 1.21.

^C NM = not measured.

^D pH of sand (FM&T, 2017).

Comparison of the concentrations of the major plant nutrients indicated that CPL contained 3.3 times more TN than screened pine bark. All the TN in pine bark was in the organic form whereas 89% of the TN in CPL was organic. Composted poultry litter contained a small amount of soluble N as nitrate and neither ingredient contained any ammonium-N (TAN = 0). The compost contained 3.3 times more P_2O_5 and 20 times more K_2O than the pine bark. While the pine bark contained significant, but small amounts, of the secondary and minor plant nutrients, the CPL contained 13 times more Ca, 3.3 times more Mg, and 1.4 times more Mn than pine bark.

Pine bark contained more C and OM than CPL resulting in a much higher C:N ratio for the pine bark. The C:N of the pine bark was 161:1 as compared to 9.2:1 for the composted litter. The high C:N of the pine bark would be expected immobilize a large portion of the soluble N provided by any type of N fertilizer (Franklin et al., 2015). Addition of low



C:N compost to a potting mix would be expected to lower the C:N and improve N availability.

The sodium content in CPL was higher than for the pine bark. However, the electrical conductivity (EC₅), which is a general indicator of soluble salts, was much lower in the CPL. While neither ingredient had an excessively high EC₅ (Marble et al., 2010), blending the two ingredients would be expected to lower the EC₅ of the CPL and pine bark blends.

The high value of VS/TS for the pine bark, 0.994, indicated that it contained very little soil. The very low VS/TS of the sand indicated that it was clean and not contaminated with organic matter.

Finally, the pH of the pine bark was very low at 5.1 and was slightly higher than other published values (Baumscha et al., 2007; Marble et al., 2010;). The higher pH of the CPL would be expected to improve the pH of the mix when blended with pine bark and sand.

As expected, the bulk density of the sand was the greatest and the MC of the sand was the lowest. The BD of the pine bark was essentially the same as published values provided by Baumscha et al., (2007) and BCMA (2015). The extreme variation in ingredient moisture contents mandated that all blending calculation be performed on a dry matter basis.

Characteristics of the base mix and the three compost-base mix blends

The dry matter concentrations of all the measured nutrients and elements were calculated for the base mix (8 parts PB:1 part sand) and the three CPL blends using the data shown in Table 1 with Eq. (9). The results are provided in Table 2.

Table 2. Co	omposition and	characteristics	of the base	potting mix	and the	three mi	ixes containing	20%, 40%,	and 60% c	omposted
				noultry lit	tor (CDI))				

	Base Mix	20% CPL	40% CPL	60% CPL
	(% d.b.)	(% d.b.)	(% d.b.)	(% d.b.)
TAN	0	0	0	0
Org-N	0.176	0.455	0.643	0.778
NO ₃ -N	0.000	0.042	0.070	0.090
TN	0.176	0.497	0.713	0.868
$P_2O_5^A$	0.064	0.916	1.488	1.899
K ₂ O ^B	0.117	0.368	0.537	0.658
Ca	0.179	1.669	2.669	3.387
Mg	0.058	0.165	0.237	0.288
S	0.024	0.087	0.130	0.160
Zn	0.002	0.009	0.014	0.018
Cu	0.001	0.007	0.011	0.014
Mn	0.007	0.013	0.016	0.019
Fe	0.159	0.342	0.464	0.552
Na	0.013	0.063	0.096	0.121
Al	0.203	0.557	0.795	0.966
С	28.0	21.6	17.2	14.1
OM	49.5	36.7	28.1	21.9
C:N	160:1	43:1	24:1	16:1
pH ^C	5.3	5.7	6.1	6.5
BD (g $DM \text{ cm}^{-3}$) ^D	0.273	0.340	0.407	0.473
Moisture (%) ^E	53.2	47.7	42.2	36.6

^A To convert P_2O_5 to total P divide by 2.29.

^B To convert K_2O to total K divide by 1.21.

^C Calculated using Eq. (11).

^D Calculated using Eq. (10).

^E Calculated using Eq. (12).

As expected, blending CPL with the base mix resulted in substantial increases in the concentrations of all major, secondary, and minor plant nutrients. The TN concentration was increased by a factor of 2.8 to 4.9 as the percentage of CPL increased from 20% to 60%. Also, adding CPL added nitrate-N to the media that was equivalent to 8% of the TN for the 20% CPL mix to 10% of the TN for the 60% CPL mix. Adding CPL to the base mix decreased the carbon content from 28.0% for the base mix to 14.1% for 60% CPL mix. The increase in TN and decrease in C provided a large decrease in C:N that would be expected to improve the availability of the Org-N (Franklin et al., 2015). This result would be expected to reduce fertilizer N requirements for growing most woody plants which may reduce fertilizer costs. The addition of CPL to a pine bark and sand mix will most likely eliminate the need to purchase secondary or minor plant nutrients. The most undesirable increase was for Na. However, the Na contents of all the CPL blends was lower than for the CPL alone (Table 1).



The weighted average pH and moisture contents were calculated from the measurements of the ingredients (Table 1) using Eq. (11) and (12) and are also provided in Table 2. Addition of CPL decreased the MC of the mixes because the CPL happened to be dryer than the pine bark. The pH of all four mixes was increased by adding sand and CPL. The base mix had a pH below the preferred range of 5.5 to 6.4 (Warncke and Krauskopf, 1983), but adding 20% to 40% CPL to the base mix increased the pH to 5.7 and 6.1 which would be suitable for growing many plants. Addition of 60% CPL to the base mix increased the pH to 6.5 which was considered undesirable since high media pH will reduce the availability of Fe and other minor plant nutrients and is to be avoided (Warncke and Krauskopf, 1983; Yeager et al., 2010). Therefore, the 60% CPL blend in this study would be undesirable, and the high pH would eliminate it from further consideration in most practical applications.

Most nursey managers add slow-release granular fertilizer (SF) to soilless media to provide a base level of N, P_2O_5 , and K_2O fertility. Typical application rates are 2 to 5 kg of SF per cubic meter of media. In addition, expressing the nutrient concentrations in potting media on a volume basis (g $C_{j MIX}$ m⁻³) is more useful in practical applications. The mass-based concentrations of the four mixes given in Table 2 were converted to volume basis using Eq. (13) and are provided in Table 3. The plant nutrient concentrations resulting from mixing 2 to 5 kg SF m⁻³ with the base mix are also shown in Table 3 to provide a basis for comparison with the mixes blended with composted poultry litter.

Not all of the organic nitrogen contained in pine bark or compost will be mineralized during the growing season. Several publications have indicated that bark-based soil amendments tend to immobilize soluble-N severely requiring increased N fertilization to achieve good plant growth (Buamscha et al., 2007; Marble et al., 2010; Yeager et al., 2010). Franklin et al. (2015) measured the release of organic-N for fourteen soil amendments that included un-composted pine bark soil conditioners and several types of compost. They reported the following correlation to estimate the mineralization factor (m $_{fCS}$, g N released g Org-N applied ⁻¹) for the range of products included in their study (Franklin et al., 2015):

$$m_{fCS} = 0.139 - 0.0036 \text{ C:N}, \text{ } \text{R}^2 = 0.84.$$
 (14)

Table 3. Comparison of plant nutrient contents, C:N, and pH of the pine bark and sand base mix blended with 2 to 5 kg m⁻³ of a commercially available slow-release fertilizer with the mixes blended with 20% to 60% composed poultry litter.

		Base	Base			
		Mix ^A	Mix ^A			
		+ 2 kg SF	+ 5 kg SF			
	Base Mix	m ⁻³	m ⁻³	20% CPL	40% CPL	60% CPL
	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)
TAN	0	164	408	0	0	0
Org-N	479	478	477	1547	2614	3681
NO ₃ -N	0	116	289	143	285	428
TN	479	758	1174	1689	2899	4109
m fCS	-0.44	-0.22	-0.10	-0.02	0.05	0.08
PAN-est.	-211	175	649	112	416	722
PAN-est/TN	- 44%	23%	55%	7%	16%	18%
P_2O_5	175	455	872	3113	6051	8989
AP ₂ O ₅ -est	0	280	697	1245	2420	3596
AP ₂ O ₅ -est/P ₂ O ₅	0%	62%	80%	40%	40%	40%
K ₂ O	319	598	1015	1252	2184	3117
Са	489	488	487	5672	10854	16036
Mg	158	158	158	561	963	1365
S	67	66	66	297	528	758
Zn	5	5	5	32	59	86
Cu	2	2	2	23	44	65
Mn	20	20	20	43	66	89
Fe	435	434	433	1161	1888	2615
Na	34	34	34	213	392	571
Al	555	555	553	1894	3233	4572
С	76530	76403	76213	73291	70052	66813
OM	135197	134973	134638	124748	114299	103850
pH	5.3	5.3 ^B	5.3 ^B	5.7	6.1	6.5
C:N	160:1	101:1	65:1	43:1	24:1	16:1
BD (g DM $/cm^3$)	0.273	0.275	0.277	0.340	0.407	0.473

^A Slow-release granular fertilizer (SF) contained 8.2% NH₄-N, 5.8% NO₃-N, 14% P₂O₅, and 14% K₂O with BD = 1.205 g cm⁻³, volumetric concentrations, pH, and BD calculated using Eq.(9) through (13).

Actual pH was unknown. However, it was expected to be similar to the base mix.

The correlation provided by Franklin et al. (2015) was used to estimate the amount of Org-N that would be released during a growing season based on the C:N of the mixes (Table 2). The plant available nitrogen was estimated for each

(15)

mix using the following relationship:

$$[PAN-est] = m_{fCS} [Org-N] + [TAN] + [NO_3-N].$$

The PAN estimates given in Table 3 indicate that the large amount of bioavailable carbon in the base mix would be expected to immobilize N at the rate of - 211 g N m⁻³ greatly inhibiting plant growth. Addition of 2 to 5 kg SF per m³ to the base mix overcame the N-deficit to provide 175 to 649 g PAN per m³. The proportion of the TN that was estimated to be available ranged from - 44% for the unfertilized base mix to 55% after adding 5 kg SF per m³.

Replacing the granular fertilizer with 20% to 60% CPL resulted in a sharp decrease in C:N which resulted in PAN estimates ranging from 112 to 722 g PAN per m³. Limiting the addition of CPL to 40% to avoid high media pH, indicated that adding 20% to 40% CPL to the base mix would be expected to provide enough N to overcome the PAN deficit caused by the un-composted pine bark and yield enough PAN to provide a low-level of N fertility. Adding 20% CPL to the base mix would provide 64% of the PAN provided by application of 2 kg SF m⁻³ to the base mix. Likewise, the 40% CPL mix would provide 64% of the PAN associated with the 5 kg SF/m⁻³ rate. Therefore, blending CPL with the base mix could reduce the need for N fertilizer by about 64%.

The phosphorus contained in compost and bark-based soil amendments is also not all available to a plant during the first growing season (Rynk et al., 1992; Franklin et al., 2015). Franklin et al.(2015) observed the release of P in a laboratory incubation study of a soil conditioner that contained chopped pine bark and forest by-products. Their results indicated that soil amended with such a product would experience immobilization, release ,and re-immobilization of P over a full growing season (214 d). Therefore, none of the P_2O_5 contained in un-composted pine bark could be relied upon to grow a plant. The fraction of P released for pine bark (PR_f, g P released g P applied ⁻¹) was set to zero for practical estimation. The full-season P release for manure-based compost products ranged from 24% to 64% which was similar to the range of 25% to 40% reported by Rynk et al. (1992). The value of PR_f used to estimate the availability of P₂O₅ for the blends that contained CPL was 0.40 which was about the average observed for manure-based compost (Rynk et al., 1992; Franklin et al., 2015). The general relationship that was used to estimate the available P₂O₅ (AP₂O₅-est) contained in the mixes was:

$$[AP_2O_5 - est] = PR_f [P_2O_5]_{MIX} + [P_2O_5]_{SF},$$
(16)

where $PR_f = 0$ for the base mix fertilized with fertilizer (SF); and $PR_f = 0.40$ for base mix fertilized with CPL.

The results shown in Table 3 indicate that the 20% CPL mix provided about 1.8 times more available P_2O_5 than the mix fertilized with 5 kg per m³ of a fertilizer containing 14% P_2O_5 . Therefore, blending a small amount of CPL with the base mix would be able to eliminate the need for granular P_2O_5 fertilizer.

Potash (K₂O) contained in compost products and organic materials have the same availability as commercial fertilizers (Rynk et al., 1992). As a result, compost can often be used as a K₂O fertilizer substitute. The 20% CPL mix provided 1.2 times more K₂O than a 14% K₂O granular fertilizer applied at 5 kg per m³. If the plant being grown requires a high level of K₂O blending 30% to 40% CPL with the base mix may provide adequate fertility for more than one growing season.

Blending the base mix with only 20% CPL provided more secondary and minor plant nutrients per m³ of mix than the pine bark alone. These results indicate that using a compost product similar in composition to the one used in this study would eliminate the need to purchase a secondary and minor nutrient product to blend with potting media.

Blending the base mix with 20% to 40% CPL could potentially eliminate the need for a granular SL fertilizer to provide a base-level of TN, P₂O₅, and K₂O fertilization for bark-based container media. The CPL provided about 64% of the available-N that would normally be provided by fertilizer. The additional N needed could be added later through irrigation water or by surface applying granular N fertilizer after filling pots. The amount of additional N would depend on the N rates recommended for the type of plants produced. The increase in media pH provided by application of CPL may also reduce the amount of lime needed. The results suggest that blending CPL with a bark and sand base mix could greatly reduce fertilizer and lime cost for a commercial producer of woody ornamentals. The optimal formulation would need to be determined by testing the mix by way of a small growth study using the actual plants to be produced.

These results only apply directly to the materials used in this study. However, another type of compost could be evaluated in a similar manner by having samples of the soilless media and compost analysed for plant nutrients, carbon, and bulk density and following the calculation procedures described with Eq.(9) through Eq.(16). If the compost being considered contained less nutrients than the CPL used in this study, then the percentage of compost in the optimal mix may be larger than 20% to 40% compost.

WHC, AP, TP, BD, and water capacity (g W/pot)

Proper plant growth is affected by the physical properties of the potting media. A good media must retain adequate water and air. As a result, the aeration porosity (AP) and the water holding capacity (WHC) are of great importance. A media that does not retain enough water at saturation will also tend to lose excessive amounts of soluble nutrients via drainage water resulting in a decrease in the efficiency of fertilizer use. The AP and WHC were measured for the for potting mixes using the previously described procedure with Eqs. (3), and (5), and the total porosity (TP) was calculated from the results, Eq.(8). The bulk density of each of the mixes was calculated from measurements described previously

(Methods). The means of these physical properties are compared in Table 4.

the four potting mixes.							
	Pine Bark	Base Mix	20% CPL	40% CPL	60% CPL		
	(PB)	(BM)	(C20)	(C40)	(C60)		
WHC (%)	44	46	48	50	46		
Different from	None	None	None	None	None		
	De	esirable range for WHC	= 45% to $65%$ ^B				
AP (%)	38	30	18	15	12		
Different from	BM,C20,C40,C60	PB,C20,C40,C60	PB,BM,C60	PB,BM,C60	PB,BM,C20,C40		
	Γ	Desirable range for AP =	10% to 20% $^{\mathrm{B}}$				
TP (%)	82	76	66	65	58		
Different from	BM,C20,C40,C60	PB,C20,C40,C60	PB,BM,C60	PB,BM,C60	PB,BM,C20,C40		
	Ι	Desirable range for TP =	50% to 70% $^{\rm B}$				
BD $(g_{DM}/cm^3)^A$	0.16	0.31	0.37	0.42	0.47		
Different from	All	All	All	All	All		

Table 4. Water-holding capacity (WHC), aeration porosity (AP), total porosity (TP), and bulk density (BD) of screened pine bark and the four potting mixes.

^A These bulk densities were measured after formulating the base mix and the three mixes that were blended with CPL as described in Methods.

^B Robbins and Evans (2005)

A one-way analysis of variance (Steel and Torrie, 1980) was used to calculate a pooled variance for the screened pine bark, base mix, and mixes that were made by mixing 20%, 40%, and 60% CPL with the base mix. The least significant difference, using the 95% level of probability, was calculated from the pooled variance as: $LSD = t_{0.025,edf} (2 SP^2/r)^{0.5}$. Where, the error degrees of freedom (edf) was 10, and the number of replications per treatment was 3 (r). The LSD values were used to test for differences between treatment means for each of the physical characteristics. The comparison between treatment means was also provided in Table 4.

Surprisingly, addition of CPL did not influence the water holding capacity (WHC) on a percent volume basis. However, all the mixes had a WHC within the desirable range of 45% to 65% (Robbins and Evans, 2005).

Neither the screened pine bark nor the base mix would provide proper aeration as indicated by AP values that were greater than the desirable range of 10% to 20% (Robbins and Evans, 2005) indicating that addition of another ingredient such as sphagnum moss or peat moss would be needed to improve AP. Blending the base mix with 20% to 60% CPL decreased the AP to the desirable range with the 40% CPL mix being in the middle of the desirable range at 15%. Comparison of treatment means indicated that the AP for the 20% CL and 40% CPL mixes were not significantly different, and both were significantly different from the 60% CPL mix. These results indicate that mixing 20% to 40% of the compost used in this study with the base mix provided the needed improvement in AP and may eliminate the need for other organic media ingredients, such as peat moss. The 60% blend of the compost product used in this study was already shown to elevate the pH of the mix too much (Table 2) and would not be recommended.

The total porosity (TP) of the base mix was too high when compared to the desirable range of 50% to 70% (Robbins and Evans, 2005). Addition of 20% and 40% CPL to the base mix lowered the TP to 65% and 66% indicating that both mixed provided the needed improvement in TP.

A pot should be heavy enough to prevent tipping due to plant weight or wind. Addition of CPL resulted in a significant increase in the dry bulk density of potting media and would be expected to reduce pot tipping. Comparison of the measured bulk densities of the mixes given in Table 4 with the calculated values given in Table 2 indicated good agreement. The differences between the measured and calculated bulk densities for the three mixes that contained CPL ranged from - 8.8% for 20% CPL to 3.0% for 40% CPL. The greatest difference between the measured and calculated BD was for the base mix at 10.6%.

The ability of a potting media to hold water, g W/ pot, has an impact on the frequency of watering. It was hypothesized that adding CPL to a bark and sand potting mix would increase the mass of water available to a growing plant and may alter the rate of water loss from a pot by evaporation. The impact of adding CPL to the base mix on the water capacity was observed by measuring the mass of dry matter, mass of water, and the water content in 15 cm pots after bringing the media to saturation and then allowing the pots to dry for four days as described previously (Methods). The results are shown in Table 5.

Addition of composted poultry litter to the base mix had a significant effect on the mass of dry matter (g DM/pot) and water in a container at saturation (g W/pot). Blending CPL with the base mix at the rate of 20% to 60% increased the mass of dry matter per pot by 20.9% to 54.6% as compared to the base mix. At saturation, the mass of water per pot was 7.7% greater than the base mix when the mix contained 20% CPL. Doubling the CPL percentage to 40% increased the mass of water held in the container to 20.0% more than the base mix which was a 2.6-fold increase over the 20% CPL mix. Increasing the CPL percentage from 40% to 60% CPL provided an additional increase in water mass by a factor of 1.7 (34.1% more water than the base mix). The total mass per pot (DM + W) also increased by 13.4% to 43.1% as the percentage of CPL in the mix was increased. Therefore, addition of compost to a bark-sand base mix



increased the mass of the potting mix as well as the mass of water held by the mix at saturation.

Table 5. Pot water contents obtained by analysis of entire po	ot contents at saturation and after 4 days of drving in the laboratory.
In the second seco	

	Base Mix	20% Compost	40% Compost	60% Compost
Saturation Conditions				
Mass of DM, g DM/pot	302	365 (+ 20.9%) ^A	414 (+ 37.1%)	467 (+ 54.6%)
Mass of Water, g W/pot	390	420 (+ 7.7%)	468 (+ 20.0%)	523 (+ 34.1%)
Total Mass, g/pot	692	785 (+13.4%)	882 (+ 27.5%)	990 (+ 43.1%)
WC at saturation, g Wg DM ⁻¹	1.29	1.15	1.13	1.12
Moisture, % wet basis	56.3	53.5	53.1	52.8
After 4 Days of Drying				
Water Remaining, g W/pot	316	355 (+ 12.3%) ^B	407 (+28.8%)	413 (+30.7%)
Total Evaporation, g W/pot	74	65	61	110
Evaporation Loss, %	19.0	15.5	13.0	21.0
WC, g W g DM ⁻¹	1.05	0.97	0.98	0.88
Moisture, % wet basis	51.1	49.3	49.6	46.9

^A Comparison with the mass per pot for the base mix at saturation .

^B Comparison with the mass per pot for the base mix after 4 days of drying.

The saturation water content decreased from 1.29 g W g DM⁻¹ for the base mix to 1.15 g W g DM⁻¹ for the 20% CPL mix. As the percentage of CPL was increased to 40% and 60% the saturation WC continued to decrease by small amounts as shown in the table. This unexpected result was due to fact that adding compost to a bark-sand mix increased both the dry matter and the amount of water in the mix. The moisture content, on a wet volume basis, was also provided for the four mixes in Table 5 and the value decreased in a similar manner as the water content. Previous measurements of water holding capacity (WHC, Table 4) indicated that addition of CPL did not significantly impact the water holding capacity of the base mix. However, the measurements at saturation shown in Table 5 indicate that addition of CPL provided an increase in mass of water held in a container. The difference was due to that fact that water holding capacity was calculated on a wet, volume basis whereas the evaporation study was carried out on a dry mass basis. This seemingly contradictory result was because mass is conserved in a thermodynamic system and volume is not. In short, the mass of water contained in a pot of media (g W/pot) provided the most straightforward indication of the amount of water retained to grow a plant.

After four days of drying the mass of water remaining in the pots was measured which allowed calculation of the amount of water lost by evaporation. The 20% CPL and 40% CPL mixes lost the least amount of water to evaporation as compared to the base mix and the 60% CPL mix. However, all three CPL blends contained more water after 4 days of drying than the base mix. The mass of water per pot for the 20% CPL mix was 12.3% greater than the base mix and the 40% CPL mix contained 28.8% more water than the base mix after 4 days of drying. Therefore, the results from this study indicate that adding CPL to a base mix would improve water retention per pot and that measurements of WHC and WC did not provide a clear indication of the potential water saving benefits of adding a compost product to bark-based container media.

Conclusions

Sample analyses and experiments were conducted to determine if composted poultry litter (CPL) could be used to fertilize a base mix that was formulated by mixing 8 parts of screened pine bark with 1 part sand. The compost product was mixed with the base mix at the rates of 20%, 40%, and 60% on a volume basis. The plant nutrient concentrations of the base mix and the three CPL-base mix blends were compared with common plant nutrient concentrations provided by fertilizing the base mix with a 14-14-14 granular fertilizer at the rate of 2 to 5 kg per m³. If was found that the 20% CPL mix and the 40% CPL mix could replace granular fertilizer for P₂O₅, K₂O, secondary, and minor plan nutrients included in the study. The CPL blends could also replace about 64% of the available N needed to fertilize a potting media. Additional N fertilizer could be added after filling and planting the containers based on plant needs. The higher pH of the CPL may also allow a commercial producer of woody ornamentals to greatly reduce lime requirements since adding CPL to the base mix increased the pH from 5.1 to 5.7 for the 20% CPL mix to 6.1 for the 40% CPL mix. The mix containing 60% CPL had a pH of 6.5 which was considered too high for many practical uses.

Measurements of the aeration porosity (AP), and water holding capacity (WHC) indicated that the base mix in this study did not meet the recommended values. Adding 20% to 40% CPL to the base mix yielded potting media that met the recommendations for AP and WHC. It was also observed that blending CPL with the base mix at rates of 20% to 40% increased the water contained in a pot by 8% t 20% at saturation and by 12% to 29% after 4 days of drying as compared to the base mix. Therefore, CPL has the potential to eliminate the need to add sphagnum or peat moss to the media to improve these physical characteristics.

It was concluded that mixing CPL with a bark-sand base mix has the potential to eliminate the need for nonrenewable ingredients, such as peat moss, and to reduce the cost for fertilizer for a commercial nursery. The use of other



types of compost can be evaluated using the measurements and procedures provided in this study. The final decision concerning the use of a compost product should be made after growing some trial pots of the plant that is to be produced.

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Improving Monitoring of Broiler Production Through an Early Warning System Employing Low-Cost Environmental Network in Tropical Climates

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Abstract

Providing environmental thermal comfort conditions for broilers is challenging for any intensive production system. Heat stress events have severe impact in the productivity levels because the long time the birds required to recovered. Thus, a tool that allows moving from corrective actions to preventive ones, based on measurement of environmental variables of broiler facility and superficial body temperature of birds, is required. For this, a real-time wireless environmental monitor network based on low-cost sensors was developed for monitoring the microclimatic conditions of three groups of broilers, located in 2x2 m2 sheds each one, from 7 to 28 days growth, in order to find the solution in real time to avoid thermal stress that could generated productivity and loss of birds, that it is very common in small and medium farms.

The sheds were located inside a natural ventilated facility located in Antioquia, Colombia. The network consists of three modules. The first one was located in the exterior of the facility to measure the dry-bulb temperature, relative humidity, wind velocity, solar radiation and atmospheric pressure. The second and third ones were located inside each shed to measure the dry-bulb temperature, relative humidity, and computing the superficial body temperature of the birds using an infrared thermal camera and a custom made open-source image analysis software. The third module also received the measurements from the other modules, compute thermal index and send the information in real-time through a hosted bot from the Telegram instant message application.

It was found that the birds were repeatedly subjected to stress conditions, negatively impact their wellness. The wireless network successfully sent warning messages when microclimatic conditions were not favourable, proving to be a reliable system to provide relevant and timely information for decision-making.

Keywords: poultry, bioclimatic, stress, thermography. precision livestock farming

Introduction

Smart farming could represent the application of modern and important information and communication technologies to animal production systems. According to Ivanov et al (2015) and Elijah et al (2018) cited by Saqib et al (2020), The Smart Farming can potentially deliver productive and sustainable agricultural production based on a precise and resource efficient approach. Furthermore, the sensors in agricultural farms allow farmers to obtain detailed data in real time as variables, such as soil and ambient temperature, irrigation water and soil conductivity, and soil or irrigation water pH, and microclimates variables as temperature, relative humidity, radiation and others, in animals facilities.

In farm systems fields many researchers have been developing some works using new technologies with low cost sensors, in order to obtain more suitable information looking to improve de animal behavior and production, for instance, Maroto et al (2019) carried out a work with the objective of develop a low-cost solution to enable the monitorization of a whole herd, and an IoT-based system, which requires some animals of the herd being fitted with GPS collars connected to a Sigfox network and the rest with low-cost Bluetooth tags, was developed, and it was proved the system effectiveness for the monitorization of all the animals in a herd. In this field, despite the advances in GPS-based technologies for animal tracking in recent years, several constraints limit their use as PLF tools in commercial farms, especially in the case of extensive production systems (Davis et al, 2011).

Other important application field, it is how big data can help detect animal diseases earlier than conventionally possible. For example, Sadeghi et al (2015) recorded broiler vocalizations in healthy and Clostridium infected birds. Similarly, they found as infection may lead to discernible differences inmovement patterns and the surface temperature of animals, leading to earlier diagnosis or even prediction of disease outbreaks.

De Oliveira et al (2017), developed an Android mobile applications to determine animal thermal comfort indices in order to apply in poultry facilities.



At a broader level, Neethirajan (2020), wrote a paper in order to explores the challenges and opportunities that sensor technologies present in terms of helping animal farmers produce more meat and animal products. More specifically, that paper explores the role of sensors, big data, artificial intelligence and machine learning in helping animal farmers to lower production costs, increase efficiencies, enhance animal welfare and grow more animals per hectare. It also explores the challenges and limitations of technology. The paper reviews various animal farming technology applications to understand its value in helping farmers improve animal health, increase profits and lower environmental footprint.

In practice, these advanced technologies can be used to determine optimal solutions to many animal farming problems. A few examples include finding optimal solutions to minimize costs, maximize production, increase efficiencies and create optimal diet formulations (Ferguson, 2014).

Obando et al (2020) and Rowe et al (2019) concludes that future works should focus on the improvement of PLF systems and commercial uses, to improve animal welfare and its productive potential, and It will be an important challenge in special in tropical and subtropical countries, where the facilities have a different configurations compare with Europe and USA installations, which it is in part the focus of this paper.

Materials and Methods

Location

The tests were carried out at the Universidad Nacional de Colombia Agrarian Station, located in 6º07'56"N 75°27'17"W at 2.154 m above sea level. m.o.s.l, in Medellín - Colombia. The Agrarian Station has an average temperature of 16.2 °C, mean RH of 82 % and rainfall average of 2,645mm, and it is located in a tropical climate.

Experimental broiler house

The research was carried out in three 2 x 2 m² experimental sheds, that have been working with natural ventilation, with a bird density of 21 birds per m², from 7 to 28 days of age, and the birds were distributed as male and female mixed for each shed, respectively (Figure 8).



Figure 1. Experimental broiler houses. a) Internal sheds; b) External equipment; c) Internal equipment

Experimental development

The tests were carried out during 21 days, and each experimental shed was the repetition during the experiment. Their primary food was the same commercial concentrate for all three sheds evaluated.

The External unit was based on the ESP8266-12 microcontroller (Espressif Systems), It was used to measurement the environmental variables such as dry bulb temperature and relative humidity (SHT31 sensor; accuracy ± 0.3 °C and ± 2%), solar radiation flux density (LP02 pyranometer; measure range 0 to 2000 W/m²) and air speed (C2192 cup anemometer; accuracy ±0.2 m/s). The ADS1115, analog to digital converter (16-bit resolution; I2C communication protocol; Texas Instruments, USA), was used to amplify the signals from the pyranometer and from the anemometer.



Internal monitoring unit was based on the ESP32-WROOM32 microcontroller (Espressif Systems) used to measurement dry bulb temperature and relative humidity (SHT31 sensor; accuracy ± 0.3 °C), black globe temperature (DS18B20 temperature sensor inside a 8 cm diameter black metal sphere; accuracy ± 0.6 °C) air speed (hot wire Rev. P6 wind sensor; measure range 0-67 m/s). The ADS1115, analog to digital converter (16-bit resolution; I2C communication protocol; Texas Instruments, USA), was used to amplify the signal from the hot-wire anemometer. The measurement data, include the ones received from the external environmental unit, was recorded in a microSD module every 5 seconds.

To measurement the variables relative of the bird, It was used a small single-board computer Raspberry Pi 4B (https://www.raspberrypi.org/) with built-in Wi-Fi capability. This unit was also provided with a dry-bulb temperature and relative humidity sensor (SHT31 sensor; accuracy \pm 0.3 °C). The principal function of this unit was to monitoring the surface temperature of the birds by means of a thermal camera (Lepton 3.5; 160 x 120 active pixels; FLIR, USA) connected to an acquisition module (PureThermal 2; GroupGets, USA). The thermal images acquisition was done using the open-source OpenCV image processing library (https://opencv.org/) for Python's programming language (https://www.python.org/), at a rate of five frames per second. The images were arranged in a video file with AVI extension, with one-minute length, each one.

The values obtained with the thermal camera were aligned with the measurements of the temperature of the birds, that were taken manually using a thermography camera FLIR (Range -20 - 1200 °C, Accuracy ± 2 °C or 2 %). Then, it was possible to use the temperature estimated with the thermal camera to predict the temperature of the birds

The network consisted of three modules, that were located in the same place. The first one was located in the exterior of the facility to measure the dry-bulb temperature, relative humidity, wind velocity, solar radiation and atmospheric pressure. The second and third ones were located inside each shed to measure the dry-bulb temperature, relative humidity, black globe temperature and computing the superficial body temperature of the birds using an infrared thermal camera and a custom made open-source image analysis software, and the third module also received the measurements from the other modules, compute and sending the information in real-time through a hosted bot from the Telegram instant message application. Figure 2 shows a schematic interaction between the monitoring unit in real time.



Figure 2. Communication between the units and the monitoring devices.

Statistical analysis

The information of Temperature-Humidity Index (THI) computed using the equation proposed by Rowe et al (2019) (THI = $0.61T+0.41T_{wb}$), collected manual (THI) and with the devices developed (THI_d), was subjected to an analysis of variance (ANOVA) to evaluate the Significant Difference, using the statistical software R. The means were compared using the Tukey's test with a significance level of p <0.05.

Results and Discussion

Figure 3 shows the results obtain with the devices developed (THI_d) , with the manual devices (THI_m) in the three sheds. There was not Significant Difference between THI_d and THI_m , that's why It means that the device developed can be suitable to measure different climate variables in real time.





Figure 3. Comparison between THI_d vs TH_m.

Internal and external THI was measure during the entirely experiment and show as THI was greater internal than external facilities (Figure 4). This type of behaviour could be considering as normal in cold tropical climate in countries as Colombia, where the temperature average between 12:00-15:00 hours in April, it could reach 23°C as maximal temperature.



Figure 4. Internal and external THI during the test

Figure 5 shows the internal and external temperature and relative humidity of the sheds. It was found that the birds were repeatedly subjected to stress conditions, situation that likely caused negatively impact their wellness and in those situations, and the wireless network successfully sent warning messages when microclimatic conditions were not favourable, in special with high temperatures and relative humidity as is show in the Figure 5.



Figure 5. Internal and external: a) temperature and b) relative humidity of the sheds.



Figure 6 shows a sample of Bot developed in the Telegram instant messaging service. The monitoring unit responds entirely time to the user inquiries about the conditions of the broiler shed, sending reports of the environmental conditions inside and outside of the broiler house, and even sending a thermal image of the birds in real time



Figure 6. Sample of the BOT receiving an internal and external environment conditions

Conclusions

The developed devices showed that it was possible to monitor in real time the environmental variables of the bird's sheds as the surface temperature of the birds trough thermal imaging, determinate either internal or external THI index, and measure others variables as solar radiation and air velocity.

This low cost 4.0 technologies allows the monitoring of parameters that facilitate to the producer to take any decision-making in real time in order to optimizing the productivity of the processes.

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Sustainable Production in Almería Solar Greenhouses Increasing Photosynthetic Activity by Passive Climate Controls Systems

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Abstract

In 2020-2023, several experimental trials have been developed in solar Almería greenhouses. The main objective is to improve the photosynthetic activity use of different passive climate control techniques. Three multispan greenhouses were divided in two sectors, maintaining standard conditions in one of the sectors (commercial greenhouse cover with 85% transmissivity, no double roof, 1 m high side vent opening and black polypropylene film soil mulching). The increase of 10% of the total ventilation surface in the experimental sector allowed the concentration of indoor CO2 in the crop area to increase by 5% compared to the standard sector. In addition, the use of the double roof with a spectrum converter film without whitewashing of the greenhouse cover allowed to increase the photosynthetically active radiation (PAR) by 39%.

During the 2021/22 season, the use of the double spectrum converter roof (without cover whitewashing) allowed an increase in photosynthetic activity in the leaves of the pepper crop by 16.6%. Maximum daily PAR radiation was 7-10% higher in the sectors with the double roof with the blue spectrum converter film. The photosynthetic activity with the double roof film and commercial production was higher in all cases with a double roof photoconverter spectrum (3-5%). In the same way, the use of an experimental cover film with 90% light transmissivity produced an increase in PAR radiation of 9-20% and a marketable yield of 3-17%. To counteract the negative effect of temperature excesses when the greenhouse cover is not whitewashed, in the season 2022/23 a white marble gravel mulch was installed in the experimental sector of one of the experimental greenhouses with a tomato crop in the autumn-winter cycle. White marble mulching with an increased side vent surface increased 13% photosynthesis in leaves and 4% marketable tomato production.

Keywords: Solar greenhouses, photoconversion film, white marble gravel mulch, radiation transfer.

Introduction

Greenhouses on the Mediterranean coast are characterised by the use of passive climate control techniques, thus avoiding energy inputs that would make crop production more expensive. These greenhouses achieve high efficiency in the use of area resources due to technological development in crop production processes (Baudoin et al., 2017). In Almeria greenhouses it is common to use passive climate control systems, which do not require energy inputs to achieve their objectives, thus reducing the cost of crop production (Valera et al., 2016). Among the most commonly used passive climate control techniques in greenhouses in Almería, present in structures in the province, is the use of natural ventilation of the area, by opening or closing greenhouse vents to control climatic parameters such as temperature and humidity (Moreno-Teruel et al., 2022; Molina-Aiz et al., 2004). Natural ventilation is a climate control technique that requires little or no external energy consumption and is often chosen because it is the most economical method available (Bournet and Boulard, 2010). Ventilation in the greenhouse prevents excessive heating during the day, moves the greenhouse air, ensures minimum CO values and controls hygrometry (Castilla, 2007).

New horticultural films designed to improve the higher quality and quantity of radiation reaching the crop offer the opportunity to increase plant growth and productivity compared to traditional standard films (Wargent et al., 2011). The choice of greenhouse cover material is one of the main factors to consider for the development of protected crops. Greenhouse cover materials that modify light properties, such as films with high light diffusivity, have been developed and evaluated by several researchers (Kittas et al., 2006; Ilic and Fallik, 2017; Murakami et al., 2017). Spectrum converter films amplify the green wavelength in the red wavelength range, where photosynthetic activity is highest (Nishimura et al., 2012). Spectral photoconversion films modify the solar spectrum reaching crops by modifying plant photosynthesis and the microclimate around crops; these films enhance the photosynthetic activity of crop leaves by 15% (Yoon et al., 2020). An increase in cover transmissivity not only increases photosynthesis and production, but also reduces energy input during cold periods (Dieleman et al., 2006). Under normal conditions of CO2 concentration and adequate greenhouse temperatures, photosynthetic activity is primarily affected by light intensity (Zhang et al., 2015).

The use of double roofs in greenhouses is another passive climate control technique normally used for the development of crops in cold periods (Cemek et al., 2006). Double roof greenhouses provide better insulation from



external climatic conditions (Papadakis et al., 2000), which results in energy savings for greenhouse heating of 40% to 50% in active climate systems but affects the transmissivity of light reaching the crop. The double roof reduces heat losses in greenhouses by 35-40% (Landgren 1985) and reduces energy inputs to the greenhouses to maintain the temperature (Ahamed et al., 2019).

Among passive climate control systems, mulch could be of interest in improving the air/soil thermal regime during the early stages of crop cycles beginning in winter, such as melon and watermelon, when the leaf area index is small and most of the soil surface is free of vegetation (Bonachela et al., 2012). The use of mulch in the soil is almost as old as agriculture itself, using in its beginning ashes, coals, sands or stones (Lightfoot, 1994). Mulch breaks evaporation by capillary, avoiding water and nutrient losses and reducing humidity around the crop and with it pathogen and disease problems (Lima et al., 2017). Crop growth and productivity are often influenced by water availability (Hatfield et al., 2017). Mulch materials, by modifying the microclimate and reducing soil evaporation, exert a significant impact on water savings in agriculture (Kader et al., 2017). Gravel mulching has been widely used for a long time in agriculture to reduce surface soil evaporation (Yuan et al., 2009).

The main objective of this work was to use different passive climate control techniques to increase the photosynthetic activity of greenhouse crops, which will result in increased production, improved profitability and economic and environmental sustainability of low-cost Mediterranean greenhouses.

Materials and Methods

The present investigation was carried out during the 2020-2023 seasons at the Centre for Innovation and Technology Transfer "Fundación UAL-ANECOOP" (Latitude: 36°51'53.2" N. Longitude: 2°16'58.8" W; Altitude: 87 m). During the development of the work, the behaviour of photosynthetic activity and yield of different crops under the influence of different passive climate control techniques were analysed.

High transmissivity cover film

The main objective of this first trial was to analyse the effect on photosynthetic activity and yield of a film cover with high PAR-transmissivity. The greenhouse used in this trial has 1800 m^2 and roof vent openings on the ridges of its five spans. The greenhouse was divided into two isolated sectors (Table 1), separated by a vertical film sheet, with the same characteristics as those used on the roof of the greenhouse in the West sector (Figure 1).

Table 1. Characteristics of the two sectors of the experimental greenhouses. S_C : crop surface S_V : vent opening surface and S_V/S_C : ventilation surface percentage.

Sector	Film cover	Dimensions	$S_{C}[m^{2}]$	$S_V[m^2]$	S_V/S_C [%]
West	Experimental	$40 \text{ m} \times 25 \text{ m}$	1000	109.1	10.9
East	Commercial	$40 \text{ m} \times 20 \text{ m}$	800	84.9	10.6

The experimental cover film (AA Politiv (1999) Ltd., Kibbutz Einat, Israel) was installed in the West sector, while the commercial cover film was installed in the East sector. Both films were developed by Politiv Europa S.L. (Israel) according to UNE-EN 13206 (2017) and ASTM D 1003-13 for optical properties (Table 2).

Table 2. Optical properties of the films cover used in the trial. Transmission of photosynthetically active radiation TPAR [400-700nm], UV light transmission TUV [300-380], light diffusion D, thermal efficiency T.

Sector	Film cover	T _{PAR}	T_{UV}	D [%]	T [%]
West	Experimental film	0.90	0.24	55	90
East	Commercial film	0.85	0.24	60	85

To determine the effect of the cover films on photosynthetic activity and yield, two of the main crops grown in Almería, tomato (HM's HMC44698 F1 variety from Clause Ibérica S.A., La Mojonera, Spain) and cucumber (Insula variety of Rijk Zwaan Ibérica, S.A., Almería, Spain), were used (Table 2). The crops were grown in 'arenado' sand mulched soil, which is stratified soil commonly found in Almería greenhouses (Valera et al., 2016). On 23 December 2019 was transplanted the tomato crop (density of 1.2 plants/m²) was transplanted and on 7 September 2020 the cucumber crop (1.5 plants/m²).




Figure 1. Tomato and cucumber crop inside the sector East with commercial film (a) and the sector West with experimental film (b).

Increased ventilation area + no whitewashing + double roof with spectrum converter film

The main objective of this trial was to improve the photosynthetic activity of greenhouse crops by increasing the ventilation surface, the use of reflective mulch in warm periods and double roof with spectrum converter film in cold periods, and a reduction in the level of whitewashing. During the 2021/2022 season, two crops were grown in a multispan greenhouse (Table 4), a first tomato crop (Ramyle variety of Rijk Zwaan Ibérica, Almería, Spain) in the spring-summer cycle (transplant data: 05/02/2021) followed by a second pepper crop (Bemol RZ variety of Rijk Zwaan Ibérica, Almería, Spain) in spring-summer (transplant data: 23/02/2022). Both crops were grown at a density of 1 plant/m² in coconut fibre bags.

Table 4. Characteristics of the two sectors of the experimental greenhouses. S_C : crop surface S_V : vent opening surface and S_V/S_C : ventilation surface percentage.

Sector	Dimensions	$S_{C}[m^{2}]$	Double roof	Whitewashing	$S_V[m^2]$	$(S_{V/}S_C)$ [%]
East	$24\ m\times 25\ m$	600	No	Yes	99.65	16.6
West	$24 \ m \times 20 \ m$	480	Spectrum converter film	No	125.04	26.0

In the west sector, a double roof with a spectrum converter film was installed together with side windows with an opening of 3 m (Fig. 2 a,b). No whitewashing of the roof was carried out in this sector. In the eastern sector, the crop was grown without a double roof with standard windows with a 1 m opening and whitewashing of the roof (Fig. 2 c,d).



Figure 2. Tomato crop in the West sector with double roof with spectrum converter film (a) and 3 m high side vents with maximum opening of 3 m (b). East sector without double roof (c) and with 1 m side vents (d).

Increased ventilation area + marble gravel mulch

To counteract the negative effect of temperature excesses when the cover is not whitewashed and at the same time avoid the loss of photosynthetic activity caused by reduced PAR radiation when it is whitewashed, a white marble gravel mulch was installed in the western sector of greenhouse 2 in September 2022 with a tomato crop (Realsol RZ variety of Rijk Zwaan Ibérica, Almería, Spain) transplanted on 02/09/2022 (Fig. 3a). In the eastern sector, a black polypropylene film mulch was maintained (Fig. 3b).





Figure 3. Tomato crop in the West sectors with white marble gravel mulch and 3 m high side vents (a) and the East sector with 1 m side vents and black polypropylene mulch (b).

Measurement of photosynthesis activity, PAR radiation and yield.

The measurement of photosynthetic activity, PAR radiation, and CO₂ concentration was carried out in 12 plants by randomly chosen treatment with a LCi SD portable sensor (ADC BioScientific Limited, Hertfordshire, UK), equipped with a CO₂ and H₂O IRGA concentration sensor (infrared gas analysis) with a CO₂ measurement range of 0–2000 ppm, 0–75 mbar H₂O (accurately \pm 2%), and 0–3000 m⁻² s⁻¹ PAR radiation.

To determine the crop yield, four lines of plants were selected in each sector (considered statistical replications). Marketable and non-marketable yield was weighed weekly with a Mettler Toledo electronic balance (Mettler-Toledo, S.A.E., Spain) with a sensitivity of 20 g and a maximum capacity of 60 kg.

Statistical analysis

Statistical analysis of the data was performed with Statgraphics Centurion XVIII software (Statgraphics.Net) using a variance analysis and comparing the average values with Fisher's least significant difference (LSD) method for a confidence level of 95%.

Results and Discussion

High transmissivity cover film

Statistical analysis showed significantly higher photosynthetic activity in the tomato leaves of plants in the West sector with the experimental film (with a mean value of 13 μ mol CO₂ m⁻² s⁻¹) than in the East sector with the commercial film (10.7 μ mol CO₂ m⁻² s⁻¹). This represents an increase in photosynthetic activity of 17.7%. PAR radiation values were also statistically significantly higher in the West sector with the experimental film, which has greater transmittance (Table 5).

Table 5. Average values of the measurements on the leaves of plants. Photosynthetic activity P_A [µmol CO₂ m⁻²s⁻¹], radiation R_{PAR} [µmol m⁻²s⁻¹], leaf temperature T_L [°C], concentration of CO₂ [ppm], transpiration E_L [mmol m⁻²s⁻¹], and stomatal conductance C_E [mol m⁻²s⁻¹].

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Sectors	Film cover	P_{A}	R _{PAR}	T_L	C_{L}	E_L	$C_{\rm E}$
East	Commercial	10.7 ^a ±3.4	432.8 ^a ±178.5	31.1 ^b ±2.7	421.6 ^a ±27.8	2.3 ^a ±0.7	0.1 ^a ±0.06
West	Experimental	13.0 ^b ±3.9	$489.9^{b} \pm 174.4$	29.0 ^a ±3.0	438.9 ^a ±47.9	2.3 ^a ±0.8	$0.2^{b}\pm 0.08$

^a Values with different letters in the same column show statistically significant differences (*p*-value ≤ 0.05).

The results of tomato crop production show an increase in marketable and total yield of 0.25 kg m⁻² (+4.2%) and 0.61 kg m⁻² (+4.4%), respectively, in the West sector with experimental film.





Figure 4. Marketable (a) and total (b) tomato yield of the greenhouse sectors equipped with the commercial film cover (\blacksquare) and the experimental film (\blacksquare).

The photosynthetic activity measured in the cucumber leaves was higher in the plants in the West sector with the experimental film, with an average value of 13.7 μ mol CO₂ m⁻² s⁻¹ compared to 12.5 μ mol CO₂ m⁻² s⁻¹ in the East sector (an increase of 8.7%), although without statistically significant differences. The use of the experimental film with higher light transmittance allowed for an increase in PAR radiation at the leaf level of 10% with statistically significant differences (Table 6).

Table 6. Average values of the measurements on the leaves of plants. Photosynthetic activity P_A [µmol CO₂ m⁻²s⁻¹], radiation R_{PAR} [µmol m⁻²s⁻¹], leaf temperature T_L [°C], concentration of CO₂ [ppm], transpiration E_L [mmol m⁻²s⁻¹], and stomatal conductance C_F [mol m⁻²s⁻¹].

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Sectors	Film cover	P_A	R _{PAR}	T_L	C_L	E_L	C_{E}
East	Commercial	12.5 ^a ±3.7	659.7 ^a ±197.0	26.7 ^a ±3.9	415.9 ^a ±20.2	2.3 ^a ±1.0	$0.2^{a}\pm0.1$
West	Experimental	13.7 ^a ±3.7	$733.7^{b}\pm210.1$	27.8 ^a ±3.1	430.7 ^a ±37.5	$2.5^{a}\pm0.9$	$0.2^{a}\pm0.1$

^a Values with different letters in the same column show statistically significant differences (*p*-value ≤ 0.05).

The results for the cucumber crop show an increase in marketable yield of 0.47 kg m⁻² in the western sector of the greenhouse with the experimental film (Fig. 5a), an increase of 4.9%. The increase in yield observed in the wester sector with the experimental film (Fig.5b) agrees with the increases observed in photosynthesis activity at the leaf level.



Figure 5. Marketable (a) and total (b) cucumber yield of the greenhouse sectors equipped with the commercial film cover (\blacksquare) and the experimental film (\blacksquare).



Increased ventilation area+ no whitewashing + double roof with spectrum converter film

The 10% increase in the total ventilation surface (Table 4) through the 3 m side vents (Fig. 2a) increased the indoor CO_2 concentration in the cultivation area by 5% (Fig. 6a). Furthermore, the use of the double roof spectrum converter without whitewashing the cover allowed a 39% increase (Fig. 6b) in photosynthetically active radiation (PAR), with a slight increase in tomato leaf temperature (Fig. 6c).



Figure 6. CO_2 concentration (a) photosynthetically active radiation (b) and tomato leaf temperature (c) in the West sector with double roof with spectrum converter films, with 3 m high side vents and without whitewashing (PSC) \Box and East sector with 1 m side vents, without double roof and with whitewashing (NO) \Box . Data measured in the spring-summer tomato crop of 2021.

The use of the double roof with spectrum converter film without whitewashing the cover allowed a 10% increase in photosynthetically active radiation (PAR) at the crop level in the western sector (Fig. 7a). As a consequence of this increase in PAR, an increase in photosynthetic activity in the leaves of the pepper crop of 16.6% was also observed in the western sector (Fig. 7b). Additionally, the 10% increase in total ventilation surface in the western sector (Table 4) through the 3 m side windows allowed keeping the indoor CO_2 concentration in the crop area similar in both sectors, despite the higher absorption generated in the western sector.



Figure 7. Mean values of photosynthetically active radiation, PAR (a) and photosynthetic activity (b) measured at leaf level of the pepper crop in the two sectors of the experimental greenhouse. East sector with standard vents and whitewashing of the cover (□) and West sector with a double spectrum photoconverter roof and 3 m side vents (□).

Increased ventilation area + marble gravel mulch

In order to counteract the negative effect of temperature excesses when the cover is not whitewashed and at the same time to avoid the loss of photosynthetic activity caused by the reduction of PAR radiation when it is whitewashed, a white marble gravel mulch was installed in the west sector of greenhouse 2 in September 2022 (Fig. 3a). In the eastern



sector, a black polypropylene film mulch was maintained (Fig. 3b). The combination of marble gravel mulch and the increased ventilation area resulted in an 8% increase in net photosynthesis in tomato leaves (Fig.8a). In the western sector, a weaker whitewash was carried out, which allowed for 10% more PAR radiation. The placement of a white marble gravel mulch combined with increased lateral ventilation resulted in an increase in marketable yield of 0.45 kg/m² (+7.6%) compared to the reference sector with black polypropylene mulch and standard side ventilation (Fig. 8b).



Figure 8. Mean values of photosynthetic activity (a) measured at the level of the leaves of the tomato crop and total yield (b) in West sector with white marble mulching and side vents of 3 m (\blacksquare) and in East sector with black polypropylene mulching and standard side vents of 1 m (\blacksquare). Values measured in the South (S) and North (N) half of every sector.

Conclusions

From the results obtained by using different passive climate control techniques to increase the photosynthetic activity of greenhouse crops, the following conclusions can be drawn.

- The average photosynthetic activity measured on the leaves of the cucumber crop was 8.7% and the tomato was 17.7 % higher, as a result the marketable yield of the cucumber crop was 4.9% and the tomato crop was 3.2 % higher with the experimental film with high PAR transmissivity.
- The combination of the double roof with the spectrum converter film without whitewashing the cover with the increased ventilation area resulted in an increase in PAR radiation of 39% in the tomato crop and 16% in photosynthetic activity in the pepper crop.
- The combination of marble gravel mulch with the increased ventilation area resulted in an increase in net tomato photosynthesis of 8 % and consequently an increase in total yield of 7.5 %.

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Preliminary study on the quantification of livestock effluent production in Portugal

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Abstract

Livestock effluents are by-products of livestock production, and their management has impacts on animal production systems. These impacts affect decision making regarding operational efficiency, profitability, and technicaleconomic viability. As the livestock sector faces increasing accusations of causing serious environmental imbalances, it becomes of vital importance to obtain updated knowledge about the quantities of livestock effluents produced. This is important not only to understand the impacts that these effluents can cause but also to consider their valorization from a Circular Economy perspective. With the aim of estimating the quantity of livestock effluents produced in Portugal, a systematic data collection was carried out, organized by administrative regions, subdivided by municipality, livestock species, and management types. Metrics were applied to estimate the amount of effluent produced per animal unit and per utilized agricultural area. The use of geographical maps proved to be a adequate tool to identify areas in the country with higher and lower total effluent production, as well as municipalities with the highest and lowest values of the Effluents/animal unit and Effluents/utilized agricultural area indicators. Through these maps, a significant geographical dispersion was observed in the effluent production, as well as in the volume of effluents generated in relation to the number of animals.

Keywords: sustainable farming; circular economy; precision livestock farming and animal waste management

Introduction

Livestock effluents today constitute a surplus from livestock production, the management of which has significant impacts on animal production systems, particularly in decision making regarding their operability, profitability, and technical-economic viability. According to Decreto-Lei 81/2013 (NREAP), livestock effluent refers to manure and slurry. The recent Portaria 79/2022 of February 3rd, which defines the regime applicable to the management of livestock effluents, classifies manure as "the mixture of feces and urine from livestock species, which may contain animal feed waste, vegetal origin bedding, and the solid fraction of slurry that does not present runoff during its application." The same Ordinance classifies slurry as "the liquid or semi-liquid mixture of feces and urine from livestock species, as well as wash water from livestock facilities, structures, and equipment associated with livestock activities, which may contain animal feed waste or bedding, runoff from nitrate stores or silos, and rainwater not diverted from the area where the animals are housed."

As the livestock sector is increasingly accused of causing serious environmental imbalances, it becomes of vital interest to have up-to-date knowledge of the quantities of livestock effluents produced in Portugal. This is important not only to assess the potential impacts of these effluents but also, from a Circular Economy perspective, to explore their valorization. Therefore, with the aim of estimating the quantity of livestock effluents produced in Continental Portugal, a systematic data collection was carried out by administrative regions, subdivided by municipality, livestock species (poultry, cattle, pigs, goats, horses, and sheep), and different management practices. Subsequently, several metrics were applied to provide an insight into the amount of effluent produced per livestock unit (LU) and per utilized agricultural area (UAA) in each municipality.

Materials and Methods

The documentary research for the characterization of livestock effluent production in Portugal was conducted in four stages.

Database

In the first stage, a search was carried out on the database of the National Statistics Institute (INE, 2022). Data were collected on the number of animals of bovine, swine, poultry, sheep, goat and equine species, and the utilized agricultural area (UAA, in hectares) by administrative region, namely, Entre Douro e Minho, Trás-os-Montes, Beira Litoral, Beira Interior, Ribatejo e Oeste, Alentejo and Algarve, and their respective municipalities.

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Quantification of livestock effluents

Using Annex II of Decreto-Lei 81/2013 (NREAP) as a reference, the equivalences of the animal herd in livestock unit (LU) were determined. Based on the number of livestock unit, and Annex V of Portaria 259/2012, were determined the quantities of livestock effluents (slurry and manure) produced annually for each of the animal species. After determining the production of livestock effluents, number of livestock unit and agricultural surface used, the relationships were calculated: LU/UAA, Effluent/LU and Effluent/UAA.

Systematization of data

A informação das etapas anteriores foi sistematizada em quadros demonstrativos. Os quadros foram elaborados considerando cada uma espécie animal, numbe of livestock unit, tipo de efluente pecuário e as regiões administrativas.

Mapping of livestock effluent production

Maps were developed, at municipal level, for: total volume of livestock effluent produced in each municipality, volume of livestock effluent produced per livestock unit, and volume of livestock effluent produced per utilized agricultural area.

Results and Discussion

Table 1 presents data on the total production of livestock effluents (slurry and manure) by administrative region, as well as the number of livestock unit and the utilized agricultural area. It also presents the relationships between: livestock unit and utilized agricultural area; quantity of effluents and livestock unit; and quantity of effluents and utilized agricultural area.

Region	Utilized Agricultural Area – UAA (ha)	Livestock Unit (LU)	Efluent (m ³)	LU / UAA (LU/ha)	Efluent /LU (m ³ /LU)	Efluent / UAA (m ³ /ha)
Entre Douro e Minho	212639	264958	3894973	1,2	14,7	18,3
Trás-os-Montes	450701	95218	1008803	0,2	10,6	2,2
Beira Litoral	129848	352599	2280784	2,7	6,5	17,6
Beira Interior	391754	98589	909199	0,3	9,2	2,3
Ribatejo e Oeste	409095	496223	3793870	1,2	7,6	9,3
Alentejo	2144066	292405	3348586	0,1	11,5	1,6
Algarve	100605	13247	143890	0,1	10,9	1,4

Table 1. Livestock effluent production by administrative region

Figures 1 show the percentages of livestock effluent production for the territory of Portugal.



Figure 1. Livestock effluent production in Portugal

Observing the table and figure, it can be seen that the regions that produce the most effluents are Entre Douro e Minho, Ribatejo e Oeste and Alentejo, with the Algarve region presenting residual production.



Regarding the Effluents/LU and Effluents/UAA indicators, the Entre Douro e Minho region records higher values for both indicators. The Beira Litoral region has the lowest values for the Effluents/LU indicator, and the Algarve and Alentejo regions have the lowest values for the Effluents/UAA indicator.

According to Table 2, the livestock species that generate the most effluents in Portugal are cattle, followed by swine and sheep. Cattle record the highest volumes of manure and slurry production. However, swine produce amounts of manure close to those of cattle, while sheep practically only produce manure.

a •		Effluent (manure e slurry)		Manur	e	Slurry		
Specie	Livestock Unit (LU)	Volume (m ³)	Livestock Unit (LU)	Volume (m ³)	Livestock Unit (LU)	Volume (m ³)		
	Birds	473875	661266	392507	490393	81368	170873	
	Cattle	449004	6954062	250599	3394329	198406	3559733	
	Swine	281757	3610098	11963	105090	269795	3505008	
	Goats	63630	636302	63630	636302	-	-	
	Sheep	310646	3106465	310646	3106465	-	-	
	Equids	34326	411912	34326	411912	-	-	
	Total	1613238	15380105	1063671	8144491	549569	7235614	

Table 2. Effluent production by animal species

In Figures 2, 3 and 4, the total production of livestock effluents and the Effluent/LU and Effluent/UAA indicators are presented geographically, at municipal level. Through mapping, it is possible to identify the areas of the national territory where the highest/lowest total production of effluents is concentrated, as well as the municipalities where the highest and lowest values of the Effluents/LU and Effluents/UAA indicators are found.

Figure 2 shows a large geographical dispersion in relation to effluent production, with municipalities producing high amounts of effluent both on the coast and in the interior of the country, with the exception of the Algarve region.



Figure 2. Total volume of livestock effluent produced in each municipality

Figure 3 also shows a large territorial dispersion in relation to the indicator volume of effluents produced per livestock unit. However, there is a tendency for this indicator to be higher in some municipalities in the Entre Douro e Minho region, although some municipalities located in other regions, namely in Trás-os-Montes, Ribatejo Oeste and Alentejo, also present high values.





Figure 3. Volume of livestock effluent produced per livestock unit

Figure 4 shows that the coastal regions located north of the XXX river present higher values for the Effluents/UAA indicator, while the interior regions from the north to the south of the country present relatively low values for this indicator.



Figure 4. Volume of livestock effluent produced per utilized agricultural area

Conclusions

The amount of effluents produced per region follows the concentration of animal production in coastal areas. In inland areas with more beef cattle and sheep, manure production is clearly higher than slurry production.



The interior regions, having a smaller animal herd and a higher UAA, are much more suitable for the agricultural valorization of livestock effluents.

These aspects must be taken into account in national livestock effluent management plans.

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Microgreen Nutrition Within Light Treatments and Shelf-Life Analysis to Demonstrate Seed Germination and Plant Propagation Techniques

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Abstract

Microgreens are clean vegetables highly dense in nutrients that have become popular in the restaurant industry in the United States. These young seedlings are an edible food product, which can be grown and harvested quickly in a small space. Six different species of microgreens (Daikon radish [Raphanus sativus var. Longipinnatus], Red Rambo radish [Raphanus sativus L.], Kogane Chinese cabbage [Brassica rapa var. Pekinensis], red cabbage [Brassica oleracea var. Capitata] broccoli [Brassica oleracea], and mustard [Brassica juncea]) were used within the experiment. The microgreen seeds were prepared under aseptic and tabletop methods, grown under different light regimes, and compared for their mineral nutrition and shelf-life. The research objectives were to contrast light-emitting diode (LED) and fluorescent light and its effects for producing nutrient dense microgreens and growth, to observe if microgreens grown by a tabletop method were a clean food product with an acceptable shelf-life and determine if the tabletop method would be a viable technique to demonstrate seed germination and plant propagation processes in secondary agriscience curricula. Plant dry matter and nutrient density varied among the varieties of microgreens, according to light treatment and species. The experiment was repeated in a laminar flow hood under aseptic conditions and an indoor, tabletop condition to determine if these food products required an aseptic flow hood to have acceptable shelf-life. The findings indicated the variety of vegetable effected shelf life more than the facility in which it was prepared. Two weeks following harvest all treatments were in excellent condition. The tabletop method would be a viable method to demonstrate seed germination and plant propagation in secondary curricula. Agriscience teachers can benefit from professional development experiences to help them understand the process of growing microgreens in various environments to effectively teach plant propagation techniques.

Keywords: agriscience teachers, aseptic method, fluorescent light, light-emitting diode, tabletop method

Introduction

Microgreens are nutritious vegetables and herbs that are edible as young seedlings. The short time from sowing to harvest and how microgreens are utilized after harvest make them a unique commodity in our modern lifestyle. "Harvested at the first true leaf stage" results in a very young and tender plant (Treadwell, et al, 2020). Fresh vegetables and convenience are two factors not often associated with the consumer's experience. However, microgreens are clean, bite size, tender, ready-to-eat raw, and cook very quickly with large surface area to volume ratio. Microgreens are a novel commodity for the restaurant industry, being added to salads and as garnishes for entrees (Treadwell, et al, 2020). Over 75 different vegetable and herbs have been used as microgreens, thus a variety of flavors, colors, and textures are available. Microgreens are harvested at seven to twenty-one days after being sown, which allows for rapid response to market demand and provides an efficient method to demonstrate and teach sexual plant propagation. Microgreens can be grown in a greenhouse or an indoor, electrically lit environment. Being easy to produce, fast growing, and having a desirable shelf-life makes microgreen production an innovative addition to the agricultural industry. An indoor clean room contributes to marketability by reducing post-harvest sanitation needs.

Teachers need professional development and resources to effectively teach (Huberman, 1995). There has been a consistent call for science, technology, engineering, and mathematics (STEM) integration into secondary curricula for school-based agricultural education (SBAE) programs in the United States (Castellano et al., 2003 Myers & Washburn, 2008; Spindler, 2010). Microgreen production could serve as a novel crop and innovative method to demonstrate seed germination.

The41esearchh objectives outlined for this experiment were to 1) contrast light-emitting diode (LED) and fluorescent light and their effects for producing nutrient dense microgreens and growth, 2) examine if microgreens grown by a tabletop method were appropriate as a clean food product with an acceptable shelf-life that can be used for instructional purposes and 3) determine if a tabletop method would be a viable technique to demonstrate seed germination and plant propagation processes in secondary agriscience SBAE curricula in the United States.



Materials and Methods

Laboratory Preparation

Six different species of microgreens (daikon radish [Raphanus sativus var. Longipinnatus], Red Rambo radish [Raphanus sativus L.], Kogane Chinese cabbage [Brassica rapa var. Pekinensis], red cabbage [Brassica oleracea var. Capitata] broccoli [Brassica oleracea], and mustard [Brassica juncea]) were used within the experiment, (Johnny's Select Seeds, Winslow, ME). Treatment groups compared two preparation environments: 1) an aseptic clean room with a laminar flow hood, and 2) a clean tabletop in a classroom setting. Seed were measured and 12.5 grams per species were placed into nylon mesh bags (10" x 6" bag, Amazon.com) and tied closed.

The seed bags were immersed in a 40 degrees Celsius water bath with Tween 80 detergent for approximately 20 minutes. Seeds were then placed in a solution of 5% (8.25% NaOCl) bleach at 50 degrees Celsius, under agitation for five minutes. During bleach treatment, seed bags were tamped down to ensure complete submersion of seed. The bags were removed from the bleach solution and immediately placed in sterile, distilled water (in Magenta GA7, Magenta Corp., Chicago, IL). The closed containers were vigorously agitated for 30 seconds, and agitated rinsing was repeated three times.

Polyester mats (Grow King, Kent, OH) saturated in half-strength Hoagland's solution (Hoagland & Arnon, 1950) were placed in 1020 flat planting trays (601, six sections $L \times W \times H$, $16 \times 12 \times 5.5$ cm polyethylene insert, fitting a webbed 1020 polyethylene tray, Landmark Plastics, Akron, OH, USA). One full teaspoon (long handled, stainless-steel teaspoons) of seed were scooped into each 601 cell of the flat and evenly spread using sterilized spoons. The same procedures for seed cleaning and sowing under room temperature conditions in aseptic laminar flow hood and a clean tabletop setting were followed.

Growth Conditions

In the laminar flow hood, the tools were sterilized within glass bead sterilizers (Phytotechnology Laboratories, Shawnee, MO) at 245 degrees Celsius, while the tabletop was flame sterilized with 95% ethanol. Seeds were placed in the dark for two days at 22 degrees Celsius. After two days, the seeds were moved to 40-50 µmol m-2s-1 photosynthetically active radiation (PAR) for 16 hours a day provided by NutriLED (33% blue, 67% red; Hubbell Lighting Inc., Greenville, SC) or fluorescent lamps (GE Starcoat F96 T8 XLSPA 35).

Hoagland's solution was added daily to restore the mass of the flat to a set point of 1050 grams (initial mass of saturated flat with seeds). After seven days of growth, the microgreens from both treatments (aseptic and tabletop method) were harvested. The height of the microgreen shoots was measured in three places within the cell and the average length per cell was recorded. The microgreens were cut above the roots with scissors.

Ten grams of microgreens were placed into paper envelopes and dried in a convention oven for 48 hours at 60 degrees Celsius. Dried ground tissue was extracted, and mineral content measured by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Additional, 20 – gram samples of fresh microgreens from each treatment were massed and placed in quart sized zip top plastic bags and placed in a refrigerator at 4 degrees Celsius. Microgreens were monitored daily for shelf-life acceptability by observing wilting, chlorosis or necrosis, foul odors, or fungal growth.

Data Analysis

The experiment was completely randomized with 3 (species) x 2 (lights) in a factorial arrangement with 3, 601 sections per treatment factor. Data were analyzed using JMP v 14.0 (Statistical Analysis System, Cary, N.C.). ANOVA and hypotheses were tested at P = 0.05 and significant means comparisons were presented.

Results

The six crucifer species attained different heights, but in general shoots under the fluorescent light produced taller plants (6.4 ± 0.1 vs. 5.2 ± 0.1 cm). Microgreens are often sold by volume and the difference found in shoot growth can help to fill the package. However, plant growth may be better measured in dry mass since seedlings may etiolate under sub-optimal light conditions. The Daikon radish had significantly higher shoot dry mass when grown under the LED light. Mustard and Kogane Chinese cabbage had more dry matter under the fluorescent light. Broccoli, red cabbage, and Red Rambo radish had no significant differences between light treatments (Figure 1). Kopsell, et al. (2014) reviewed dry mass accumulation in other cruciferous microgreens and found they were not affected by fluorescent vs. LED light sources.





Each error bar is constructed using 1 standard error from the mean

Figure 1. Shoot dry weight (grams per 601 trays) of six crucifer species was affected by the type of lighting seven days after germination.

The nutrient value of the six species subjected to the two light treatments was recorded and compared (Table 1). When considering a 10-gram serving size, microgreens provide a significant amount of mineral nutrients. Broccoli had over 15 mg/g of calcium (Ca) in fresh weight when grown under LED light. The trend of higher nutrient content under LED versus fluorescent light for broccoli was also observed with magnesium (Mg), phosphorus (P), and potassium (K). Broccoli was the only species grown that light influenced potassium levels.

The LED (20% blue, 80% red) lighting treatment improved mineral contents in calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), sulphur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) in broccoli microgreens compared to the fluorescent light at 250 µmol m-2s-1 photosynthetically active radiation (PAR) (Kopsell, et al., 2014). LED enhanced nutrient uptake did not repeat for the other cruciferous vegetables.

Kogane Chinese cabbage tended to have more nutrients per gram of fresh weight when grown under fluorescent light when analyzing calcium (Ca), magnesium (Mg), phosphorus (P), and potassium (K). Overall, potassium (K) levels were not altered by light treatment between the crucifer species. Red cabbage had over 10 mg/g of calcium (Ca) when grown in LED light. Broccoli, Daikon radish, mustard, red cabbage, and Red Rambo radish had higher levels of magnesium (Mg) when grown under LED lighting. The other nutrient and variety combinations were not affected by light treatments.

Table 1. Miner	Table 1. Mineral nutrients content in 10 grams servings of 6 crucifer species under two light treatments.								
	Phosphorus (mg)		Calcium	Calcium (mg)		Magnesium (mg)		Potassium (mg)	
Species	LED	FL	LED	FL	LED	FL	LED	FL	
Daikon Radish	8.42	8.63	9.40	9.12	3.97	3.79	12.86	14.17	
Sig. of Contrast	NS		NS		NS		NS		
Red Rambo Radish	7.56	7.43	9.90	7.05	3.47	3.28	13.06	13.29	
Sig. of Contrast	NS		*		NS		NS		

c .



	Phosphor	us (mg)	Calcium	ı (mg)	Magnesiu	ım (mg)	Potassi	ium (mg)
Species	LED	FL	LED	FL	LED	FL	LED	FL
Kogane Chinese Cabbage	5.49	8.13	6.54	9.29	2.71	3.83	9.65	12.31
Sig. of Contrast	**		*		**		NS	
Red Cabbage	6.24	6.43	11.98	9.07	3.88	3.45	14.68	13.21
Sig. of Contrast	NS		*		NS		NS	
Broccoli	8.50	5.72	16.50	7.05	4.44	2.92	24.72	13.95
Sig. of Contrast	**		***		**		**	
Mustard	9.66	8.41	9.64	7.26	4.81	4.09	8.39	5.95
Sig. of Contrast	NS		NS		*		NS	

Table 1. (continued) Mineral nutrients content in 10 grams servings of 6 crucifer species under two light treatments.

Note: NS is not significant, and *, **, and *** denotes significantly different contrast with

Prob. > F 0.05, 0.01, and 0.0001, respectively. LED =light- emitting diode, FL = fluorescent

All vegetables were in good condition for at least two weeks. After three weeks, Kogane Chinese cabbage and Red Rambo radish displayed tissue breakdown and/or fungal growth. After five weeks, all remaining vegetables were still physically appealing. Red Rambo radish displayed fungal growth faster from aseptic culture than the tabletop method. There was no significant difference between the longevity among the six crucifer species and tabletop versus aseptic method (Table 2).

Table 2. Shelf-life of microgreens prepared from six Crucifer species were compared from plants grown on tableto	р
and aseptic laminar flow hood. The first appearance of product break-down was scored as longevity.	

Species	Treatment	Longevity (in Weeks)
Drogosli	Tabletop	5
Broccoll	Aseptic	5
Dailson radiah	Tabletop	4
Darkon radish	Aseptic	4
Kagana Chinasa ashbaga	Tabletop	2
Kogane Chinese cabbage	Aseptic	5
Mustard	Tabletop	7
Mustard	Aseptic	7
Red ashbaga	Tabletop	7
Red cabbage	Aseptic	7
Dad Damba radiah	Tabletop	6
Keu Kambo radish	Aseptic	3

Discussion

The experiment focused on a comparison of light treatments, nutrient content, and shelf-life related to the



requirements for growing microgreens for human consumption and determining if a tabletop production method could be used as a viable technique to demonstrate seed germination and plant propagation processes in secondary agriscience SBAE curricula in the United States.

When compared to a sterile tabletop setting the aseptic/clean room process did not significantly improve shelf-life of the six crucifer species selected. Interestingly, the shelf-life of the Red Rambo radish was extended in the tabletop method. Expensive facilities and systems such as light emitting diode (LED) lighting and laminar flow hoods may not be essential for this type of production method. Procedures that closely mirrored the aseptic method using a clean tabletop in a classroom type setting produced acceptable results and demonstrated that a tabletop method was a viable option to utilize for both microgreen production, experimental and instructional purposes.

The tabletop method would be a viable method to demonstrate seed germination and plant propagation techniques in secondary agriscience curricula. The methods and materials designed for this experiment could be replicated to create professional development and curricula for agriscience teachers by modelling the production process, while discussing light treatments and shelf-life analysis through microgreen seed germination. Sexual plant propagation techniques can be demonstrated, and results can be obtained from the cruciferous species used in this experiment in a relatively short amount of time to harvest within 7 - 10 days consistent with Treadwell, et al. (2020); therefore, the rapid growth of these microgreens offers an effective teaching tool. Similar to nutrition, genetics and environment interact when determining the optimal growth conditions. Introducing agriscience teachers to the science, technology, engineering, and mathematics (STEM) concepts embedded in the production of microgreens would be beneficial.

Conclusions

All six of the crucifer species used in the microgreens production for this experiment contained significant nutritional value. All species attained different heights, but in general shoots under the fluorescent light produced taller plants. An increase in dry weight was reported for all six species of crucifers under different light treatments. Two weeks following harvest all treatments were in excellent condition. Consistent results with the shelf-life and the comparison of the tabletop versus aseptic methods of production were observed.

Microgreens can be harvested as early as seven days after being sown, which allows for large volume harvesting and ease of use in a classroom setting. The tabletop production method and process of seed germination could be implemented into SBAE curricula. Agriscience teachers can benefit from professional development experiences that provide them with opportunities to understand the process of growing microgreens in various environments.

Further research should be conducted to determine how both agriscience and science teachers can be informed of the tabletop method to assist them with focusing on the science, technology, engineering, and mathematics (STEM) concepts that are easily associated with this production process for seed-based plant propagation. We recommend curricula be developed and professional development offered to teachers to provide them with experiential learning opportunities to improve their teaching effectiveness and awareness of the array of careers associated within plant science and the horticulture industry.

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Innovative Cultivation of Aloe Vera in Advanced Technological Greenhouse Systems

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Abstract

The production of Aloe Vera in advanced technological greenhouse systems supports active production communities in addressing the negative impacts of multiple economic and environmental challenges. The cultivation of Aloe vera in autonomous and low-energy consumption greenhouses aims to improve cultivation practices and increase the quantity and quality of the produced product through year-round scalable production.

Aloe vera cultivation in greenhouses is a practice not currently implemented in Greece. Research on aloe vera development has shown that exposing the plant to diffuse sunlight conditions activates the production of high-concentration polysaccharides, a condition achievable only in greenhouse cultivation. Aloe vera undergoes periods of stress that affect its availability. During winter and when the temperature drops below 18°C, the plant enters a mandatory dormancy period for protection. Aloe vera contains pharmaceutically significant phytochemicals such as polysaccharides (acemannan), anthraquinones, lectins, etc. These phytochemicals have pharmacological effects on human health, such as anti-inflammatory, antioxidant, antibacterial, and antifungal properties.

Research has shown that exposing the plant to diffused sunlight conditions in greenhouses activates the production of high-concentration polysaccharides, a state achievable only in greenhouse cultivation. The cultivation of Aloe vera enhances the production process and introduces innovative technologies for low-energy consumption greenhouse systems. Controlled microclimate conditions optimize the plant's physiological and biochemical parameters. The cultivation of Aloe vera plays a significant role in collaborations with pharmaceutical companies, creating additional employment opportunities and income. By reducing the environmental footprint and achieving energy savings using infrared heating and integrated photovoltaic panels, this cultivation method demonstrates environmental sustainability.

Keywords: Aloe Vera, Greenhouses, Polysaccharides, Environmental sustainability, Pharmacological effects

Introduction

In recent years, there has been a growing emphasis on greenhouse systems and their technological advancements. These enclosed structures heavily rely on external environmental factors, leading to significant energy consumption to maintain the desired microclimate (Hassanien and Li, 2017). The energy demand for a single greenhouse unit can be substantial, reaching up to 100,000 kWh/ha per year for cooling in the Mediterranean region. In Greece, energy consumption for a single unit is estimated to range between 1.9 and 3.2 million kWh/ha per year, attributed to heating, cooling, and artificial lighting (Paris et. al., 2022).

The majority of greenhouse operations require electricity to maintain optimal environmental conditions for plant growth. Typically, this energy comes from either the public power grid or fossil fuel-powered generators. However, these methods present challenges, especially for greenhouses located in remote areas without access to the power grid. Using fossil fuels also leads to drawbacks such as rising oil prices, high transportation and disposal costs in remote locations, and increased release of harmful pollutants like CO2, impacting the environment.

Solar radiation plays a vital role in solar power production systems, making greenhouses particularly valuable due to their unobstructed location in open fields. Nevertheless, the demand for available land creates spatial and economic challenges. Combining cultivation and energy production, such as Greenhouse-Integrated Photovoltaics (GIPV), can address these issues effectively, but it requires careful consideration due to the dual use of solar radiation (Yanno and Cossu, 2019).

GIPVs can operate independently by producing their energy or can be connected to an existing electricity grid to generate power that can be sold through net-metering, depending on whether the area has access to an electricity supply network. Different types of photovoltaic units are available, and several studies have been conducted on their feasibility. These include semi-transparent BIPV photovoltaic panels made of mono-crystalline silicon, semi-transparent organic solar cells, amorphous crystalline silicon and opaque crystalline silicon photovoltaic panels that cover only part of the roof (Hassanien et. al., 2018; Wang et. al., 2021; Waller et. al., 2021; Waller et. al., 2022; Aira et. al., 2021; Hassanien et. al., 2022 Benedicto et. al., 2019)

The research aims to optimize the production of polysaccharides (specifically glucomannans/polymannose) in Aloe Vera cultivation by utilizing controlled greenhouse conditions, enabling year-round production. Aloe Vera, known for its numerous health, medicinal, skin-care, and beauty benefits, has a botanical name Aloe barbadensis miller and



belongs to the Asphodelaceae (Liliaceae) family. Integrating Aloe Vera cultivation into low-energy and autonomous greenhouses seeks to enhance productivity and product quality while enabling year-round production (Surjushe et. al., 2008).

Additionally, the greenhouse's roof is equipped with semi-transparent photovoltaic modules, demonstrating an energy-autonomous greenhouse. Various sensors are also installed to monitor the microclimate inside the greenhouse, including the effects of the photovoltaic panels.

Materials and Methods

Greenhouse

The greenhouse utilized for research on energy autonomy with a photovoltaic system is situated at the coordinates 38°17'27.9" N, 21°47'23.9" E within the University of Patras. It comprises four distinct units that measure 3.2 m in width and 16 m in length. The ridge height of the greenhouse is 4.5 m, and the gutter height is 3.3 m. Additionally, the orientation of the ridge is in the East-West direction (refer to Figure 1).



Figure 2. Graphic illustration of the University of Patras greenhouse.

In one of the greenhouse's distinct sections, an extensive array of sensors is installed to continuously monitor and record the microclimate within the structure. The greenhouse is equipped with an automated natural ventilation system that includes roof and side openings. Various sensors, including two ad-hoc data gathering systems within the unit under investigation and an automatic weather station (AWS) located outside the greenhouse, are used to monitor the environmental conditions of the greenhouse. These sensors collect data every 10 minutes and transmit it remotely via the CR1000 datalogger from Campbell Scientific Company, which is already installed at the AWS. All the sensors used in the greenhouse are listed in Table 1, and the research by Petrakis et al. (2022) includes both sensor data and a neural network-based prediction model for indoor temperature and relative humidity, as described in Ouazzani Chahidi et al. (2021).

Table 2. Recorded parameters, sensors used to record them, sensor manufacturers, and their position in the greenhouse

	area.								
Recorded Param.	Sensor	Manufacturer	Position						
Temperature	MP101A-T7-WAW	Rotronic	AWS / Greenhouse						
Relative Humidity	MP101A-T7-WAW	Rotronic	AWS / Greenhouse						
Wind Speed	A100K	Vector Instruments	AWS						
GHI	CMP3	Kipp & Zonen	AWS / Greenhouse						
Rainfall	52203	R.M. Young Co.	AWS						
IR Rad. / Sky Temp.	CGR3	Kipp	AWS						
PAR	PAR lite	Kipp & Zonen	Greenhouse						

Furthermore, the greenhouse incorporates an IoT-based robotic system known as Kytion Aeir (Thomopoulos et al., 2021), comprising multiple sensors to measure temperature and relative humidity, enabling continuous monitoring of the greenhouse microclimate. Additionally, the system is equipped with an RGB camera that allows for remote monitoring and capturing crop photography. The robot moves along the long side of the greenhouse at 10-minute intervals. The greenhouse's operations, including the opening and closing of windows, are automated and based on recorded temperature and rainfall data. Figure 2 depicts the appearance of Kytion Aeir.





Figure 3. The Kytion Aeir.

The Photovoltaic System

The greenhouse incorporates photovoltaic modules that are not attached to the cover but are integrated into it. These semi-transparent modules strike a balance between the need for natural sunlight and various energy requirements, including heating. They possess high solar permeability and light-scattering properties, which effectively prevent the formation of strong shadows from the underlying skeletal elements. Each module measures 2089 mm in length, 1033 mm in width, and has a thickness of 5.5 mm. They contain 80 bifacial cells placed between two sheets of glass and a flexible material, enhancing the glass's strength and flexibility. The active surface area of each unit is 1.102 m^2 , and their current production relies on the light received on both sides. These specific photovoltaic solar glasses can generate a maximum power of 250 W at STP and possess electrical characteristics well-suited for their intended purpose.

As mentioned earlier, the photovoltaic modules are an integral part of the greenhouse's roof, installed at an angle of 24° with their long side aligned parallel to the ridge in the East-West direction. The greenhouse has a total of 12 semitransparent photovoltaic glasses, with 8 of them covering approximately 70% of the south sloping plane of the roof in the unit under study (located on the north side of the greenhouse), as shown in Figure 3 (a). The remaining 4 modules are installed in the adjacent unit (Figure 3(b)), covering approximately 35% of the roof plane.



Figure 4. (a) The integrated semi-transparent PVs into the roof of the construction unit under study, (b) the integrated semi-transparent PVs into the roof of the adjacent unit. The two figures represent two different construction units of the greenhouse.

To connect the photovoltaic modules, they were arranged into three quads, each connected in series. Each quad can deliver a maximum rated current of 10.81 A and has a maximum rated voltage of 92.52 V, allowing it to produce a maximum of 1000 W (in STC). The quads were then connected in parallel to create a maximum total current of 32.43 A and maximum voltage of 92.52 V. The resulting maximum power rating for the system is 3000 W.



Figure 5. (a) The hybrid inverter, (b) the battery, and (c) the solar charger.



Results and Discussion

The time series data presented in Figure 5 offers an approximate overview of the energy production from the photovoltaic modules, the greenhouse's energy consumption, and the energy supplied by the conventional electric power grid. The data covers the period from 17-11-2022 to 19-02-2023. It appears that the energy produced by the photovoltaics sufficiently covers the greenhouse's energy needs for most of the time, resulting in zero reliance on the public electricity grid. There are only two exceptions, where extended cloud cover in the morning combined with the long winter nights caused the battery voltage to drop below the desired levels, triggering the activation of the public power grid as a backup generator. However, this contribution is relatively small, amounting to approximately 1000 W on 02-12-2022 and 100 W on 16-12-2022.



Figure 6. Graph presenting the daily solar panel yield, the conventional electricity grid yield, and the greenhouse energy consumption.

Conclusions

This study proposes the implementation of innovative semi-transparent photovoltaic modules in greenhouses to achieve energy autonomy for the entire system. This approach is particularly relevant for remote areas without access to a power supply network. The photovoltaic modules can cover the basic energy needs of the greenhouse, such as heating, cooling, and artificial lighting. The study findings demonstrate that the energy produced from photovoltaics is sufficient to meet the greenhouse's energy demands continuously, without relying on additional energy from the public electricity supply network.

While semi-transparent photovoltaics show great potential for greenhouse applications, several challenges hinder their widespread adoption in the industry. Their reduced surface area containing solar cells leads to untapped solar radiation, and the absorption or reflection of light can delay crop growth due to reduced photosynthesis. Moreover, the photovoltaics' absorption of certain spectrum regions, such as red and blue wavelengths critical for plant functions, presents a significant drawback. Additionally, the cost of a photovoltaic greenhouse is high due to the need for a strong and complex frame.

Cultivating Aloe in greenhouses offers a viable solution to the typical challenges related to seasonality, climate conditions, and the need for controlled microclimate conditions. This approach is expected to yield four main benefits, ensuring the sustainability of Aloe Vera in the greenhouse:

- 1. A projected 40% increase in crop productivity compared to outdoor cultivation under greenhouse conditions.
- 2. Elimination of production seasonality, as greenhouses enable year-round cultivation, potentially leading to up to a 60% increase in demand and sale price compared to outdoor cultivation.
- 3. Aloe Vera leaves grown in the greenhouse exhibit a high concentration of Acemannan, which could increase the product's sale price by 20%.
- 4. Positive impacts on SMEs that use aloe derivatives as they gain access to a more consistent supply of highquality aloe, potentially reducing production costs and increasing profits. Farmers can also benefit by growing new high-value commercial species in greenhouse units, diversifying their crops and boosting their income.

In conclusion, future research will concentrate on investigating the greenhouse's autonomy by studying the influence of various environmental factors and additional operations necessary to maintain the appropriate microclimate. Additionally, the performance of the Aloe Vera crop under semi-transparent photovoltaic units will be evaluated, providing valuable insights into the sustainability and efficiency of the greenhouse system and the potential for similar systems in other agricultural areas.



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Limited ammonia emission by inventive manure cellar ventilation and chemical air scrubber

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Abstract

EnviVice has performed ammonia measurements on a naturally ventilated dairy stable with an adaptable manure cellar ventilation system and chemical air scrubber (based on WUR report 1032a [1]). The big advantage of this cellar ventilation system is that the ammonia is directly extracted from the source (grid floor and manure cellar). After which the ammonia rich air can directly be forwarded through the chemical air scrubber. This allows for a small ventilation flow rate, which also means that the chemical air scrubber can have relatively small dimensions.

Further ventilation of the dairy stable is done by openings in the side walls and top of the stable. The total ammonia emission is determined by emission though the top of the stable in addition to the yield of the chemical air scrubber (efficiency over 90 %). The ammonia capture of the chemical air scrubber is determined by measurements. The results show that the ammonia capture is strongly related to the ratio of natural ventilation (dependent on wind direction and speed) and chosen cellar extraction flow rate.

The amount of captured ammonia can be determined and adjusted by measuring the CO_2 -concentration in the manure cellar and the top of the stable. The ratio of the CO_2 mass flow rate in the manure cellar and the total CO_2 production (natural and cellar ventilation) is a measure for the effectiveness of the cellar ventilation compared to the natural ventilation. The average ammonia emission for the investigated stable with manure cellar ventilation and chemical air scrubber is 8.4 and 5.1 kg/animal/year for 35 % and 60 % of the maximum cellar ventilation flow rate respectively. The year-round average ventilation of a natural ventilated dairy stable is approximately 1200 m³/hour/animal (WUR report 1285[2]). This means that an ammonia emission reduction of 60 % can be achieved by extracting and scrubbing a relatively small amount of (10 %) of the total amount of ventilated air.

Keywords: emission reduction dairy stable.

Introduction

Mulkzeewolde BV commissioned Envivice to measure the ammonia emission of naturally ventilated dairy stable (test stable) with manure cellar ventilation and chemical air washer. The advantage of the setup is the extraction of ammonia from the source (cellar), which allows for a relatively small ventilation rate. The small ventilation rate results in the subsequent air washer to be of relatively small dimensions. This setup consequently requires a relatively low amount of power per kilogram of avoided ammonia. Furthermore, the setup can effectively control and assure its emission reducing principle. A description of the emission reducing principle and the executed measurements is given below.

Materials and Methods

The stable under investigation is of the cubicle type and is designed to house 185 adult dairy and calf cows. To reduce the ammonia emission of the stable the following technique is used. The air from the stable is sucked through the manure cellar using the grid floor as the air intake. The air is then directed through the chemical air washer. This ventilation system aims to collect the air with a high ammonia concentration, which is present just above the grid floor and manure layer in the cellar (see five, in figure 1). The maximum average ventilation rate of the cellar is 200 m^{3} /hour/animal. During the measurement period the maximum ventilation rate was between 60 – 110 m^{3} /hour/animal, which is roughly 60% of the maximum possible ventilation rate. Meaning that the ammonia emission can possibly be reduced further for increased ventilation rates. The stable also allows for natural ventilation via the sidewalls and top of the stable. The natural ventilation is controlled to ensure animal welfare by a closable curtain in the sidewall. The ammonia is emitted through the top and sides of the stable (see 2, figure 1). As well as through the top of the air washer (see 4, figure 1). This means that the total emissions are determined by the ordinary emission through the stable's top and sidewalls in addition to the efficiency results of the chemical air washer. The chemical air washer used in the investigated setup is accepted for dairy cows and has an efficiency of at least 90 % (BWL2012.02). However, the actual ammonia reduction is strongly determined by the effectiveness of the cellar ventilation, the homogeneity of the ventilation rate over the grid floor surface and the effectiveness of the ammonia capture above the grid floor surface. To ensure correct operation of the chemical air washer during measurement, all required parameters are registered conform the prescription of the manufacturer. To monitor the cellar ventilation system, a flow control with alarm is installed in each of the 5 air intake channels. Figure 2 schematically shows the grid floor and 5 sections with separate air intake channels.



Ventilatie concept



Figure 1. Schematic drawing of the air flow in the dairy stable, showing the cellar ventilation system (3 and 5) and subsequent air washer (4 and 6). Fresh air is supplied to the stable via the sidewall (1), natural ventilation occurs both via the sidewall (1) and top of the stable (2).



Figure 2. Schematic drawing of the 5 cellar ventilation intake sections, represented by the different colors.

The ammonia measurements are performed according to the guidelines of the standard measurement protocol [1]. In total 6 ammonia measurements are performed; every measurement takes 24 hours. The individual ammonia measurements are equally spaced in time over 1 year, so that seasonal effects are considered. To measure the natural ventilation/emission a measurement duct was installed in the top of stable. The duct consisted of 12 orifices equally spaced along the length of the stable (80m), this was done to take a volume proportional sample of the stable. To measure the air washer both the NH₃ and CO₂ concentration are determined before the air washer. After the air washer



only the NH_3 concentration is determined. The CO_2 concentration before the washer is required to determine the total ventilation rate of the stable (CO_2 mass balance method, GIGR calculation rules 6,8,9). Table 1 shows an overview of the executed measurements.

Measured components/ parameters	Location description							
	1. Stable air	2. Cellar air (Before washer)	3. Air after washer	4. Ambient air (outside stable)				
NH ₃	Х	Х	Х	Х				
Ventilation rate through CO ₂ measurements	х	Х		Х				
Ambient temperature (outside)				Х				
Stable temperature (inside)		Х						

The ammonia concentrations are measured using the wet-chemical method. The CO_2 concentrations are measured using a NDIR monitor. CO_2 concentrations are used in a mass balance method to calculate the total ventilation rate. The ambient (outside) measurement location is chosen upwind for each of the measurement sessions. The equations to determine the ventilation rate are discussed below,

In - Out = Accumulation + Production (1)

CO₂ does not accumulate in the stable, which simplifies the equation to,

$$In - Out = Production \tag{2}$$

The intake of CO_2 by the stable is the product of the outside CO_2 concentration (C_{in}) and the ingoing air flow (\emptyset_{in}). The loss of CO_2 by the stable is the product of the CO_2 concentration before the air washer (C_w) and the ventilation rate through the air washer (\emptyset_w) in addition to the product of the CO_2 concentration in the stable (C_s) and the air flow out of the stable (\emptyset_s). The production term in equation (2) can be calculated using the CIGR calculation rules [3]. Equation (2) takes the following form,

$$\underline{C_{in}} * \phi_{in} - (\underline{C_w} * \underline{\phi}_w + \underline{C_s} * \phi_s) = \underline{P_{CO2}}$$
(3)

The unit on both sides of the equation is mg/h. The underlined terms in the equation above are measured or calculated and thus known. Since the total inflow of air must be equal to the total outflow of air,

$$\boldsymbol{\phi}_{in} = \boldsymbol{\phi}_s + \underline{\boldsymbol{\phi}}_{w} \tag{4}$$

substituting equation (4) in equation (3) results in the final formula,

$$\underline{C_{in}}^{*}(\phi_{s}, \underline{\phi}_{w}) - (\underline{C_{vw}}^{*} \underline{\phi}_{w} + \underline{C_{s}}^{*} \underline{\phi}_{s}) = \underline{P_{CO2}}$$
(5)

This equation only has one unknown, the air flow out of the stable (ϕ_s). Solving for ϕ_s results in the following formula,

$$\phi_s = \frac{P_{CO_2}}{C_{in} - C_s} + \phi_w \left(\frac{C_w - C_{in}}{C_{in} - C_s}\right) \tag{6}$$



Results

Figure 3 shows the measurement results (24-hour averages) of the ammonia emission for each of the six measurements. The percentage in the brackets shows the percentage of cellar ventilation with respect to the maximum possible cellar ventilation rate. This shows that the first three measurements are conducted at 35 % of the maximum ventilation rate and the last three at 60 % of the maximum ventilation rate.



Figure 3. Graph showing the standardized ammonia emission factor for each of the six measurements. The percentage in brackets shows the percentage of cellar ventilation compared to the maximum possible cellar ventilation rate. The green bar shows the total emission, the red bar the emission from the washer and the blue bat the emission from the (top of the) stable.



Figure 4. Relation between the ratio of cellar ventilation over total ventilation and amount of ammonia captured by the chemical air washer. (Note that the linear regression line is made to show the increasing character, it is not known if the relation is linear).

Discussion

During measurements of the test stable in Zeewolde all agricultural conditions are satisfied. Meaning that the measurements are conducted with representative circumstances for a dairy stable. The measurements are conducted at two different cellar ventilation rates, namely 35% and 60% of the maximum possible ventilation rate. The results suggest that increasing the cellar ventilation rate above 60% would decrease the ammonia emission even further. The



results also allow for a calculation of the ammonia captured by the chemical air washer. This is done by comparing the ammonia concentration before and after the air washer. The ammonia captured by the air washer is strongly dependent on the ratio of cellar ventilation over total ventilation (cellar + natural). The natural ventilation is influenced by meteorological conditions, in particular wind speed and wind direction. Figure 4 shows the ammonia capture in kg/animal/year against the ratio of cellar ventilation over total ventilation. This ratio is equal to the CO_2 flow rate (g/h) divided by the total amount of CO_2 produced by the animals (g/h). This figure shows that the amount of captured ammonia can be estimated by measuring the CO_2 concentration in the cellar (before the washer) and in the top of the stable. This is to be expected as the ratio of cellar ventilation over total ventilation can be taken as a measure for the effectiveness of the cellar ventilation system itself. This means that during strong winds and thus increased amount of natural ventilation, the cellar ventilation system will have to work harder to maintain a high CO_2 concentration ratio and a high ammonia capture.

Conclusions

The average ammonia emission factor of the investigated stable with cellar ventilation and subsequent chemical air washer is 8.4 or 5.1 kg/animal/year for 35 % or 60 % of the maximum cellar ventilation rate respectively. The latter case corresponds to a cellar ventilation rate of around 120 m³/animal/hour. The year-round ventilation rate average of a naturally ventilated dairy stable is 1200 m³/animal/hour [2]. This means that if 10% of the total ventilated air is passed through cellar ventilation system with washer, an ammonia emission reduction of 60 % can be achieved (calculated using the emission of a category A1.100 housing system with an ammonia emission of 13 kg/animal/year [4]). The ammonia emission of 5.1 kg/animal/year (60 % cellar ventilation) is 41 % lower than the maximum allowed emission of 8.6 kg/animal/year from the low-emission housing decree [5].

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Use of Malt Bagasse in Ceramic Material

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Abstract

The global construction sector is progressively embracing sustainable alternatives in its practices, with a particular emphasis on the production of eco-friendly materials. Concurrently, the improper disposal of solid waste is rapidly becoming a significant concern, and this includes waste generated by agro-industries, including malt bagasse from beer production. Thus, the objective of this study was to incorporate malt bagasse residue in ceramic material using different proportions (0%, 2.5%, 5%, 10%, 15%) as a partial substitute for clay, submitted to different sintering temperatures (750, 850, 950 and 1050 °C). Properties of the ceramics with and without waste incorporation were evaluated as dilatometry, apparent density, apparent porosity, water absorption, linear shrinkage and tensile strength. The results showed that there were significant differences in the properties of the ceramic material, especially linear shrinkage and apparent porosity. It was possible to conclude that the greater the amount of malt bagasse residue incorporated, the lower the mechanical properties of the pieces, thus, being 15% of residue incorporation the lowest result, due mainly to the greater loss of mass. However, the minimum recommended value for masonry ceramic components is from 1.5 MPa and the incorporation of up to 5% of malt bagasse for all temperatures studied can be considered, thus contributing to technological and environmental aspects for civil construction.

Keywords: residue, ceramic, alternative materials, sustainability

Introduction

At present, there is a growing focus on adopting more sustainable practices in various sectors, including civil construction, by utilizing residues from agro-industries and the food industry (Azevedo et al., 2021). These industries contribute significantly to the generation and disposal of solid waste, as well as greenhouse gas emissions, predominantly CO2 (Cheremisinoff et al., 2008). Notably, the brewing industry generates substantial solid waste, with by-products like grains and malt bagasse accounting for approximately 85% of brewery waste (Swart et al., 2021). Malt bagasse, specifically, amounts to around 20 kg per 100 liters of beer produced (Mussatto et al., 2008).

The improper disposal of the substantial by-products generated by beer production, often ending up in landfills, has resulted in several negative consequences (Bonato et al., 2022). This poses significant challenges for transitioning to new sustainable practices, particularly concerning the economy and circular production principles (Silva et al., 2021). The identified hurdles stem from resource scarcity, inadequate logistics, solid waste management, and the underutilization of biomass generated by breweries (Bonato et al., 2022). To address these challenges, numerous studies have been conducted within the brewing industry, aiming to enhance the efficiency and sustainability of its technologies, production processes, and valorization of by-products (Ashraf et al., 2021; Czubaszek et al., 2021; Codina-Torrella et al., 2021).

Quaranta et al. (2016) conducted a study on the practicality of utilizing malt bagasse as a pore-forming material in the production of ceramic bricks. Their findings revealed that clay mixtures containing 10% of the residue exhibited favorable physical and mechanical properties, including appropriate values for porosity, modulus of rupture, volumetric variation, and weight loss, making them suitable for practical applications. In another investigation by Cordeiro et al. (2013), the thermal behavior and heat capacity of malt bagasse were analyzed using calorimetry, with samples containing varying moisture levels. The results indicated that the calorific value of malt bagasse decreased with reduced moisture content and density. The study also revealed a high percentage of volatile materials and a low percentage of ash and carbon in the bagasse. Furthermore, Ferreira et al. (2020) examined biodegradable composites comprised of cassava starch mixed with sugarcane bagasse, corn straw, malt bagasse, or orange bagasse. The mechanical analyses demonstrated that the addition of different amounts of agro-industrial residues enhanced the rigidity of the composites, although they became more susceptible to degradation. Nonetheless, the researchers concluded that the utilized waste materials had the potential to be effectively employed in the production of biodegradable composites.

Additionally, the construction sector has been actively seeking alternatives to enhance its environmental performance, recognizing its substantial impact on the environment (Silva et al., 2021). However, the specific focus of this study was to investigate the integration of malt bagasse residue into ceramic material, employing varying proportions as a partial replacement for clay. These composite materials were then subjected to different sintering



temperatures for further analysis and evaluation.

Materials and Methods

For this research, the following raw materials were utilized: ceramic mass (ball clay + sand) sourced from the region of Campos dos Goytacazes, RJ, and malt bagasse residue obtained from a brewery located in Niterói, RJ.

After collection, the ceramic mass samples were subjected to several processing steps. First, they were homogenized and dried in an oven at a temperature of approximately 110 °C for approximately 24 h. Following the drying process, the samples were disaggregated using a jaw crusher and further crushed using a porcelain mortar and pestle. Sieving was then performed using a 20-mesh sieve to obtain powdered material for the granulometry test, following the guidelines of NBR (Brazilian Standard) 7181 (ABNT, 2016a). Additionally, a 40-mesh sieve was used to determine the consistency limits according to NBR 7181 and NBR 7180 (ABNT, 2016b). A portion of the sample was also passed through a 200-mesh sieve for chemical and mineralogical characterization of the material.

The malt bagasse was initially subjected to a drying process to eliminate excess moisture. It was dried in an oven at 70 °C for 96 h. Subsequently, the residue underwent an additional drying step for 24 h at 60 °C to remove any remaining moisture. Given the high humidity and organic nature of malt bagasse, specific drying conditions were necessary. After the drying process, the malt bagasse was ground using a mortar and pestle until it passed through a 40-mesh sieve.

Five mixtures were formulated, incorporating different percentages of malt bagasse residue to replace the clay mass, namely 0 (reference), 2.5, 5, 10, and 15%, by mass.

Sixty grams of material (clays + sand + malt bagasse) were separated for each formulation and then homogenized in a ball mixer for 30 min. After homogenizing the mixtures, 8% of water was added in relation to the weight of each one (249.6 g) for the hydration process called "dry medium", with the aid of a sprayer. Subsequently, they were packed in closed plastic bags to be sent to the mold to be pressed.

From the preparation of the 5 mixtures, specimens (CPs) were molded in a rectangular shape using a press with a pressure of 35 MPa and dimensions of approximately $115 \times 25 \times 12$ mm via the pressing process. Thus, 275 CPs were made, 13 for each composition. The CPs were subjected to 4 different sintering (burning) temperatures, namely 750, 850, 950, and 1050 °C.

The apparent density of the dry pieces was determined according to NBR ISO 10545-3 (ABNT, 2018). The length, width, and thickness were measured using a MITUTOYO digital caliper with a resolution of 0.01 mm, and the dry mass of the pieces was weighed using a SHIMADZU scale, model S3000, with a precision of 0.01 g, according to NBR ISO 10545-3 (ABNT, 2018). Thus, the dry bulk density was calculated using Eq. (1).

$$\rho_{ap} = \frac{m}{v} \tag{1}$$

where ρap = apparent density of dry specimens (g/cm³); m = dry mass before firing (g); and v = volume of dry parts (cm³).

The apparent porosity of the specimens was determined according to NBR ISO 10545-3 (ABNT, 2018), using a SHIMADZU scale, model S3000, with a precision of 0.01 g, and calculated using Eq. (2).

$$PA = \frac{Msat - Ms}{Msat - Mi} \times 100$$
⁽²⁾

where PA = apparent porosity (%); Msat = saturated mass (g); Ms = dry mass after firing (g); and Mi = mass of the specimen immersed in water (g).

Water absorption was evaluated according to the ASTM C373-18 standard (ASTM, 2018) and calculated according to Eq. (3).

$$AA(\%) = \frac{Mu - Ms}{Ms} \times 100 \tag{3}$$

where AA = water absorption (%); Mu = mass (g) of the burned and wet specimen; and Ms = mass (g) of the burnt and dry specimen.

Linear shrinkage was determined to verify the dimensional variation of the samples that underwent the burning process based on NBR ISO 10545-2 (ABNT, 2018) Thus, the pieces were measured using a MITUTOYO digital caliper



with a resolution of 0.01 mm, and linear shrinkage was calculated using Eq. (4).

$$R_{Lq}(\%) = \frac{Ls - Lq}{Ls} \times 100 \tag{4}$$

where RLq = linear shrinkage; Ls = length of the pieces after drying (mm); and Lq = length of the parts after firing (mm).

Bending Tensile Tension

The three-point bending stress (σ) was determined using the ASTM C674-77 standard (ASTM, 1977) and calculated using Eq. (5).

$$(\sigma) = \frac{3PL}{2bd^2} \tag{5}$$

where (σ) = bending failure stress (MPa); P = load applied to the part at the moment of failure (N); L = distance between the supporting cleavers (mm); b = width of the ceramic piece (mm); and d = thickness of the specimen (mm).

For the statistical analysis, analysis of variance (ANOVA) was used to verify the existence of significant differences among the obtained results. The statistical differences were confirmed by means of the mean comparison test, using Tukey's method (p < 0.05). To process the statistical data, the software Sisvar v. 5.8 (Ferreira, 2014) was used. A completely randomized design (DIC) was used since there was no separation into blocks. As for the repetitions, 13 were used for each treatment (0, 2.5, 5.0, 10, and 15%).

Results and Discussion

3.1 Apparent Density

Regarding the apparent dry density, there was a significant difference in the values obtained in relation to the waste incorporation treatments, while no significant difference was found for the sintering temperature, in which it only differed with 2.5% malt (Table 1).

Apparent dry density (g.cm ⁻³)					
Malt hagaaa $(0/)$	Sintering temperature (°C)				
Mait bagasse (%)	750	850	950	1050	
0.0	1.83 aD	1.83 aC	1.83 aD	1.85 aD	
2.5	1.83 abD	1.81 aC	1.84 bD	1.83 abD	
5.0	1.80 aC	1.80 aC	1.79 aC	1.79 aC	
10.0	1.74 aB	1.73 aB	1.72 aB	1.71 aB	
15.0	1.59 aA	1.59 aA	1.60 aA	1.61 aA	

Table 3. Apparent dry (g.cm⁻³) density of ceramics.

*Means followed by the same letter, lowercase in the row and uppercase in the column, do not differ by Tukey's test at the 5% probability level (P < 0.05).

However, there was a trend toward a reduction in density, as there was an increase in the levels of biomass residue incorporated into ceramics, as also shown by Cotes-Palomino et al. (2016). This characteristic of lower density is intrinsic to lignocellulosic biomass (Machado et al., 2020), which is justified by its organic composition and biodegradability, especially when subjected to high temperatures. This can be observed by the significant differences in the treatments in relation to temperature. However, this mass reduction is not harmful to the behaviour of the ceramic material and can even be considered beneficial since ceramic materials are normally used as sealing blocks or tiles (Delaqua et al., 2020).

3.2 Apparent Porosity

Table 2 show the apparent porosity results between the manufactured ceramics.

Table 2. Apparent porosity (%) of ceramics.

Apparent porosity (%)					
Malt bagasse (%) -	Sintering temperature (°C)				
	750	850	950	1050	
0.0	27.57 dA	26.99 cA	26.56 bA	25.20 aA	
2.5	27.87 dA	27.35 cB	26.75 bA	25.33 aA	

5.0	28.27 dB	27.76 cC	27.20 bB	25.95 aB
10.0	29.67 dC	29.24 cD	28.65 bC	27.95 aC
15.0	31.18 cD	31.40 cE	30.68 bD	30.31 aD

* Means followed by the same letter, lowercase in the row and uppercase in the column, do not differ by Tukey's test at the 5% probability level (P < 0.05).

There was a significant difference between the treatments, both for the incorporation of the residue and for the temperature. With the increase in malt bagasse, there was an in-crease in porosity in relation to the reference sample (0%). During the sintering process, samples with malt bagasse incorporation had a greater tendency to have pores in the ceramic, which is also associated with a loss of mass that consequently causes more porosity, as confirmed by Russ et al. (2005).

3.3 Water Absorption

The water absorption after firing the evaluated ceramics is shown in Table 3.

	Table 3. Water	absorption (%) of ce	ramics.	
		Water absorption (%)	
Malt harage $(0/)$	Sintering temperature (°C)			
Malt bagasse (%) –	750	850	950	1050
0.0	19.03 bA	19.15 bA	19.01 bA	16.05 aA
2.5	19.00 bA	19.22 bA	18.67 bA	15.57 aA
5.0	18.72 bA	19.00 bA	18.67 bA	15.93 aA
10.0	22.52 bB	23.07 bB	22.60 bB	20.99 aB
15.0	28.54 abC	29.07 bcC	29.29 cC	28.29 aC

* Means followed by the same letter, lowercase in the row and uppercase in the column, do not differ by Tukey's test at the 5% probability level (P < 0.05).

The test specimens produced with different contents of malt bagasse residue showed a significant difference between the percentages of malt bagasse incorporation and between the sintering temperatures. As there was an increase in the incorporation of the residue, there was an increase in water absorption. This is justified by the hydrophilic characteristics (Russ et al., 2005) and by the combustion of organic compounds present in biomass (Delaqua et al., 2020), which also contributes to the increase in porosity. Thus, the greater the porosity, the greater the water absorption (Silva et al., 2020). However, at 1050°C, there was a reduction in porosity, which may be associated with greater formation of the liquid phase, the main mechanism of ceramic sintering (Delaqua et al., 2020).

The maximum water absorption value allowed by technical standards for ceramic sealing blocks is up to 25% (ABNT, 2017), and for tiles, it is up to 20% (ABNT, 2009). Thus, for treatments of up to 5%, the incorporation of malt bagasse residue can be recommended for ceramic blocks in terms of water absorption sintered at all temperatures studied. To produce tiles, only the ceramic mass containing 2.5% fired at 1050°C was viable for application, considering the other properties also evaluated.

3.4 Linear Retraction (RL)

Table 4 shows the linear retraction results of the manufactured ceramics.

Table 4. Linear retraction of ceramics.

		Linear retraction		
Malt bagasse (%)	Sintering temperature (°C)			
	750	850	950	1050
0.0	0.88 aBC	1.24 bA	2.00 cB	3.31 dC
2.5	0.71 aAB	1.26 bC	1.92 cB	3.32 dC
5.0	0.62 aAB	0.95 bAB	1.46 cA	2.73 dB
10.0	0.53 aA	0.88 bA	1.21 cA	1.94 dA
15.0	1.10 aC	1.20 aBC	1.74 bB	2.64 cB

* Means followed by the same letter, lowercase in the row and uppercase in the column, do not differ by Tukey's test at the 5% probability level (P < 0.05).

There was a significant difference in the linear shrinkage of the ceramic pieces since it increased according to the increase in the firing temperature for all treatments. This is due to the better disposition of the particles through the



formation of a liquid phase, which promotes their approximation and, consequently, their retraction or shrinkage (Delaqua et al., 2020). There was a great increase in shrinkage for all ceramics fired at 1050°C, indicating transformations in the sintering stage regarding the formation of more resistant compounds. In this phase of sintering, there is an increase in the amount of the liquid phase present in the material due to the amount of alkaline and alkaline earth compounds, densifying the specimens more and consequently causing greater linear shrinkage (Cargnin et al., 2011). The maximum recommended shrinkage for ceramic firing is 2% (Delaqua et al., 2020); in this case, it was exceeded at only 1050°C for all treatments studied.

3.5 Breaking Stress on the Bending of the Test Specimens

The analysis of the flexural strength of the specimens produced with different contents of malt bagasse residue showed a significant difference between the percentages of malt bagasse incorporation, as well as between the sintering temperatures (Table 5). Thus, in relation to the sintering temperatures, all ceramic masses showed an increase in flexural rupture stress due to the increase in firing temperature in relation to the reference pieces (0%). For all treatments, there was a significant increase in the tensile strength of the sintered mixtures from 750 to 850°C, which is justified by the greater loss of adsorbed water and the loss of initial mass. At 850°C, the tensions of all treatments remained more stable in this sense.

Table 5. Mean breaking strength (MPa) of the samples in relation to the sintering temperature (°C) and the
incorporation of malt bagasse residue (%).

	Break	ting stress to bending	g (MPa)	
Malt harassa $(0/)$	Sintering temperature (°C)			
Mait Dagasse (%) –	750	850	950	1050
0.0	3.45 aD	4.45 bC	4.62 bD	5.17 cD
2.5	3.15 aC	4.16 bC	4.21 bC	4.28 bC
5.0	2.00 aB	2.42 bB	2.49 bB	2.74 cB
10.0	0.85 aA	0.98 abA	1.09 bcA	1.23 cA
15.0	0.85 aA	0.98 abA	1.09 bcA	1.23 cA

* Means followed by the same letter, lowercase in the row and uppercase in the column, do not differ by Tukey's test at the 5% probability level (P < 0.05).

As for the relationship between the incorporation of malt bagasse, the greater the amount of residue incorporated, the lower the bending stress of the pieces; thus, at 15% residue incorporation, the lowest the result. This is associated with the lignocellulosic characteristics of the malt residue, highlighting its greater degradation and fragility at high temperatures (Cordeiro et al., 2013), thus causing a great loss in mass, which also leads to a reduction in the area of applied stress and an increase in porosity compared to the reference piece (0%). In addition, there were a smaller number of crystalline phases in the manufactured material, which confers mechanical resistance to ceramic materials (Klitzke, 2020). However, the recommended minimum value for ceramic masonry components is 2.0 MPa, as demonstrated by Ketov et al. (2021). Therefore, the incorporation of up to 5% malt bagasse at all studied temperatures can be recommended.

Conclusions

Regarding the ceramic pieces manufactured with the inclusion of malt bagasse residue, an observed trend was a reduction in density as the proportion of residue increased. Nevertheless, this decrease in mass did not negatively impact the overall performance of the ceramic material, especially when incorporating up to 5% of the residue. In fact, this reduction in density could be viewed as beneficial, particularly considering that ceramic materials are commonly employed as sealing blocks or tiles.

Indeed, the samples with higher levels of malt bagasse incorporation exhibited a higher tendency toward the formation of pores in the ceramics. This increased porosity is associated with a corresponding loss of mass, resulting in greater water absorption for these ceramic materials. However, it is noteworthy that for treatments containing up to 5% of malt bagasse residue, the incorporation can be deemed suitable for ceramic blocks in terms of water absorption, regardless of the sintering temperatures employed in the study.

The treatments showed a significant increase in the tensile strength of the sintered mixtures from 750 to 850°C. Above 850°C, the tensions of all treatments remained more stable. Thus, the greater the amount of malt bagasse residue incorporated, the lower the bending stress of the parts. The incorporation of up to 5% malt bagasse at all studied temperatures can be recommended for masonry ceramic components.



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Production and value chains of *Aloysia triphylla* in Portugal

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Abstract

The Portuguese Market for Aromatic and Medicinal Plants (AMPS) has consolidated information and political guidelines, having received investments from the European Union for its strengthening, with studies of the value chain of its products being directed towards the consolidation and replication of processes. Thus, the management of the production (PC) and value (VC) chains of the *Aloysia triphylla* species cultivated in the northern region of Portugal was analyzed in order to reference a management system model for the AMPS market that could be replicated in other countries. To achieve these objectives, this study used the Value Links and SWOT Matrix tools. The results showed that updates and the systematization of a management model for the theme are necessary, where monetary and non-monetary values generated by the chain are in line with the current market. There is also a need for market and competitiveness studies to promote the analyzed species with a view to expanding and consolidating its PC and VC chains. The market value for the species is not compatible with the current chain, since the valuation of activities is outdated. Based on the results obtained in Portugal, it was possible to propose adaptations and outline guidelines and guidelines that could consolidate a more efficient management of this sector with a management model that could be replicated in other countries.

Keywords: Aromatic and Medicinal plants, Market structure, Value chain, Productive chain, Phytotherapics.

Introduction

Portugal is a country that stands out in the trade of medicinal and aromatic plants, with significant utilization of these crops by the population. This segment is handled professionally, with controlled sanitary measures advocated by the current legislation in the European Union (EU), aiming at exporting high-quality inputs and products. The production chain has standardized protocols for cultivation and processing techniques, in compliance with good agricultural practices, supported by financial incentives from the EU and national support policies.

Portugal's experience can offer Brazil a model for managing medicinal and aromatic plants, with an efficient production chain, coupled with the dissemination of value chain analysis practices for various plant-based products. This model can help foster the market for medicinal and aromatic plants, focusing on empowering small producers and family farmers through qualification.

Under the systems approach, an organization is dependent on the environment that provides the necessary inputs for processing and other functions, and it delivers results to that environment. Therefore, each organization has a demand for a type of structure that is most suitable for its performance and maintenance of activities in the market (Santos, Silveira, and Santos, 2011).

The production chain is a representation of the economic reality, incorporating in the agricultural context, "the actors involved in primary production, industrialization, transportation, marketing, distribution, and consumption activities," according to Roessing (2002). It becomes a multidisciplinary study encompassing technological, technical, economic, social, political, and other aspects, with a focus on social development in regional development plans, leading to the development of the production chain (Billacrês; Costa; Nunez, 2020). It is also essential to include in this analysis the actors and activities that contribute to the functioning of the production chain, such as suppliers of inputs and services. In general, the production chain can be defined as a set of consecutive stages through which various inputs pass, being transferred and transformed (Dantas; Kertsnetzky; Prochnik, 2002).

Brazil currently lacks a competitive and significant production chain for medicinal and aromatic plants, which would make this market more attractive to producers and companies in the Brazilian pharmaceutical sector. In the current market situation, its competitiveness is measured through indicators from foreign trade, with a substantial portion of the production chain segments being imported. Despite having great prospects for economic exploration in this area, the dynamics of importation mean that part of the value-added to products does not flow through the domestic economy, as the value is generated in the country of origin. According to Rodrigues (2016), "the production chain of



medicinal plants adds significant value," compared to other agricultural chains with fewer losses in their flow. One of the advantages of this sector is the high value of its processed products compared to raw materials. Additionally, this competitiveness could be enhanced by changes in the regulatory framework and industrial policy, as well as investments in research and national technologies. By improving the regulatory environment and investing in research and technology, the Brazilian market for medicinal and aromatic plants could become more competitive, fostering local production, and retaining more value within the domestic economy.

Understanding the production chain empowers the rural producer with access to information (from planting to drying) and knowledge of market dynamics. This dynamic can be used as a tool to help the producer appropriate the income generated in subsequent stages of the chain (processing, industrialization, and commercialization). Thus, the analysis of the production chain assists in identifying the value chain - the activities that add value to the service or product - as well as identifying costs, including those that enhance quality, while eliminating those that only add value to the final price.

Therefore, the production chain presents a logical flow, ensuring a holistic view of the processes, aiding in the search for competitive advantages. In other words, it allows the species under study to have a homogeneous chain with all processes aligned and well-executed (Schiemer Vargas et al., 2013).

Thus, the objective was to evaluate the management of the production chain (PC) and value chain (VC) of the species *Aloysia triphylla* cultivated in the northern region of Portugal, with the aim of referencing a management system model for the market of Medicinal and Aromatic Plants (AMPs) that could be replicated in other countries.

Materials and Methods

This research was conducted in the northern coastal region of Portugal, in the district of Porto, more precisely in the localities of Vila Nova de Gaia, Amarante, Barcelos, Póvoa de Lanhoso, Penafiel, and Rio Tinto (Figure 1).



Figure 1: Location of the interviewed producers in the Porto district, highlighted in red on the map. Source: http://epam.pt/produtores/

In northern Portugal, approximately 50 producers of medicinal and aromatic plants were identified, and the initial contact was made via emails with a total of 16 producers who were within a suitable proximity range for travel and conducting interviews (an average of 30 km distance).

The EPAM (Medicinal and Aromatic Plants Entrepreneurial Project) is a private initiative in Portugal, but it receives assistance from funds provided by the European Union. The project features a unique format (cultivation methods, irrigation, drainage, replication of seedlings, type of commerce, among other characteristics) that can be replicated in various areas, regardless of the size of the land. In other words, it was designed in a way that any producer in any part of the country can transform their cultivation into a medicinal and aromatic plant plantation or start a production from scratch.

The initial selection of producers was made considering the cultivated species, ensuring that they were also listed in the Medicinal Plant list of interest to SUS (Brazilian Unified Health System, 2009), as well as their mode of commercialization. Their adherence to the CC-PAM (Competence Center for Medicinal and Aromatic Plants) was also verified. The CC-PAM aims to boost the medicinal plant market in Portugal, both locally and internationally. Additionally, producers linked to university research were considered, as it facilitated understanding the scope of the


present study.

In the first contact made in November 2018, introductory emails were sent to sixteen producers, inviting them to participate in the interviews and providing them with the questionnaire. The emails explained the objectives and the importance of each producer's collaboration. However, three of these emails were not received as the contact information had changed.

In April 2019, field interviews were conducted, and after completing all the questionnaires, they were compiled and sent back to the producers to ensure the accuracy and clarity of the provided information. This step also aimed to inform the producers about the content of the document.

Portuguese agricultural producers are classified based on the size of their properties, represented by their economic dimension (DE). The DEs were defined by concepts elaborated by the Planning and Policy Office in 2011, where the characteristics of the agricultural property are identified, and it is categorized based on the standard production value (VPP).

To identify the species to be studied, a survey of the main species cultivated by producers in northern Portugal was conducted. Among the species surveyed, there was a higher incidence of the following: *Aloysia triphylla* (lemon verbena), *Cymbopogon citratus* (lemongrass), *Thymus mastichina* (Spanish marjoram), *Thymus citriodorus* (lemon thyme), *Stevia rebaudiana* (Stevia), and *Mentha peperita* (peppermint). Among these species, *Aloysia triphylla* (L'Hér.) Britton (Verbenaceae) best met the pragmatic criteria, which include economic, social, and legal considerations. *Aloysia triphylla* (Figure 2) has a high market demand both nationally and internationally, ensuring the complete sale of the production. It offers potential for economic growth to the producer, competitiveness, excellent edaphoclimatic conditions for the studied region, and production with job creation and income generation.



(a) (b) Figure 2: (a) *Aloysia triphylla* in growth; (b) Cultivation of the species. Source: Producer 3.

The development and analysis of the value chain of the species *Aloysia triphylla* were carried out as supportive management tools. The Value Chain was constructed based on the concepts of Weiskopf (2009), which considers the evaluation of the sequence of production processes up to the final consumption, the identification of the actors involved in the process, and the establishment of an appropriate business model for products with greater market representativeness.

The Value Chain was designed to identify the sequence of activities from the starting point, starting from the origin of resources for planting and continuing until the product is distributed and reaches its final destination. The Value Chain was structured in stages, based on the study conducted by the Oswaldo Cruz Foundation and the Ministry of Agrarian Development (FIOCRUZ/MDA, 2016), and the synthesis of data gathered through the SWOT analysis.

Results and Discussion

According to the data gathered, it was observed that the management guidelines for the production of medicinal and aromatic plants in Portugal were incentivized as an alternative to address the issue of increasing vacant and unproductive lands in cities far from major urban centers. With the planning of actions promoted by national policies, significant contributions were made to local development and the fight against the abandonment of rural territories with low population density (Ministério da Agricultura e do Mar -Portaria n.º 31/2015 de 12 de fevereiro).



The market for Medicinal and Aromatic Plants (MAPs) is a highly profitable global trade sector, providing raw materials for the food, pharmaceutical, and cosmetic industries. Consequently, it serves as a means to mitigate the impacts created by the issues mentioned earlier. Portugal has been reversing these problems, aided by financial support from the European Union. Over a period of 10 years, in addition to addressing social issues such as healthcare, education, employment, and housing, various agricultural activities are gaining competitiveness and growth in the country.

Figure 3 shows a summary of the financial flow of program management in the Portuguese agriculture sector.



Figure 3: Financial flow of MAP management in Portugal. Source: author.

The demand for the cultivation of Medicinal and Aromatic Plants (MAPs) in Portugal has been significantly promoted through various territorial development programs and projects, such as the "Promover e Vender" (PROVE) and the "Empreender na Fileira de Plantas Aromáticas e Medicinais em Portugal" (EPAM). The sector has experienced a notable increase in the number of producers seeking investments through these programs to cultivate MAPs on their properties.

In summary, the management of aromatic and medicinal plants in Portugal is guided by a mission and vision that includes: i. developing a homogeneous chain that involves all actors in the process; ii. coordinating this chain for effective management; iii. fostering the sector by providing necessary financial support; iv. promoting growth and development in this industry; v. offering technical support through specialized organizations and projects, which helps to raise awareness and visibility for the sector. It has been observed that the more qualified the product and its processes, the greater its visibility, leading to sector growth, increased competitiveness with other cities around Porto, and positioning Portugal favorably compared to other countries.

The production chain of aromatic and medicinal plants has a high development potential and the conditions to establish itself as an innovative sector in Portugal. In the field research conducted for the development of this work, information was verified that can be seen throughout this chapter regarding the details of this Portuguese chain. The MAP production chain is attracting new producers every day, contributing to the preservation of rural populations and encouraging migration from urban to rural areas, demonstrating potential for value creation and stimulating new entrepreneurial initiatives related to these crops. As observed, a significant portion of the cultivations is predominantly organic (biological), resulting in highly sought-after products, especially in foreign markets.

The production chain is formed by processes and subprocesses that constitute a set of actions that support the value chain, comprising four links: agricultural production, input distribution, processing, and commercialization. In the case of the medicinal and aromatic plants production chain in Portugal, it is divided into five stages (cultivation, harvesting, processing, product distribution, and consumption) and their sub-stages, allowing for a clear identification of the function of each stage, aiming to achieve a harmonious flow for successful cultivation and distribution.

Developing a value chain map for the *Aloysia triphylla* species will aid in visualizing the entire process (Figure 4) from the acquisition of basic inputs to the end consumer. The map also identifies the actors involved in this chain, the commercial relationships between them, the supporting organizations, and finally, the public sectors involved in the process.





Figure 4: Mapping of the value chain of *Aloysia triphylla*. Source: Author.

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The species *Aloysia triphylla* was considered economically significant as it clearly serves as a botanical input that generates satisfactory monetary resources for the producers, with excellent commercial demand. Consequently, it represents one of the major crops in terms of cultivation area. In 2019, according to the EPAM website, it was observed that in the northern region of Portugal, 12 producers cultivated the studied species, covering approximately 6 hectares of cultivation. This resulted in a total volume of 120 tons (equivalent to 480 big bags of 250 kg each) of the product being sold in its natural state, generating a total revenue of 840,000.00 \in .

The initial stage of production is the acquisition of inputs. Despite being an initial high investment (\notin 49,300 per hectare), there are items that do not need to be purchased for each planting cycle, such as reusable bags, trays, and plastic sheets that serve as temperature regulators. In this phase, the item that adds the most value is the workforce (labor), as it is scarce and costly (approximately \notin 20,000 per year, per employee, working 50 hours per week), depending on the level of specialization (Neto; Morgado, 2013).

Next, management and production are highlighted, and among the items that compose it, the most concerning is the cutting (harvesting) phase. In this stage, besides the loss of plant material, there are also special considerations for the type of cutting machines and handling difficulties, often requiring four people to work together (two guiding the machine at the front and two making the cut at the back). A point of attention in this phase is how the cutting is performed, as it can cause damage to the next crop, hindering the growth of new branches if the machine is not suitable for the specific species.

Improving all levels of production, from planting to drying, adds quality to the final processed product. As a result, there is a direct influence on the quality of the products to be commercialized, such as natural products, tea bags, premium tea lines in cans or boxes, cosmetics, and standard and premium spice lines.

The commercialization process may have less impact because, when conducted by cooperatives, the freight to the destination country is paid by the buyer. In stores or markets, the producer, depending on the requested volume, either makes their own deliveries or hires a freight service. In open markets, producers use their own transportation to the site. The consumption varies according to the buyer's preference, with some preferring fresh products while others prefer processed ones.

Finally, producers were encouraged to reflect and analyze their productions over a period of three to five years. This self-assessment allowed the producers to evaluate and propose improvements for a desirable future, involving physical and structural enhancements, necessary parameter modifications, and required monetary investments and learning opportunities.

Through the SWOT analysis, it is possible to have a global view of the positioning of the MAP (Medicinal and Aromatic Plants) market in Portugal. It was observed that the identified characteristics often conflicted due to the diversity of production size and the local market. However, the situations identified reflect the scope of production in an expanding market.

The MAP sector is in full development, with some points to be aligned and improved. The major threat to the sector is the scarcity of skilled labor, as this problem directly impacts the industry, affecting and creating other internal and external issues.

The established strengths (internal factors) are as follows: (1) Portugal has a good variety of species of interest for consumption, providing producers with a wide range of choices for cultivation; (2) The increasing demand for a more natural and healthy lifestyle has led to a higher consumption of MAPs by the Portuguese population; (3) There is ease in the distribution of production both in the domestic and international markets; (4) The interviewed producers show significant interest in research within the field, recognizing its importance for growth and overall production.

The weaknesses (internal factors) identified are as follows: (1) Pest control presents a challenge as organic productions face difficulties in combatting pests due to the high cost of acquiring organic pesticides; (2) The removal of plastic mulching generates a large volume of plastic waste that impacts the environment and takes up space on-site; (3) Residual dust during the processing stage requires readapting warehouses with the installation of filtration systems to reduce airborne particle concentration and increased investment in Personal Protective Equipment (PPE) for workers involved in this stage of production; (4) The use of inadequate machinery for harvesting each species results in volume losses during harvesting and damages the plant for a new growth cycle, as generic machinery often fails to adapt to the size and volume of the plant; (5) The lack of qualified labor is a significant problem to be addressed, as there is a lack of interest in training and a shortage of technical professionals to meet the demand in the MAP market.

The opportunities (external factors) identified are as follows: (1) The market is in full development with an



established management of values and product/service quality, which can lead to the expansion of both the domestic and international markets; (2) The sector offers research opportunities in various fields of knowledge, as it is transdisciplinary, resulting in a positive impact on increasing confidence and consumption by the Portuguese population; (3) There is a diversity of final products, not only dried or fresh plants but also products for the cosmetics, food, essential oils, pharmaceutical industries, among others. All these factors contribute to significant market growth, establishing improvements in productivity and facilitating distribution both in the domestic and international markets, which motivates producers.

The threats (external factors) identified are as follows: (1) The absence of specific professionals in the field of PAM for project oversight; (2) The need to incentivize new qualified producers to enter the sector in a consolidated manner and adhere to regulations; (3) Low financing value, where an increase in government funding would help in the development of new processing techniques; (4) Lack of qualified workforce to assist in technical improvement and optimize work in the field; (5) High labor costs, which directly affect the final product's price; (6) Challenges in registering and managing new producers due to the rapid growth of the market, leading to the loss of certain information by the management sectors; (7) Difficulty in finding organic pesticides and acquiring inputs conveniently in the vicinity of the properties; (8) Climate instability affecting cultivation, as some species, such as *A. triphylla*, cannot withstand low temperatures, leading to certain productivity restrictions. These limitations can be overcome with research investments to find solutions related to adapting cultivation. Research efforts aim to increase productivity for the species during milder temperature periods, balancing the lower productivity during colder times. Additionally, studies on the economic, social, and environmental viability of indoor cultivation for this species could represent new perspectives for productivity growth, provided its implementation ensures the sustainability of the entire supply chain across these dimensions.

Conclusions

The results of the case study on the value chain for the *Aloysia triphylla* species demonstrate the need for updates in order to align the monetary and non-monetary values generated by the chain's actions with the current market.

In a certain way, the management of aromatic and medicinal plants in Portugal is controlled, and the stages are executed. However, there is a need for more in-depth market studies and competitiveness analysis specifically for the *Aloysia triphylla* species. These studies should be focused on promoting this species, as its high market potential, economic interest, and diverse forms of utilization and processing represent elements that ensure the viability of expanding its productive and value chains.

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Carbon Footprint in Agriculture - Studies carried out on: potato, carrot, onion, melon, watermelon, wheat, corn, barley and triticale crops.

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Abstract

In Portugal, agriculture represents 10.8% of total greenhouse gas emissions (GHGE) (National Inventory Report, 2021). The commitment to reach carbon neutrality by 2050 means achieving a neutral balance between GHGE and carbon sequestration, for which substantial reductions in emissions and/or substantial increases in national carbon sinks will be required, which have to materialise between now and 2050 (Roadmap for Carbon Neutrality 2050 Portugal, 2019). However, looking further ahead, the European Commission has proposed a land sector focus, combining emissions from agriculture (mainly livestock and fertiliser) and net removals from LULUCF (Land Use, Land Use Change and Forestry). The aim is to reach climate neutrality in the land sector by 2035 and net negative emissions thereafter (EU Climate Action Progress Report 2022).

It's important not only to quantify emissions but also to understand the processes that lead to emissions so that we can reach carbon neutrality. One of the main goals of the PEGADA 4.0 project is to identify, study and develop digital technologies and solutions that can reduce agriculture's carbon footprint, promoting wealth and well-being.

In this study, GHGE were calculated for horticultural plots (Potato, Carrot, onion, watermelon and melon) and cereal plots (barley, corn, wheat and triticale) trying to compare the carbon footprints amongst crops.

This assessment was carried out by collecting data from several companies regarding the different crops presented earlier. The methodology followed the Portuguese National Inventory Report 2021 guidelines, which are based on the models established by IPCC 2006.

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Keywords: Agriculture Climate Neutrality, Carbon Footprint, GHG Emissions.

Introduction

It is public that was established in the Paris Agreement (2016), and reaffirmed at COP26 (2021), the reduction of *Carbon Emissions* (CE) and *Greenhouse Gases Emissions* (GHGE) worldwide, so that it is possible to stop the increase in temperature and climate change. Thus, all sectors of society, including the agricultural sector, must be committed to this purpose.

Recently (2022), the European Union included in the "Fit for 55 legislative package" (which is a package of rules to achieve the "zero carbon" emissions in EU countries) measures to increase carbon sequestration through land use, forestry and agriculture to achieve climate neutrality by 2035 (EU Climate Action, 2022). Portugal, as a member of the EU, will also have to implement the necessary measures to achieve agriculture climate neutrality by 2035.

Knowing that the world population has already reached 8 billion people (UN, 2022), that feeding this population is degrading terrestrial and aquatic ecosystems, that it is contributing to climate change (Poore & Nemecek, 2018) and that agriculture production contributes between 30 to 40% to total anthropogenic GHGE (Parajuli et al., 2018); the challenge is to find carbon neutrality solutions that are effective in the various types of agricultural production in the world (Poore & Nemecek, 2018).

For all these reasons, it is essential to know the production systems, assess their impacts and develop more financially and environmentally sustainable production techniques.

The *Carbon Footprint* (CF) is an indicator, generally used, to quantify CE and GHGE (Chen et al., 2021), assess the performance of a particular system and its impacts on the environment.

In agricultural systems, one of the most used methods to assess CF is the so-called system *Life Cycle Assessment* (LCA), which quantifies production data and translates them into environmental impacts (Poore & Nemecek, 2018) (see Figure 1). The LCA includes on-farm activities (greenhouses, irrigation system, soil tillage, etc.) but also pre-exploration (fertilizers, energy, etc.) and post-exploration (packaging, storage, waste, etc.) (Dorr et al., 2021).





Figure 1 - Example of an LCA and the points to be included in the assessment. They are considered the most important procedures of the production cycle. (Extracted from Dorr et al., 2021).

The objective of this study is, therefore, to understand what investigations have been carried out in the agricultural sector, in particular in horticulture and cereals, and to answer the questions: Which is the CF value of horticultural and cereal crops in Portugal? Which cultural operations have the highest and lowest CF? How to optimize the production system?

Materials and Methods

The crops carbon footprints were calculated considering the activities carried out exclusively within each Production Unit (PU), not including the pre-exploration part of the life cycle (sowing in nurseries, transport of inputs to the exploration) and post-exploration (transport to warehouse, processing, packaging, refrigeration). Considering the example in Figure 1, the part of the study considered corresponds to the phase marked in orange as Farm Stage.

This study is supported by the project PEGADA 4.0 – Sustentabilidade da Actividade Agrícola Suportada por Processos e Tecnologias Inteligentes (PRR-C05-i03-I-000099).

Carbon Footprint Calculation

The CF calculation was made according to the methodology developed by the IPCC (2006), considering 2 types of GHG sources:

1. DIRECT SOURCES – Fuel consumption, application of synthetic fertilizers and change in land use (when there is suppression of native vegetation to use the area for other purposes);

2. INDIRECT SOURCES – CO_{2-eq} volatilization, leaching and run-off (considering biochemical processes and climatic conditions).

For this study, the *Life Cycle* of each crop begins with tillage of the soil and ends with the harvest. The transport of the products to the warehouse or their subsequent processing were not considered.

To calculate the GHGE it was necessary to collect data, related to each production cycle and each PU, between 2019 and 2022. These data are:

1. Soil Management and Fertilization (fertilizers type, amount applied (Kg/ha), application technique);

2. Fuels (type of fuel, fuelling date, quantity fuelled, vehicle work location and cultural operation);

- 3. Harvest (date, quantity harvested, sold and discarded);
- 4. Irrigation Water (Irrigation allocation (L/ha), irrigation rate, energy consumption).

Study Areas

The Production Units (PU) are located in the Ribatejo and Alentejo areas.

The climate, according to the Köppen classification, corresponds to the Csa subtype, with hot, dry summers and almost cloudless skies. Winter is cool, with precipitation, overcast skies and occasional occurrence of frost and fog. Throughout the year, the temperature varies between 5 and 33 °C, rarely below 0 °C or above 40 °C. Insolation is high



and can exceed 3000 hours per year.

The existing soils in the different PUs under analysis have different characteristics, but with some points in common, such as: soils with few slopes, poor in nutrients, low in organic matter (< 1 %), slightly acidic pH (between 6 and 7).

The water source is usually underground, with constant availability of water throughout the year. The irrigation systems used were essentially 2, sprinkler and drip.

Results and Discussion

GWP Average Results for Horticultural Crops

In general, the average GHGE results obtained for the different crops are quite similar, with watermelon being the crop with the lowest average GHGE, with 0.04 Ton _{CO2-eq}/Ton _{product} (Graph 1).

Potato and onion have similar values of GHGE, ± 0.06 Ton _{CO2-eq}/Ton _{product}, however, potato was the crop with the maximum GWP recorded, 0.14 Ton _{CO2-eq}/Ton _{product}, and it is the crop with the greatest results variance. This was a consequence of a parcel low productivity, caused by a disease (appeared in an early stage).

The greatest variance observed, both in potatoes and onions, seems to be related to the climate and the period in which the crops are established, which is between the winter and spring. In Portugal, in this period of time, the climate can have a large variation in terms of precipitation and temperature. Sometimes, high precipitation combined with high temperatures can occur, which enhances the appearance of diseases, nutrient leaching and, consequently, a productivity decrease. In terms of GHGE, the consequence is an increase in the crops GWP.

Carrots are the crop with the lowest variance, with an GWP average of 0.05 (Ton $_{CO2-eq}/Ton _{product}$), minimum value of 0.03 (Ton $_{CO2-eq}/Ton _{product}$) and maximum value 0.06 (Ton $_{CO2-eq}/Ton _{product}$).

Carrots seems to be a more resilient crop, with greater adaptability to climatic variations, maintaining more constant values, even being cultivated at different seasons of the year.

Although watermelon is the crop with the lowest GWP average value (0.04 Ton _{CO2-eq}/Ton _{product}), it is a crop with a high rate of fruit wastage. In this case, what seems to affect the GWP variance are the chosen varieties, which are more susceptible to climate variation, but also, because they are more perishable products.

Melon, on average, is the crop with the lowest production per hectare. As with watermelon, this could be caused by the chosen varieties and because they are perishable products to. This could be the main reason why this crop is the one with the highest GWP average value (0.061 Ton $_{CO2-eq}/Ton _{product}$).



Graph 1 - GWP (Ton co2-ea/Ton product) average, minimum and maximum values obtained in the analysed crops.

With regard to GHGE by sources, it appears that for horticultural crops the greatest contribution comes from the fuels used in the several crop operations (Graph 2), corresponding to 58% of the total emissions, followed by the application of synthetic fertilizers with 31%.

Within fuel consumption, evaluating the average distribution obtained, we can see that harvesting is the crop operation that most requires the use of fuels, corresponding to 43% of the total, and consequently, it is the operation with the greatest impact on GWP average values.

Soil mobilization, which requires the use of implements that need greater traction, also ends up having a significant impact, corresponding to 23%.





Graph 2 – Average distribution of GHGE by Sources in horticultural crops (DE – Direct Emissions; IE – Indirect Emissions).



Graph 3 – Average distribution of Fuel Consumption by cultural operations carried out in the horticultural production.

GWP Average Results for Cereal Crops

In cereal production, we found that the crop with the lowest GWP variance values is corn, with a variance of 0.002 Ton $_{CO2-eq}/Ton _{product}$, even so, greater than the highest value recorded in horticultural crops, 0.0012 Ton $_{CO2-eq}/Ton _{product}$.

The cereals here studied are mostly produced in a rainfed system, thus, climatic conditions affect the yield of crops much more, since they depend on the precipitation occurrence during the life cycle of these crops. The exception is corn which, being a spring/summer crop, is normally produced using irrigation water. Possibly, this is the reason why the variation in GWP values are lower, compared to the other cereals, and the average value is also the lower one, 0.09 Ton $_{CO2-eq}/Ton_{product}$.

Triticale is undoubtedly the crop with the highest GWP and the reason is the much lower yields than other cereals. The low yields are caused by lack of water and by lack of nutrients because producers do not apply water and fertilizers in sufficient quantities to meet all the plant's needs. The main reason for this behavior is the commercial purpose of the crop.



Graph 4 - GWP (Ton _{CO2-ea}/Ton _{product}) average, minimum and maximum values obtained in the analysed crops.

For cereals, the main source of GHGE are the applied synthetic fertilizers, especially urea, corresponding to 41% of total emissions (Graph 5). In this type of crop, fossil fuels also have a major impact on total GHGE, representing 27%.

When compared with horticultural crops, we can see that cereals have a lower fuel consumption because: i) some of them are sown in direct seedling ii) require less phytosanitary treatments; and iii) a faster harvesting and less fuel when compared to horticultural crops.

In cereals, one can also verify that the crop residues left in the top soil are also significant (15%).

Indirect emissions, related to nitrogen volatilization, leaching and disposal, correspond to 17% of the total GHG Emissions. This value is therefore a consequence of the greater amount of nitrogen fertilizers applied, contributing to higher cereal GWP.





Graph 5 - Average distribution of GHGE by sources in cereal crops (DE – Direct Emissions; IE – Indirect Emissions).

Conclusions

The main objectives of the PEGADA 4.0 project, as mentioned in the Introduction, is to better understand the productive system of the most predominant crops in Portugal, understand its impact on GWP how we can optimize the system and how we can mitigate GHG Emissions in the PUs.

The assessment of GWP in these productive systems required data collection, systematization of these data, giving us a much more precise and global idea of the PUs CF impacts. With this assessment it is possible to detect critical points and understand the best strategies to follow, to minimize the risks at these critical points. This allows to reduce the negative impact on the environment, also bearing in mind economic sustainability and social benefits.

In the study of these agricultural systems, we were able to identify the following critical points:

- 1. Soil/plot management (tilling operations and applied fertilizers);
- 2. Sowing/Harvest management (chosen varieties, sowing and harvesting times);
- 3. Management of fuel consumption (cultivation operations carried out and equipment used);
- 4. Harvest management (production, rejects and crop residues);
- 5. Management of the irrigation system (equipment, allocation).

In horticultural production, the GWP is considered low when compared to other types of agricultural production, even cereals. In this analysis, watermelon was the crop with the lowest GWP average value (0.04 Ton $_{CO2-eq}/Ton _{product}$) and melon is the crop with the highest GWP average value (0.061 Ton $_{CO2-eq}/Ton _{product}$).

In cereals production, the lowest result obtained were for corn, with GWP average value of 0.09 Ton $_{CO2-eq}/Ton$ $_{product}$. and triticale is the crop with the highest GWP (0,46 Ton $_{CO2-eq}/Ton$ $_{product}$).

The variation of these values depends mainly on 3 main factors: the productivity obtained, the consumption of fuel spent in the different cultural operations and soil management (tilling operations and applied fertilizers).

Briefly, we can say that the strategies to adopt in GWP mitigation and adaptation to climate change, in the supply chain of horticultural and cereals crops, include the implementation of:

1. Soil and water conservation practices in order to reduce fertilizers and fuel consumption;

2. Integrated pest and disease management in order to reduce fuel consumption and improve productivity;

3. Crop management with greater rotation, reprogramming of sowing and harvesting in order to reduce weeds pesticides and others

4. Use of species and varieties tolerant to climatic stress in order to have resilient yields in time;

5. More efficient irrigation systems;

7. Other interventions such as: green manuring or ecological corridors (to boost biodiversity) in order to reduce nitrogen mineral fertilizers and promote yields considering the pollinators promotion.



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Safety and Maintenance Conditions in Tractors and Agricultural Machinery - A Case Study in Alentejo

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Abstract

The data published by the National Road Safety Authority demonstrates a significant cause-and-effect relationship between the poor state of maintenance and misuse of agricultural tractors, leading to severe or fatal accidents involving these vehicles. This study, conducted in 2018 with the aim of contributing to the understanding of the condition of the tractor and agricultural trailer fleet in the Alentejo region, gathers information obtained from a sample of 81 tractors and 40 trailers randomly distributed across the districts of Évora, Portalegre, and Beja. The data collection is based on a checklist that assesses compliance with legal requirements for the operation and scheduled maintenance of such vehicles, as well as the type of training that operators have received.

From the observations made, it can be concluded that only 12% of the tractors and 5% of the trailers were found to be free of non-compliance issues. Among agricultural tractors, most non-compliance issues were related to failures in the lighting systems, visibility components, and power take-off mechanisms, particularly in medium-range tractors over 10 years old. In the case of trailers, tire conditions and lighting were the areas with the highest percentage of non-compliance. In both types of vehicles, there was a positive correlation between the incidence of non-compliance and their age.

These findings highlight the need to expand this study to a larger sample of agricultural vehicles and other regions of the country. They also support the implementation of a legal framework that regularly monitors and controls the condition of agricultural vehicles. Furthermore, the results demonstrate the significant role played by local stakeholders in updating and training agricultural machinery operators, particularly regarding tractor operation safety courses.

Keywords: mechanization fatal injuries, workplace health and safety, inspection, operators training

Introduction

Agriculture in Europe is encountering mounting challenges and issues. Certain factors lie beyond our control, such as the global economy, climate change, weather extremes, and the abandonment of rural areas. On the contrary health and safety is an issue that can be controlled, reducing accidents, ill health, and the possibility of loss of property and production. Machinery is used in almost every type of agricultural operations. Whatever the type of business or its degree of automation, inevitably it relies on machinery to a certain extent.

In Portugal 2019, approximately 81% of agricultural farms utilized tractors, either owned or rented from third parties, a representation that showed no significant changes compared to 2009 (INE, 2021). The mechanization index of farms with their own tractors, measured by the ratio between the number of tractors and the utilized agricultural area (UAA) operated, showed a trend of stabilization at 5 tractors per 100 hectares of UAA. The size of the landholding and, naturally, the predominant production orientation of the farms, determines significant regional differences in this indicator: while in Alentejo region, only 1 tractor is needed to cultivate 100 hectares of UAA, in Entre Douro e Minho and Beira Litoral regions, this figure rises to 16 and 29, respectively.

Observing the national panorama of agricultural tractors there were a total of 168,067 tractors and industrial units (DGADR, 2015) Despite an increase of approximately 7% in the number of registered agricultural tractors, particularly those with a useful power exceeding 80 HP, the trend of aging in the national agricultural machinery fleet continues. According to the same source, in 2015, the percentage of tractors older than 20 years went from 46% to 47%, while the percentage of tractors less than five years old decreased from 10% to 9%. In 2018, the Portuguese market for new tractors recorded just over 6000 units (ACAP, 2019), and the trend for conventional tractors with power ranging between 40 and 59 kW persisted. Regarding the Alentejo region with the highest UAA, where the average number of tractors per 100 hectares of UAA ranges from 1 to 5 (INE, 2011), the average power levels hover around 74 kW or higher. A brief analysis of the market reveals that these tractors are more technologically advanced and boast higher safety levels compared to models with lower power ranges.

However, regardless of the type of tractor and power range, an agricultural tractor is a vehicle designed for field work that also operates on public roads. Its proper functioning depends on operators adhering to the manufacturer's prescribed periodic maintenance and interim checks outlined in the operator's manual. Failure to comply with these plans not only jeopardizes the warranty terms provided by manufacturers but also often leads to breakdowns and an increased risk of safety structure failures that can endanger the lives of the operator and all others on the public roads. In 2022 in Portugal the agricultural sector was the one with the third highest fatal accident rate after construction and

processing industries (ACT, 2023).

A recent study conducted by the European Committee of Agricultural Machinery Manufacturers (CEMA, 2017) revealed that 80% of road accidents involving agricultural vehicles appear to stem from four main factors, one of them being maintenance failures, and still there is not a mandatory legislation to support technical inspections of agricultural machinery.

With this background, the objectives of the present study were to contribute to the understanding of the conservation status of the fleet of agricultural tractors and semi-trailers currently in use in the Alentejo region, and its impact on the eventually figure of a mandatory technical inspection.

Materials and Methods

Throughout the years of 2017 and 2018, the conservation and maintenance status of 81 agricultural tractors and 40 semi-trailers, registered and in operation in public and private entities located in the districts of Portalegre, Évora, and Beja, were analyzed. Similar to the inspection criteria for goods vehicles, all the observed tractors were over 2 years old. The technical evaluation of each tractor and/or semi-trailer took place on the agricultural farm by applying a checklist based on legal requirements for circulation and scheduled maintenance of these types of vehicles.

Brand, model, year, and legal documentation were identified, and different items were analyzed according to the tractor or semi-trailer. For tractors the items supporting the technical evaluation were the Platform/Chassis or Monocoque Structure, Cabin/Safety Structure, Engine compartment, Interior/Driver's Seat, Coupling Devices and Power Take-Off (PTO), Visibility and Lighting system, Wheels and Tires, Braking system, Exhaust system (Figure 1).

For trailers the items supporting the technical evaluation were Body structure and coupling devices, Lighting system, Wheels and Tires and Braking system.



Figure 1. Local observation of engine compartment and tires condition.

Given the exploratory nature of this case study, for the most items evaluated, the verification did not require specific instrumentation and it was performed through the observation and/or activation of the respective controls with the vehicles parked. An exception was made for the Braking system in tractors, where the performance of the tractor during emergency braking was observed after a 25 m full acceleration transect, recording the stopped distance and any deviations from the trajectory. Additionally, the tractor was parked on a slope plane using only the parking brake, and the perfect immobilization of the vehicle was observed, respectively.

Data was analyzed using Excel software by means of descriptive statistics and an analysis of correlation between the year of the vehicle and the number of non-conformities.

Results and Discussion

With a representation equally distributed across the districts of Portalegre, Évora, and Beja, the most representative power output ranging was from 36.7 kW to 73.5 kW, aged over 10 years and operating in agricultural and mix agricultural and livestock farms. The items most negatively targeted in a total of 185 non-conformities were those related to lighting, visibility, wheels and tires, and non-conformities in the coupling structures of operating machines and power take-off.

These results demonstrate that despite the observed average age of tractors being much lower than the estimated national tractor fleet average, tractors aged a minimum of three years are still prone to developing faults that can lead to accidents both during their use in the field and on the road.

Related to the semi-trailers, the observed sample showed a total of 54 non-conformities in vehicles with an average gross vehicle weight of 6250 kg and aged over 21 years. The most common non-conformities were visibility/lighting system, wheels and tires, and coupling structures. Figure 2 show the relative percentage of the non-conformities of tractors and semi-trailers, respectively.





Figure 2. Relative percentage of the non-conformities observed on tractors (left) and semi-trailers (right).

In both types of vehicles, a positive correlation was observed between the presence of non-conformities and the age of the vehicles (Figure 3). This relationship was more pronounced in semi-trailers, likely due to their greater number of years in comparison to the tractors.



Figure 3. Correlation observed between the presence of non-conformities and the age of the vehicles, tractors (on the right), and semi-trailers (on the left).

Conclusions

The findings, although they need a broader territorial scope, show that even more recent vehicles are likely to have faults that could lead to future accidents. As these vehicles, similar to goods vehicles, operate in both private spaces and public roads, the study highlights the importance of implementing legislation that mandates periodic inspections for this type of vehicle as well. Alongside this measure, the significance of incentives for renewing the tractor fleet, as already approved by the authorities, should be emphasized. Extending these incentives to other machines would not only enhance their efficiency but also contribute to the safety of those operating these vehicles and those sharing the road with them while working or using public highways.

In complementarity to these measures, the importance of training machine operators must be ensured to sensitize them to equipment maintenance and accident prevention.

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RNA extraction and reconstruction of emetin and cephalin metabolic pathways in *Carapichea ipecacuanha*

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Abstract

Emetine and cephaline are two isoquinoline alkaloids used in pharmaceutical formulations, naturally produced in the roots of the medicinal plant Carapichea ipecacuanha. The unrestrained extraction of its roots from its habitat and its slow growth have contributed to its inclusion in the list of endangered species. In the search for more information about this species, the objective of this research was to extract high-quality RNA (RIN > 8), reconstruct the transcriptome, and subsequently the metabolic pathways of isoquinoline alkaloid biosynthesis, cephaline, and emetine, from Carapichea ipecacuanha (ipeca or ipecacuanha). For this purpose, RNA extraction was performed from roots of plants being cultivated in a greenhouse, followed by sequencing of these samples. Fresh root samples + NucleoSpin RNA Plant and Fungi Kit + adapted RNA extraction protocol were used for the total mRNA extraction from the roots. The reconstruction of ipecac transcripts was based on sequencing data from plant roots generated by us, and two RNA-seq libraries obtained from NCBI, the BioProjects PRJEB21674 and PREJDB13238, which are derived from in vitro cultured plants. The sequencing libraries were subjected to quality analysis with FastQC software and then cleaned with Trimmomatic software. The clean reads were used for transcript reconstruction, which was performed using the Trinity software. Subsequently, the Transdecoder software was used to obtain protein sequences, resulting in a total of 40,272 long proteins, the major isoform for a specific gene, for project 1, and 125,731 for project 2. For the data generated by us, for roots, a total of 81,675 transcripts and 50,010 proteins were obtained. Despite the differences in results between the projects, they may be complementary, as a relationship between the number of bases in the project and longer transcripts was observed, demonstrating greater completeness of the transcripts.

Keywords: vulnerable species of extinction; primary and secondary metabolism; RNA-seq; isoquinoline alkaloids.

Introduction

Plants that contain active compounds, such as medicinal plants, can be found in various environments, and Brazil is globally recognized for its vast biodiversity in its biomes, where different medicinal species can be found (Teixeira et al., 2019). However, often due to uncontrolled extractivism driven by the economic importance of their active compounds, deforestation and agricultural occupation (Oliveira et al., 2010; Coelho et al., 2013; Silva et al., 2018) lead to genetic erosion and inclusion in the list of species vulnerable to extinction, as is the case of *Carapichea ipecacuanha* (Brot) L. Andersson (Rubiaceae) (Lameira 2002; Oliveira et al., 2010; Coelho et al., 2013; Zappi et al., 2013; Silva et al., 2019), a species of understory, native to Central America (Nicaragua, Costa Rica, and Panama) and South America (Colombia and Brazil) (Edwards et al., 2015; Simões et al., 2017). This species, also known as Brazilian ipecacuanha, poaia, ipecac, or ipecacuanha, produces emetine (non-phenolic structure) and cephaeline (phenolic structure) in its rhizome and roots, which are among the main existing isoquinoline alkaloids (Dewick, 2002; Simões et al., 2017). Its extracts are used in various pharmaceutical preparations and formulations, and the alkaloids obtained from it have biological activity as expectorants, providing relief for coughs and colds (Edwards et al., 2015).

Indeed, despite the significant potential for the use of these substances by the pharmaceutical industry, there are few studies on the metabolic pathways of ipecacuanha, which is of fundamental importance to understand how the biosynthesis of emetine and cephaeline occurs in ipecac. The characterization of the biosynthetic pathways of emetine and cephaeline can be of great value for the genetic improvement of this plant, aiming to increase the biosynthesis of economically valuable secondary metabolites for commercial purposes. In this context, messenger RNA sequencing has



been used to generate information about proteomes and metabolic pathways through the translation of expressed transcripts, as well as for studying gene expression (Martin et al., 2013).

The prediction of proteomes from transcriptomes enables the reconstruction of metabolic pathways in both model organisms with sequenced genomes and non-model organisms without sequenced genomes. This approach is an efficient way to identify genes encoding enzymes involved in metabolic pathways of a particular organism (Martin et al., 2013; Xiao et al., 2013). Moreover, a significant portion of the secondary metabolites of interest are derived from non-model plants, which often have limited genomic resources. Therefore, the integration of metabolomic and genomic data is essential for the efficient identification of specialized metabolic pathways in non-model plants (Xiao et al., 2013).

RNA sequencing technology has enabled the study of a wide range of non-model species, such as the 1KP project (Matasci et al., 2014), which provides transcriptomes of a thousand plant species, available for download in public databases like onekp and NCBI (National Center for Biotechnology Information). Through the use of these libraries, it is possible to characterize transcripts and reconstruct metabolism, allowing for a better understanding of their metabolic pathways, adaptation to stress, and production of secondary metabolites, such as emetine and cephalin.

Obtaining desirable chemical compounds can be challenging due to the complexity of metabolic pathways and their regulation, especially in a natural environment. Therefore, studying these metabolic pathways has become crucial in obtaining these compounds (Xiao et al., 2013). Additionally, there is limited information in the literature about the most suitable cultivation methods for ipecacuanha. In Brazil, the main way of obtaining this plant for commercialization is through wild harvesting. As a result, the areas where this species can be found are becoming increasingly limited. Since the marketable product is present in the root, the plant needs to be extracted from the soil, preventing it from re-establishing, as ipecacuanha reproduces vegetatively through gemmiferous roots (Lameira, 2002; Martins and Oliveira, 2004; Oliveira et al., 2010; Silva et al., 2015).

Another important factor in this aspect is deforestation of the forests that serve as its natural habitat, restricting the availability of places where these plants can reproduce (Oliveira et al., 2010). As a consequence, the species is categorized as "vulnerable" and at risk of extinction in the country, with occurrences of subpopulation extinction and possible population decline in the coming generations, making studies seeking to understand its metabolism of extreme importance. Such studies may enable the maintenance or even reintroduction efforts in the native environment to ensure its genetic diversity (Zappi et al., 2013).

In the literature, there is a greater number of works related to propagation methods, mainly focusing on micropropagation, and very few regarding propagation by root cuttings in the field. Therefore, the search for more efficient methods of asexual propagation by root cuttings in the field is one of the primary tasks for the cultivation of this species, making it more accessible to farmers (Ribeiro et al., 2019a; 2019b), with suggested management practices for its cultivation in artificial environments due to its socio-economic importance. Additionally, there is a demand for molecular studies with this species, and both studies can contribute to the production of greater knowledge about its metabolic responses and the production of its pharmacologically important chemical compounds.

Thus, the objective of this research was to extract high-quality RNA (RIN > 8), reconstruct the transcriptome, and subsequently the metabolic pathways of the biosynthesis of the isoquinoline alkaloids, cephalin, and emetine, in *Carapichea ipecacuanha* (ipecac or ipecacuanha), in search of more information about this species.

Materials and Methods

Adult plants of *Carapichea ipecacuanha* were already in development and acclimated to the study site (greenhouses) in the municipality of Niterói-RJ, latitude 22° 54′ 00′′ S, longitude 43° 08′ 00′′ W, and altitude 8 m, within the greenhouses belonging to the "Pharmacy Viva" Phytotherapeutic Program, subproject "Active Germplasm Bank of Ipecacuanha." The plants were approximately six years old and were propagated as described by Ribeiro et al., 2017, and irrigated to maintain the substrate (soil) close to field capacity.

For the study, data were obtained from the NCBI (National Center for Biotechnology Information), and RNA was extracted from the roots of plants being cultivated in the greenhouse, followed by subsequent sequencing of these samples.

The extraction of total RNA from the roots posed numerous challenges, as there were several issues, such as thick and woody roots that were difficult to grind into a fine powder, being rich in polyphenols and polysaccharides, which hindered RNA isolation. Moreover, the roots contained many secondary metabolites, leading to agglomeration with other substances during the separation process (Figure 1).



Figure 1: Adult plants in the greenhouse (A); Root extraction from the plants inside the laboratory (B, C, and D); application of the protocol (E, F, and G); readings on the Nanodrop (Nano Spectrophotometer) (H).

After numerous attempts, a protocol that yielded more suitable results was adapted using fresh samples + NucleoSpin RNA Plant and Fungi Kit + an adapted RNA extraction protocol, found in the literature and modified for this purpose, (Zeng and Yang, 2002).

After the extraction, it was sent for sequencing to GenOne Biotech Company (Rio de Janeiro), which involved the following described service: mRNAseq service using Illumina[™] platforms, including total RNA quality control by electrophoresis, Qubit, and nanodrop, followed by RNA library preparation. The library quality control was performed by qPCR, Bioanalyzer, and Qubit. Sequencing was done with paired-end 2x150bp reads, generating 1Gb of raw data per 3.3M reads. The generated data should have at least 80% of bases with a quality score above Q30.

Results and Discussion

The results of RNA extraction using the adapted protocol were better compared to RIN. Thus, the original protocol was designed for the homogenized solution of leaves from the woody plant *Cinnamomum tenuipilum*, which is relatively viscous, gluelike, and rich in polysaccharides and polyphenols, making the isolation of RNA particularly difficult. If a pipette tip is used to draw the solution, continuous filaments are formed at the end of the tip. Guanidine-based and phenol/SDS methods resulted in brown and water-insoluble RNA pellets (Zeng and Yang, 2002), when adapting the protocol for ginger root, the buffer was replaced as indicated in the article. Additionally, another extraction method was analyzed without heating the protocol (due to the presence of a high amount of starch) in the roots, and polyphenols, as they were aggregating with the RNA and hindering its isolation. In this new method, there was no formation of a viscous layer (Figure 2).



Figure 2: Fusion of the NucleoSpin RNA Plant and Fungi Kit protocol (A); plus the adapted RNA extraction protocol (obtained from a protocol in the literature) (B) and end of centrifugation, phase separation (C).

Thus, the new adapted RNA extraction protocol for *Carapichea ipecacuanha* from its roots (Extraction buffer) consisted of: 2% CTAB; 2% PVP; 100 mM Tris-HCl; 25 mM EDTA; 2 M NaCl; 0.05% spermidine trihydrochloride; 2% beta-mercaptoethanol (added just before use); Chloroform-isoamyl alcohol (24:1); 10 M LiCl. Two strategies were used: (1) Using the new protocol directly, and (2) Using the new extraction buffer and then proceeding with a commercial RNA extraction Kit protocol after the lysis step. Thus, we employed four different extraction methods until obtaining a more suitable response in the results, and the ginger rhizome protocol eventually worked for ipecacuanha, enabling subsequent sequencing (Chart 1) and Figure 3.



Sample	Concentration (ng/µL)	260/280	260/230	Qubit (ng/µL)	Total RNA
RNA_Ipeca_1	178.4	2.11	2.12	63.5	2286 ng
RNA_Ipeca_2	138.2	2.14	2.11	39.5	1422 ng
RNA_Ipeca_3	116.8	2.18	2.11	33.2	1195.2 ng

Chart 1: Initial results obtained with the second extraction kit used.



Figure 3: New lysis buffer + SV Total RNA Isolation System with identification of 18S and 28S.

Two RNA-seq experiments of ipecac were obtained from NCBI, BioProject PRJEB21674 (project 1) and PREJDB13238 (project 2), both originating from in vitro-cultivated plants. The transcript reconstruction was performed using the Trinity software in a docker environment, resulting in a total of 63,230 transcripts for project 1 and 141,377 for project 2 (Table 1). However, the reconstructed transcripts may not be protein-coding, so the Transdecoder software was used to isolate the protein-coding transcripts, resulting in a total of 40,272 long proteins, representing the largest isoform for a specific gene, for project 1, and 125,731 for project 2 (Table 1).

	PRJEB21674	PREJDB13238	Our sequel
Transcripts	63.230	141.377	81.675
Genes	40.272	64.960	54.439
N50	1.654	2.264	1.092
Average size of contigs	538	929	440
Total bases mounted	38,3 millions	193 millions	57,6 millions

Table 1. F	Results	of transcri	pt reconstr	uction.
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In addition to the libraries obtained from the NCBI, sequencing of root samples from plants grown in the greenhouse was performed. Before collecting roots for total mRNA sequencing, samples were collected for alkaloid extraction and quantification of emetine and cephalin. Once the detection of the target metabolites was confirmed, the samples were then collected and subjected to total mRNA sequencing. The sequencing quality was high, with a phred score above 28 for 99% of the sequenced bases. Based on these nucleotides with good quality, the transcript reconstruction resulted in a total of 81,675 transcripts and 50,010 proteins (Table 1). Despite the differences observed between the projects, they can be complementary, as there was a relationship between the number of bases in the project and longer transcripts, indicating greater completeness of the transcripts.



The reconstruction of ipecacuanha's metabolic pathways was performed based on the assembled transcripts from the different libraries used in this study. The web tool GhostKOALA was used for this purpose. However, for the transcripts from both projects and our sequencing, the results from GhostKOALA were not sufficient to reconstruct the metabolic pathway of interest, namely the biosynthesis of emetine and cephalin (Figure 4). Both projects from the NCBI are from plants grown in vitro, and there is no evidence of cephalin and emetine biosynthesis in this cultivation. However, the sequenced root samples for this study showed the biosynthesis of emetine and cephalin, meaning that they expressed the metabolic pathway of these molecules. Therefore, another approach was needed for the characterization of the metabolic pathway.



Figure 4. Isoquinolone biosynthesis pathway, two of the compounds are emetine and cephalin. Result from GhosthKOALA.

Conclusions

Ipeca plants are an important source for the metabolites emetine and cephalin, which are of pharmaceutical interest.



A first attempt at reconstructing metabolic pathways for emetine and cephalin biosynthesis was conducted using RNA sequencing data available at NCBI. However, because the plants come from in vitro cultivation, they may not be expressing the metabolic pathway of interest, and because of this, total mRNA sequencing was performed for samples that demonstrably express the metabolic pathway of interest.

The quality of sequencing is of crucial importance for the robust reconstruction of transcripts, and this quality was shown to be high. To reconstruct metabolic pathways based on transcriptomic data, the KEGG platform is widely used. However, it was not effective for the reconstruction of the metabolic pathways of interest for the three datasets used in this study.

Indeed, for future perspectives, a targeted *gap filling* approach is sought, specifically focusing on the metabolic pathways of emetine and cephaline biosynthesis, particularly the isoquinoline and monoterpenoid biosynthesis pathways. This approach has the potential to provide more relevant data and insights.

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Working Conditions on Goat Farms in the Northeastern Trás-os-Montes (Portugal): From the Past to the Current Situation

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Abstract

In the region of northeast of Trás-os-Montes (Portugal) goat breeding has been and still is a very significant activity over time, not only in terms of milk and meat production, but also because breeders operate within an underdeveloped region where alternative economic activities are extremely scarce, especially in rural areas.

The "Serrana" goat is a major Portuguese local breed and is largely predominant in the region. Breeders value their rusticity and ability to adapt to the local conditions. It is generally bred to produce milk for cheese making and meat (kids).

Goats are raised in extensive systems. So, generally buildings and facilities are simple, supplying shelter and meeting the basic needs of the animals. The mechanization and organization of indoor space in goat housing is almost non-existent and this has consequences for carrying out work with animals.

Addressing these constraints, ANCRAS (the national Serrana breeders association) has developed actions in order to alert breeders to these problems and implement improvements in buildings and goat facilities.

For more than two decades we have collaborated with ANCRAS in programs for the divulgation and demonstration of equipment and techniques for carrying out the work with goats. In interviews carry out in previous studies, goat breeders from the region have identified the most difficult and painful tasks as being milking and manure management.

With this presentation we intend to show the changes that have occurred over the last two decades in milking and manure removal methods. In this period of time we verified that number of breeders decreased but there has been an improvement in working conditions, mainly due to greater mechanization and improvements in buildings facilities.

Keywords: Extensive systems; goat breeding; "Serrana" breed.

Introduction

The region

In the northeast of Portugal, a region known as Trás-os-Montes (approximately 41° to 42° N and 6,2° to 7,4° W) is bordered in the north and east by Spain. It is a mountainous region, composed of several plateaus above 700 m and various mountains with peaks between 1.000 m and 1.500 m.

This region comprises 12 municipalities, covers about 6.600 km2 and it has a population of less than 123.000 inhabitants, with a density of 19 inhabitants / km2 . The population has been decreasing since the 60's. It is one of the most disadvantaged Portuguese regions, and has been subject to a rural exodus to urban centers and regions along the country's coast (INE, 2021). This situation is due, besides other reasons, to the scarcity of economic activities both at the local and regional level.



Figure 7. The region of northeastern Trás-os-Montes.



Regarding economic activities there are not many alternatives. Agriculture and animal production are the main activities in rural areas. Also, goat breeding has great socioeconomic importance for the rural areas in the region of northeastern Trás-os-Montes due to the number of families that are economically dependent on these activities.

It should be noted that animal production activities has always played a major role in Trás-os-Montes agriculture throughout time. As a result of this fact we can find several local breeds of sheep, goats and cattle.

Over the last decades, goat farming (and also other small ruminants) has continued to be the main source of income for many families in the region. This importance is particularly due to the scarcity of alternative economic activities.

The "Serrana" goat and the breeding system

The "Serrana" goat is the leading Portuguese local breed, which accounts for the greatest number of goats in the country and can be found in the North and Center of Portugal. As well, in Trás-os-Montes this breed is largely predominant and breeders value their rusticity and ability to adapt to the environment, farming system and grazing system (rangeland).

In this region, "Serrana" goat is generally bred to produce milk for cheese making and meat (kids). Closely linked to the "Serrana breed", there are two PDO (Protected Denomination of Origin): the Transmontano goat cheese PDO and the Transmontano kid PDO.

Goats are raised in extensive systems. Flocks are small and don't use animal housing intensively. Generally, buildings are simple, often rudimentary, sometimes old, supplying shelter and the basic requirements to animals. They rarely have suitable milking facilities. Mostly, goats are hand-milked inside the shelters in which they are housed during the night (Barbosa and Teixeira, 2003; Barbosa et al., 2005; Barbosa et al., 2010).

Despite the value of these DPO products, the high market demand and good level of income compared with other agricultural activities, the number of goat breeders has been steadily decreasing. Besides other reasons, this fact could be due to the arduous working conditions for breeders, also related with the fact that "Serrana" goat breeding farms have followed, for a long time, traditional farming systems (Barbosa et al., 2006).

The working conditions on local goat farms

Buildings for goat housing must have a number of requisites, in order to meet animal welfare conditions; they must allow an advanced level of mechanization; have a positive effect on the organization of work performed. Moreover, buildings and equipment have a major impact on production quality, and mainly on milk production. The building must provide the breeder with good working conditions and ensure that all of the animals' needs are properly met.

However, as stated before, in this region goats are raised in extensive systems and breeders scarcely make use of buildings to handle flocks. Most of the buildings used for goats do not have adequate facilities and/or equipment for handling the animals. The work in these farm buildings is often difficult and painful.

In previous studies, goat breeders from the region have identified milking and manure removal as the most arduous work, mainly because it is performed manually and involves prolonged periods of physical effort. In fact, during traditional manual milking, the milker remains in an awkward posture. Manual manure removal is also hard and physically demanding. In addition, these manual labor it is a very time-consuming work (Barbosa et al., 2005; Fitas da Cruz and Barbosa, 2007).

About 20 years ago, only one member of the ANCRAS association had a milking machine. For almost everyone, milking is an arduous task because it is manual and, the awkward working posture makes milking stressful and potentially debilitating. Goats are hand-milked in buildings or shelters where they are housed during the night and, usually, there are no places specifically designated for milking, which is done in the straw-bedding area. To deal with the animals, the breeder uses fences to contain lactating goats, but he has to catch the animals by hand (Barbosa and Teixeira, 2003; Barbosa and Fitas da Cruz, 2009).

Also, manure removal required manual work on the majority of goat farms. On a large number of goat farms, manure handling was entirely manual, and manure was gathered and carried outdoors manually. In other buildings, manure was loaded onto a trailer in which it was transported outdoors. A small number of breeders remove manure mechanically, generally a tractor equipped with a loader on the front. Only a few of the buildings had slatted floors for manure management (Barbosa and Fitas da Cruz, 2009, Barbosa et al., 2010).

Manual, arduous and painful work constitutes an obstacle and constraint to the development of goat production in the region. Bad working conditions are one of the main reasons for the low attractiveness of this activity for younger people. Furthermore, these jobs require physical effort, are time consuming, with inappropriate body postures, uncomfortable and physically debilitating.

Therefore, it is important to promote the improvement of facilities and encourage the adoption of machinery and equipment to carry out these works. This has been a concern of ANCRAS, which for several years has been developing actions in order to promote the improvement of working conditions. These actions involved rural extension activities, dissemination of technical information, equipment demonstrations, training and technical visits.

Goat farms reveal some differences, sometimes significant, regarding their operation and farming system. And this



also applies to work with animals, that is, at times of the year and during periods of time during which milking and manure removal work is carried out.

Among ANCRAS breeders, the vast majority do not milk goats throughout the year, and do so only during some spring and summer periods. These breeders do not milk in periods in which they give priority to raising kids, or during periods when there is scarcity of food resources (pastures). Also, there are breeders who live in very isolated villages and it is not economically viable to include them in the milk collection transport circuit for the processing unit.

Manure removal also differs throughout the year, depending on the winter or summer seasons, as well as the frequency with which the removal is carried out. It is different because the material used for animal bedding is also different and there are differences in the consistency of the animal manure. It is in the winter season that the work of removing manure is most painful and difficult.

Objectives

The main objectives of this work were to identify the current methods of carrying out milking and manure removal work in goat housing facilities; to identify the changes verified over the last two decades in the referred working methods; and to identify the improvement of working conditions on goat farms in the region

Materials and Methods

Since 2001, we have carried out several studies on goat buildings facilities and working conditions on goat farms in this region. With ANCRAS we collaborated in rural extension projects; also, promotion and training on equipment and techniques to improve facilities and work in these facilities.

In three distinct periods: 2007/2008, 2015/2016 and 2022/2023, we gathered information about the facilities and working methods in which the work was carried out on these farms. We collected data through interviews with goat breeders, with the collaboration of technicians from ANCRAS. In the last year, we collected information (about facilities and working methods) from ANCRAS technicians and from interviews with goat breeders in the region.

The universe of breeders studied is not exactly the same in the three periods analysed. Over the years there have been changes in the universe of goat farmers in the region. Of the breeders interviewed several years ago, some have already ended their activity and a few breeders have started their activity more recently.

The number of breeders interviewed varied between 79 and 86 breeders, in these different periods.

Since it is not possible to compare exactly all the goat farms, we can make a more generic analysis, with emphasis on the adhesion of the breeders to the use of machines and equipment to carry out milking and manure removal work. Thus, we can have an overview of trends in the adoption of machinery and equipment by goat breeders and the consequent impact on improving working conditions.

With the information and data collected in the last year about milking (such as type of milking, milking facilities, milking machines used); and on the removal of manure (such as method of removal, machines or equipment used, adaptation of buildings and facilities), we will compare it with the data collected in the two previous periods (2007/2008 and 2015/2016) mentioned above, so we can evaluate the improvements and evolution in working conditions on goat farms in the region.

Results and Discussion

The data collected over the years of the study periods, allows us to understand the different methods used by goat breeders of this region to carry out milking and manure removal work.

Milking

Milking work is performed in four different ways (see Figure 2): manual, on the ground; manual, with goats on a platform; mechanical with goats on a platform and a mobile machine; and mechanical in a milking parlor.



Figure 2. Different methods of milking in Trás-os-Montes.



On the majority of goat farms, animals are hand-milked. While milking, the milker remains in an awkward posture that makes milking stressful labor, especially when manually milking on the ground.

Manual milking takes a long time, and to milk all the goats in the herd the breeder spends much more time working. Larger herds would require more time for milking. For this reason, manual milking on the ground is a time-consuming job that is an obstacle to the growth of the number of animals in goat farms.

When the goats are placed on a platform above the ground, even if it is manual milking, the work is less painful as the milker stands up straight and does the work standing up.

This way, it is easier for the breeder to check and evaluate the goats and the condition of their udders and teats; hygiene and cleanliness of milking can be better; the organization of work is more efficient, due to the imprisonment and reduction of the time required to replace goats for milking; and this work organization allows the breeder to milk all his goats in a shorter time.

With the goats placed on a platform above the ground, an improved method can be used. Using a portable milking machine, generally a double goat portable milker.

This method has many advantages over the previous ones, mainly because it does not require physical effort from the milker, better work organization and shorter milking time.

With the milking parlor, work is easier, faster and cleaner. The implementation of a milking room already involves the organization of space and the movement of animals. The milking parlor is the most effective and recommended method for carrying out goat milking work.

Manure removal

Manure removal is carried out using different ways (see Figure 3) that depend on the type of floor/soil; the conditions of the building used to house the goats, and the equipment available at the goat farm.



Figure 3. Different methods of manure removal in the region.

There are a very small number (only four) of buildings with slatted floor, this being the manure handling system used on these goat farms. Besides this minority, on the majority of goat farms, manure removal was entirely manual (the traditional way) in a hard and painful work that requires physical effort.

Over time, many goat farms began to use a trailer/wagon to transport manure. Manure is loaded manually onto a trailer or wagon on which it is transported outdoors. It continues to be hard and physically demanding work, but takes less time.

A mechanical method has been increasing in breeders' options: the use of a tractor equipped with a front loader to remove manure. This way, the work is faster and without physical effort.

For this mechanical manure removal, the building where the animals are housed must have some conditions that allow easy access and circulation of the tractor like wide, high doors and wide circulation corridors. It should be noted that this represents an improvement in buildings and animal facilities on goat farms.

Developments in working conditions

Since the first data collection in the period 2007/2008, there have been some improvements in working conditions both in milking and in manure removal.

Aside manual milking, in Figure 4 we can see the evolution of the number of goat farms that use improved facilities (in relation to milking on the ground) over the past almost twenty years.

It is evident that there has been an increase in the number of goat farms that have started to use milking machines, especially with the use of milking parlors.

It is important to emphasize the role of adopting a platform for milking on goat farms. We know that the use of the platform, even when it was initially used for manual milking, was an incentive for the purchase of a portable milking machine and, later, for the construction of a milking parlor.

Almost all goat farms that currently have a milking parlor have gone through an experience phase of milking with a platform, first manually and later with a machine. Therefore, it is important to develop actions in order to encourage the adoption of the platform on goat farms.



This simple equipment is the first step towards adopting facilities to improve milking conditions on goat farms in the region of Trás-os-Montes



Figure 4. Evolution in milking work facilities.

Aside the entirely manual way, in Figure 5 we can see the evolution verified over the past almost twenty years, of the number of goat farms that mechanized the work of manure removal.

The manure handling system with slatted floor remained practically constant, going from three goat farms in 2007/2008 to four goat farms in 2022/2023



Figure 5. Evolution in manure removal facilities.

There has been a very important increase in the number of breeders who remove manure from their goat housing using tractors with front loader. From the period 2015/2016 to the period 2022/2023 the number of goat farms using tractor with front loader more than doubled.

Also during this period, several breeders changed their work method for removing manure. They abandoned the entirely manual method (the traditional way) and began to remove manure with a tractor with front loader. In these cases, the breeders carried out some improvements in the animal facilities.

There appears to be a tendency, in recent years, to abandon the manual manure removal, towards a reduction in manual work.

Conclusions

With the data collected in different periods, we can conclude that:

- Although the vast majority of breeders still practice manual milking, on the ground, there is a growing number of



breeders who have improved milking facilities and who have opted for mechanical milking, with a portable milking machine or with a milking parlor. It also appears that some breeders improve manual milking conditions by adopting the use of a platform, which improves the milker's body posture, and that this serves as a step towards the subsequent adoption of mechanical milking.

- Although the vast majority of breeders still do manual remove, there is a growing number of breeders who have started to remove manure using a tractor with a front loader, which constitutes a significant improvement in working conditions.

These results suggest that the dissemination and demonstration actions carried out by ANCRAS in the region of Trás-os-Montes had a positive effect on improving working conditions, and there was a slow but progressive trend in the adoption of machines and equipment to perform the work.

Although still small, the increase in the number of goat farms that have improved working conditions both in milking work and manure removal work, it is an incentive to continue with the programs for the divulgation and demonstration of equipment for carrying out the work on goat farms in the region of Trás-os-Montes.

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A survey of pig and poultry farmers' readiness and attitudes towards smart technologies

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Abstract

Digitalization in livestock farming can foster economic and environmental efficiency of production, as well as the improvement of animal health and welfare. Several newly developed information and communication technologies (ICTs) are available on the market; thus, a number of studies focus on exploring these solutions and assessing their impact on productivity and sustainability. At the same time, much less attention is paid to farmers' (especially in the pig and poultry sector) willingness to adoption, expectations and experiences with advanced technologies and the barriers of technology uptake. This study investigates the readiness and attitudes of pig and poultry farmers towards smart technologies. The assessment relies on a survey conducted in January 2022 in five European and one Middle Eastern country. Standardized on-line questionnaires were completed by 121 pig farmers and 145 poultry farmers. Based on the responses it was found that various factors, such as the level of automatization of farms, average age of the buildings and production technology, internet connection opportunity and the existence of network within the livestock building (which is able to connect to the internet) were strongly influencing ICT-tool use, hence determine the ICT-readiness of the farms. Depending on whether respondents were users or non-users of smart technology, their perceptions differed significantly regarding the ease of access to technical assistance to them. This study improved our current understanding of factors influencing technology adoption rates on commercial farms.

Keywords: smart technologies, farmers' attitudes, barriers of adaption, pig farming, poultry farming

Introduction

Drive for improved profitability, animal health and welfare, and reduced environmental impact of livestock farming stimulate the need to improve the knowledge about farmed animals and their relationship with their living environment by collecting and evaluating data and information (Banhazi et al., 2022b). Precision livestock farming (PLF) technologies allow farmers to monitor groups or individual animals in a timely manner, capture information, process and analyse data sets to provide credible information and alerts regarding animal welfare, health and productivity by using modern technologies (Guarino et al., 2017; Krampe et al., 2021).

A number of PLF technologies are commercially available for monitoring pigs and poultry, such as cameras, accelerometers, microphones, photoelectric sensors, radio-frequency identification (RFID) for tracking, load cells and flow meters and so on (Gómez et al., 2021; Schillings et al., 2021). Papers related to PLF are largely focusing on reviewing these state-of-art technologies (Benjamin and Yik, 2019; Berckmans, 2015; Fountas et al., 2015; Neethirajan and Kemp, 2021), introducing technology innovations (Banhazi et al., 2011; T M Banhazi et al., 2012; Neethirajan, 2022), investigating what can be learned by using a technology (Banhazi et al., 2015; Fournel et al., 2017; Scheel et al., 2017; Tikász et al., 2022) and exploring the added value to farmers gained by using PLF technologies (Bewley et al., 2015; Kamphuis et al., 2015; Rojo-Gimeno et al., 2019). In contrast, social issues associated with PLF technologies as regards the applicability of the tools and the expectations and experiences of especially pig or poultry farmers with advanced technologies, as well as the barriers of uptake have been much less investigated, though the number of papers have been published about these matters in the past few years (Akinyemi et al., 2023; Hartung et al., 2017; Krampe et al., 2021). Therefore, the aim of this study was to investigate the readiness and attitudes of pig and poultry farmers towards smart technologies.

Materials and Methods

Questionnaire survey, as a quantitative research method, was used to study the conditions and attitudes of pig (specialized in farrow-to-finish, grow-to-finish, or mating-farrowing-weaning) and poultry (chicken meat and



commercial egg production) farmers towards smart technologies. Standardized on-line questionnaires with a total of 21 (pig farmers) or 22 (poultry farmers) technical questions (single choice, multiple choice, matrix and Likert scale type of questions) and 5 segmenting type of questions (as regards the age, education, position of the respondents and the size and legal form of the farm they represented) were developed and made available in five European (Denmark, Estonia, Hungary, Poland and Sweden) and one Middle Eastern (Israel) country in January 2022. The questionnaires consisted of three main technical parts: (1) infrastructural conditions, (2) respondents' expectations and experiences as regards the benefits, availability and operation of PLF technologies, (3) information on the users' application practices and satisfaction regarding smart technologies. Questions were grouped by (1) users, (2) potential users (respondents who plan to use smart technologies within a short time) and (3) non-users to investigate each type of technology users in the PLF product chain.

Non-probability judgemental sampling method (Malhotra, 2010) was used, since there has been very limited information available about the characteristics of the sample population. A common request was to preferably reach farms that can be considered as intensive, in terms of the number of animals raised. The threshold of intensive rearing of pigs and poultry is defined in the IED Directive (Directive 2010/75/EU, 2010), that is more than 750 places for sows and/or 2000 places for production pigs (over 30 kg), while more than 40,000 places for poultry. The reason of focusing as much as possible on intensive farms was the hypothesis that early users of PLF technologies are mainly capital-intensive farms with large herd. As total, 266 responses (121 from pig farms and 145 poultry farms) were received, out of which 81% were intensive farms (66% of pig farms and 93% of poultry farms) (Table 1).

Statistical analyses were conducted by MS Excel and IBM SPSS (27.0.1) on 269 surveys (121 from pig farms and 148 from poultry farms) as 3 poultry farms producing both chicken meat and commercial eggs were split into 6 individual farms. Descriptive statistics, such as the sum and distribution, mean and standard deviation were calculated by using MS Excel Pivot Tables to determine the general characteristics of the sample. Pearson Chi-square tests were used to compare differences by the following categories: users (n=177), potential users (n=56) and non-users (n=36).

		Pig farme	Poultry farmers					
Countries	Distribution	of respondents	Intensive farms	Distribution	of respondents	Intensive farms		
	Ν	% of total	% of country total	Ν	% of total	% of country total		
DK	28	23%	86%	29	20%	79%		
EE	11	9%	82%	3	2%	67%		
HU	36	30%	97%	48		98%		
IL				25	17%	100%		
PL	23	19%	17%	22	15%	91%		
SE	23	19%	35%	21	14%	100%		
Total	121	100%	66%	148	100%	93%		

Table 1. Distribution of the responses by countries and intensity of farms

In regard to specialization, Figure 1. shows that 52% of responding pig farms specialized in farrow-to-finish (FF), 26% in growing finishing (GF) and 22% in mating-farrowing-weaning (MFW). The distribution of respondents was almost equal in Denmark (32% FF, 39% GF and 29% MFW), while FF specialisation dominated (50-82%) in all other countries. Out of the respondents of poultry farmers, 70% represented chicken meat production (CMP), 30% egg production (EP). Near to 50-50% was the share of CMP and EP respondents in case of Denmark (45% and 50%) and Poland (55% and 45%). At the same time, the distribution of CMP and EP was around 70-30% in Hungary respectively, while in Estonia, 100% of the respondents represented EP, in Israel and Sweden the same was true for CMP (Figure 1).



Farrow-to-finish Grow-to-finish Mating-farrowing-weaning Chicken meat production Egg production

Figure 1. Distribution of the responses by specialization of the responding farms

Results

Main characteristics of the farms represented by ICT users and non-user

Pearson Chi square tests were calculated on responding farmers' infrastructural conditions (level of automatization, age of buildings and production technologies, internet connectivity of farm and network availability of individual buildings), size (intensive or not) and legal form (sole proprietorship or corporation) across technology adoption level (users, potential users, or non-users of PLF technologies). Strong significant difference (P<0.01) was found between infrastructural conditions of users and potential users, as well as of users and non-users, while significant difference (P<0.05) showed up between the farm size of users and potential users (Table 2). As it is shown in Figure 2, users can be characterized by being intensive farms in terms of animal places (85%) having highly (55%) or moderately (32%) automatized farm operation, the average age of their buildings and production technology is less than 20 years (84%), or even less than 10 years. Internet, (at least wireless) is accessible by 96% of the farms, while network within the livestock buildings, being able to connect to the internet, is available by 77% of the farms in various forms (wireless: 32%, cable: 16%, both: 29%).

Table 2: Statistical results of survey answers for questions regarding farm characteristics

					P value				
Q	Farm characteristics	Respon- ses (N)	All	Users (U) (N=177)	Potential users (PU) (N=56)	Non-users (NU) (N=36)	UxPU	UxNU	PUx NU
Q3	Level of automatization	269	2.28±0.74	2.42±0.71	2.07±0.74	1.92±0.73	0.01	< 0.001	0.61
Q4	Age of infrastructure	267	$3.04{\pm}0.81$	3.23±0.72	$2.84{\pm}0.89$	2.44±0.77	0.001	< 0.001	0.08
Q5	Internet connectivity	268	2.60±1.03	$2.59{\pm}0.93$	2.54±1.19	2.75±1.20	0.02	0.001	0.34
Q6	Network in the barns being able to connect to the internet	265	2.08±1.44	2.39±1.35	1.57±1.46	1.33±1.37	< 0.001	< 0.001	0.56
SIII	Size of farm (intensive/not intensive)	269	0.81±0.39	0.85±0.36	0.73±0.45	0.72±0.45	0.04	0.06	0.10
SII	Legal form of the farm (sole proprietorship, kind of corporation)	269	1.47±0.50	1.50±0.50	1.36±0.48	1.50±0.51	0.07	0.98	0.17

In contrast to users, potential users and especially non-users have much older farm infrastructure (potential users: in 46% of cases – 10-20 years old infrastructure; non-users: in 44% of cases – 10-20 years old, and in 39% of cases – variously aged infrastructure), despite representing mostly (73% and 72%) intensive farms. On top of that, 9% and 11% of potential users and non-users, respectively, operate in more than 20 years old infrastructure, while the same holds only true for 1% of the users. Automatization level is medium in general at both potential users (46%) and non-users (47%), whereas internet accessibility, compared to users, is a little bit lower, 86% by these two groups of respondents, which means primarily the wireless form (45%) in case of potential users, and both wireless and cable (36%) for non-users. Although there was no major difference in the frequency of internet access between users and potential or non-users, the network availability in the barns of the letter was much less, only 45% in case of potential users and 44% in case of non-users compared to 77% in case of users as mentioned above (Figure 2).



Non users Potential users Users

Figure 2: Comparison of responding PLF-technology user, potential user and non-user farms' characteristics

3.2. Main perceiving of PLF users, potential users, and non-users about the technology itself

Results of survey on the perceived characteristics of PLF technologies by users, potential users and non-users of smart technologies are presented in Table 3. Respondents were asked to score a list of statements on the benefits, operation and availability of PLF technologies according to their level of agreement, on a 6-stage Likert scale (0: did not know the answer, 1: strongly disagree,... 5: strongly agree) (Malhotra, 2010). Pearson Chi-square tests were used to establish the differences between the general level of agreement of users, potential users and non-users in each statement. Significant differences (mostly on P<0.01 level) were found between the mean scores of users and non-users in 15 out of 19 statements. The same holds true for users and potential users in case of 6 statements (Q9e, Q11b, Q11d, Q9g, Q10a and Q10b) (Table 3). There were only 4 statements (Q9e, Q11b, Q11d and Q10d) where significant difference at the level of P<0,05 could be determined between potential users and non-users. This implies that, in case of Q9e, Q11b and Q11d, the perception (about the characteristics of PLF technologies) of all 3 respondent categories was found to be significantly different. No significant difference was demonstrated in case of four statements: respondents agreed moderately (3.37) that PLF technologies have the potential to foster enterprise, marketing and investment decisions, and were neutral with the statements on PLF technologies' ability to cope with labour shortages (3.11), being secure in terms of data management (2.88) and connectivity with equipment and software of different developers.

The general pattern of statements showing significant differences in respondent groups' opinion, that users expressed the strongest (Means: 2.81-4.48), potential users somewhat moderate (2.41-4.09), while non-users the lowest level (1.69-3.89) of agreement. According to Lokeswari (2016), the reason of this is that frequent usage and exposure to ICTs lead to a positive attitude towards ICT usage.

A number of statements on the benefits of PLF technologies received highly positive agreements (where the mean scores were above the value of 3.5). All groups of the respondents agreed that PLF technologies contribute to the increase of production efficiency (average score: 4.19 ± 1.01). The average scores referred on agreement in case of the ability of these innovative technologies to prove/improve transparency within production (3.94 ± 1.21), contribute to the early detection of problems in the herd (3.94 ± 1.15) and help day-to-day decision making in the livestock buildings (3.77 ± 1.33). However only users and potential users were supportive, non-users remain neutral on these issues. On the role of new technology solutions in meeting environmental pollution reduction obligations, users group agreed moderately (3.51 ± 1.56) that it would be helpful, while the other two groups where not convinced about this, but neither were they convinced of the opposite (PU: 3.30 ± 1.44 , NU: 2.94 ± 1.39).

In relation to the operation of smart devices/technologies, it was agreed by all three groups of respondents that they provide reliable information (4.04 ± 4.0) in a real time manner (4.32 ± 1.06) . At the same time, only the user group confirmed that these new technologies are easy to operate (3.82 ± 1.09) and work in a reliable manner (3.69 ± 1.21) , while potential users, just as non-users were unsure about these points (PU: 2.98 ± 1.53 , 3.13 ± 1.66 NU: 2.69 ± 1.26 , 2.53 ± 1.52). In addition, the difference between the mean scores of users' and non-users' responses was especially large, 30% in case of the easiness and 31% in case of reliability of operation, respectively. The gap between the same two groups increased to 35% as it came to the maintenance costs of PLF technology. The opinion of users and potential users was neutral (3.20 ± 1.27) and 2.61 ± 1.45) while non-users disagreed that the maintenance costs of smart technologies were reasonable (2.08 ± 1.27) .

The deviation of the scores was highest by the statements on the availability of PLF technologies. This implies that the difference between the mean scores of users and non-users was above 32% by every statement. Accessing these technologies on the market and getting information on them and their distributors seemed not being a problem for users $(3.95\pm1.24, 3.55\pm1.38)$, while potential users expressed neutrality accompanied by a high standard deviation $(3.21\pm1.52, 3.18\pm1.53)$ and non-users a week disagreement $(2.42\pm1.42, 2.39\pm1.38)$. Mean values of all scores on easiness of getting technical assistance, just like obtaining proper education on smart technologies remained below 3.0. Out of the three clusters, mean scores of users group was the highest $(3.15\pm1.40, 3.10\pm1.50)$ whereas non-users scores reached only 1.89 and 2.11 average values, respectively. Securing technical assistance for these innovative technologies appeared to be especially challenging for non-users' opinion on the statement regarding the purchase price of smart technologies, as this statement reached the lowest level of agreement of all (2.58 ± 1.25) . This means that besides users showing a week neutrality (2.81 ± 1.19) on that topic, the mean scores of potential users (2.43 ± 1.26) and especially non-users (1.69 ± 1.04) expressed obviously that they did not consider the purchase price of PLF technologies to be affordable.

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		Responses (%)								Response (P value				
Q	Statements on PLF technologies	0	1	2	3	4	5	Responses (N)	All	Users (U) (N=177)	Potential users (PU) (N=56)	Non-users (NU) (N=36)	UxPU	UxNU	PUxN U
Benefit o	of PLF technologies. They														
Q9e	enable to increase the effectiveness of production.	1%	2%	3%	13%	32%	48%	269	4.19±1.01	4.38±0.82	4.04±1.19	3.53±1.23	0.01	< 0.001	0.03
Q9f	prove/improve transparency within production.	3%	2%	6%	15%	34%	40%	269	3.94±1.21	4.14±1.12	3.68±1.34	3.39±1.23	0.11	< 0.001	0.59
Q91	contribute to the early detection of problems in the herd.	1%	3%	7%	16%	33%	39%	269	3.94±1.15	4.10±1.06	3.79±1.20	3.44±1.36	0.61	0.00	0.35
Q90	the livestock buildings.	2%	8%	7%	14%	32%	37%	269	3.77±1.33	3.92±1.25	3.70±1.39	3.14±1.46	0.46	0.00	0.31
Q90	reduction obligations.	4%	11%	10%	21%	20%	33%	269	3.39±1.52	3.51±1.56	3.30±1.44	2.94±1.39	0.20	0.04	0.15
0	investment decisions.	4%	8%	12%	23%	27%	25%	269	3.37±1.41	3.33±1.46	3.57±1.31	3.25±1.30	0.48	0.44	0.41
Q9a Operatio	on of PLF technologies. They	4%	19%	12%	19%	19%	27%	269	3.11±1.57	3.27±1.58	3.00±1.50	2.53±1.52	0.86	0.19	0.17
O9h	provide information in a real time														
Q9a	manner.	1%	3%	4%	7%	25%	59%	269	4.32±1.06	4.48±0.92	4.09±1.23	3.89±1.24	0.08	0.00	0.06
Q9g	provide renable information.	1%	3%	1%	19%	39%	37%	269	$4.04{\pm}1.00$	4.19±0.90	3.82±1.11	3.61±1.10	0.04	0.01	0.18
QIIb	are easy to operate.	4%	2%	14%	30%	22%	29%	269	3.49±1.30	3.82±1.09	2.98±1.53	2.69±1.26	< 0.001	< 0.001	0.02
Q11d	operate in a reliable manner.	6%	4%	11%	25%	28%	26%	269	3.42±1.42	3.69±1.21	3.13±1.66	2.53±1.52	0.01	< 0.001	0.01
QIIa	cost.	9%	5%	19%	29%	28%	10%	269	2.93±1.37	3.20±1.27	2.61±1.45	2.08±1.27	0.09	< 0.001	0.21
Qile	management.	17%	5%	6%	31%	30%	12%	269	2.88±1.59	2.98±1.54	2.91±1.68	2.31±1.60	0.87	0.18	0.34
Q11c Availabi	can be connected well with other equipment/software. ility of PLF technologies.	17%	5%	15%	28%	23%	12%	269	2.72±1.58	2.93±1.52	2.41±1.72	2.22±1.46	0.33	0.10	0.52
Q10a	PLF technologies are easily accessible														
Q10c	on the market. It is easy to get information on smart	4%	5%	12%	22%	20%	37%	269	3.59±1.43	3.95±1.24	3.21±1.52	2.42±1.42	0.00	< 0.001	0.18
O10d	technologies and distributors. It is easy to get technical assistance for	3%	10%	17%	22%	19%	29%	269	3.32±1.46	3.55±1.38	3.18±1.53	2.39±1.38	0.26	< 0.001	0.05
Q10e	smart technologies.	6%	12%	20%	23%	23%	16%	269	2.91±1.46	3.15±1.40	2.84±1.52	1.89±1.17	0.16	< 0.001	0.01
Q10b	smart technologies.	7%	13%	25%	19%	16%	21%	269	2.88±1.53	3.10±1.50	2.66±1.63	2.11±1.24	0.32	< 0.001	0.08
Q100	affordable price.	6%	15%	24%	31%	20%	4%	269	2.58±1.25	2.81±1.19	2.43±1.26	1.69±1.04	0.03	< 0.001	0.14
0:	Did not know;	1:	Stro	ngly	disag	gree;	2:	Disagree;	3:	Neutral;	4:	Agree;	5:	Strongly	agree

Table 3: Statistical results of survey answers for questions regarding perceiving of ICT users, potential users and non-users



Application practices and satisfaction with PLF technologies

Respondents were able to select whether they were using, planning to use, or not using (and not even planning to use) different smart technologies listed in the survey. The results of the responds indicated that the most commonly used technology was the monitoring of buildings and animals by sensors and/or cameras, both in case of poultry (81%) and pig (64%) farms, as well as the monitoring of microclimate (temperature, humidity) and air quality (CO_2 , NH₃ and dust concentration) within the barns (77% and 55%) by fixed or portable sensors. Other frequently used technologies of responding poultry farmers were weight measuring devices by using bird scales or cameras (71%) and lightning control in commercial egg production (57%). The same holds true for the use of robots (for cleaning or feeding or monitoring) in case of pig farmers (42%). The least-used technologies were infrared cameras (for oestrus monitoring) by pig farmers (11%) and radio frequency identification (RFID) by poultry farmers (0%), just like portable Near Infrared (NIR) instrument for nutrient analysis for feed and feed ingredients by both, poultry and pig farmers (7% and 14%), respectively (Figure 3).





Figure 3: Frequency of applied smart technologies by responding pig and poultry farms

To explore the satisfaction of respondents with frequently used smart technologies, they were asked again to score the listed technologies according to the level of satisfaction on a scale of 1-5 (1: very dissatisfied,... 5: very satisfied). Based on the results of responses (Table 4), it can be established that the mean score of each technology was above 3.6, that means that respondents were generally satisfied with all the listed technologies. The highest level of satisfaction (4.19) was found in case of technologies monitoring building climate and air quality. Standard deviation was low (0.85), which indicated homogenic opinion. Pig farmers showed a little bit higher satisfaction (4.26±0.68) than poultry farmers (4.16±0.93). The same holds true for animal weighing, where the mean score of pig farmers was 4.15 (±0.99) and poultry farmers 3.74 (±1.20). Behaviour and animal health monitoring technologies reached the lowest level of satisfaction (3.67±1.01), though users were still satisfied with them in general, especially poultry farmers (3.73±0.94) who indicated similar level of satisfaction to that of animal weighing. Average score of pig farmers was far lower (3.58) compared to the previous technologies, accompanied by high standard deviation (1.14) showing that their level of satisfaction was more heterogeneous.

Table 4: Statistical results of survey answers for questions regarding users' satisfaction with different smart

technologies

Smart technologies	Very dis- satisfied	Dis- satisfied	Neu- tral	Satis- fied	Very satis- fied	Respon- ses (N)	Total	Pig farms	Poultry farms
Building climate/air quality monitoring	1%	3%	15%	38%	42%	120	4,19±0,85	4,26±0,68	4,16±0,93
Animal weighing	4%	10%	20%	27%	35%	89	3,80±1,18	4,15±0,99	3,74±1,20
Behaviour and animal health monitoring	2%	4%	11%	22%	12%	134	3,67±1,01	3,58±1,14	3,73±0,94

To establish the main reasons of dissatisfaction, respondents were asked to choose from a list. Out of PLF-user respondents, 97% chose at least one issue. The top reason of dissatisfaction which was marked by 57% of the user respondents, was that 'Because of less human care, some problems remain hidden inside the herd'. Besides this, all other issues were on much lower level of importance, which means that at most 31% of the user respondents marked



them, respectively, as shown in Table 5.

Table 5: Statistical results on the frequencies of the marked reasons of dissatisfaction

Reasons of dissatisfaction	Responses (N)	Pig farms	Poultry farms	Total
Because of less human care, some problems remain hidden inside the herd.	177	25%	32%	57%
Proper operation of the device needs better quality internet connection.	177	14%	17%	31%
Farm staff's skills are lacking in data analysis.	177	13%	17%	30%
I don't get enough technical assistance.	177	10%	16%	27%
It's impossible to establish a connection between different devices.	177	12%	14%	26%
Too many malfunctions.	177	11%	15%	26%
Maintenance fee is too high.	177	12%	12%	25%
The device/technology is not compatible with the current structure of the buildings/barns.	177	13%	10%	23%
Extension service is not available.	177	10%	12%	23%
Needs too much time to work with the data (more than expected).	177	10%	11%	21%
The device needs too much care.	177	9%	11%	20%
Unable to see the value brought by the devices.	177	7%	12%	19%
The software is too complicated to use.	177	8%	10%	18%
Unreliable data (data cleaning lacks).	177	7%	9%	16%
I don't receive the information in a real-time manner, but later.	177	7%	6%	13%

Discussion

The survey indicated that the automatization, the age, and the infrastructure, including internet accessibility, of pig and poultry farms are important preconditions of the successful operation of PLF systems. This is in accordance with several literature (Akinyemi et al., 2023; Guarino et al., 2017; Nääs et al., 2022; Neethirajan and Kemp, 2021) that highlighted that the obstacles of PLF-technology adoption are internet connectivity and the design of existing farm buildings, especially the older ones, where the barns are rarely able to accommodate PLF technology.

The respondents of this survey, regardless of whether or not they used smart technologies, confirmed the wellknown benefits of applying these new solutions, such as improving of production effectiveness and transparency, by continuously monitoring and providing information about the performance and the environment of the animals, enabling early problem detecting and fostering decision making (Akinyemi et al., 2023; T. M. Banhazi et al., 2012; Hartung et al., 2017; Krampe et al., 2021; Schillings et al., 2021). Similarly, it was agreed by the respondents that ICTs provide reliable information in a real time manner which, according to Guarino et al. (2017) is core to PLF and makes it different from other technological solutions, since this ensures immediate warning as mentioned above. In contrast, easiness and reliability of the operation of PLF systems was not approved consensually, only by the users, while potential users and non-users remain unsure in this regard. The simplicity and ease of use was identified by Borchers and Bewley (2015) as an important purchase criteria of precision farming technologies. Users of the technology would like to apply not just easy to operate devices, but receive the data in an easy to read, comprehensible format (Akinyemi et al., 2023). The fear of unreliable operation paired with slow or difficultly available maintenance service expressed by the respondent does not seem unfounded, as several studies reported similar experiences (Hartung et al., 2017; Maselyne et al., 2022; Tikász et al., 2022; Tuyttens et al., 2022), since these systems may be subject to a many hardware and software failures. Obtaining technical assistance to innovative technologies appeared to be especially challenging for non-users as established in this survey. For successful implementation and application of PLF technologies in livestock farms, proper training and education is necessary (Cosby et al., 2022), as technical knowledge associated with PLF systems is usually missing. However, the lack of training in digital skills is a problem in general within the pig and poultry industries as indicated by Maselyne et al. (2022) and Nääs et al. (2022) and was also reflected by the respondents, especially those representing the non-users group.

Though a lot of PLF solutions are available on the market (as stated in the beginning of this article), accessing smart technologies and getting information on them and their distributors appeared to be particularly difficult for non-users, being much less familiar with the sources of information than users. Besides, the purchase price of these technologies was found to be too high. This is in line with the experiences of Boothby and White (2021) and Nääs et al. (2022) who pointed out that the reason for the relative high technology setup costs is that on most farms, the installation costs of reliable internet connections and sometimes the costs of improvement of electrical network must be added to ensure the successful operation of the advanced technologies. Moreover, respondents agreed only in part that the costs of



maintenance of PLF systems would be reasonable. This might be explained by the lack of knowledge, especially among non-users, of what kind of expenses are covered by the maintenance cost. According to Farooq et al., (2022), the operating cost, beyond ensuring the sound operation of the equipment, covers the expense of IoT systems in order to facilitate the data processing, knowledge exchange, as well as the data sharing among cloud servers, IoT devices, and gateways. These three perceptions – i.e., difficulties in accessing ICTs on the market, high price and maintenance costs – together are mutually reinforcing barriers of technology uptake. To eliminate this hinderance, according to Borchers and Bewley, (2015) the return of investment regarding such systems should be proved urgently along with a more intensive knowledge-sharing activity.

In relation to the applied technologies by the respondents of this survey, the results indicated that the most commonly used technologies were non-invasive biometric sensors. This was the case for both poultry and pig farms, with the aim of monitoring the health and wellbeing of animals in the barns without increased contact time as demonstrated by Neethirajan and Kemp (2021) which more specifically means the continuous monitoring of buildings and animals, as well as the microclimate and air quality conditions. In general, the respondents expressed satisfaction with the technologies. Dissatisfaction was most frequently indicated in relation with less attention to animals by humans, which may cause hidden problems in the herd, similarly to the findings of Krampe et al. (2021); Schillings et al. (2021) and Tuyttens et al. (2022). Internet connection deficiencies were recognized as the second biggest problem, as reported by many studies (Banhazi et al., 2022a; Nääs et al., 2022; Piñeiro et al., 2019), which makes clear that the quality of internet connectivity is similarly important as the existence of communication infrastructure on the farm.

Conclusions

This study investigated the readiness, expectations and experiences of pig and poultry (chicken meat and commercial egg producing) farmers towards PLF technologies by using quantitative surveying methodology. The results highlighted that current automatization of farms, the age of infrastructure, the on-farm internet connectivity and the network availability within the livestock buildings are important limiting factors for the adoption of smart technologies. Besides these, farmers' attitude especially their perceiving regarding the operation and availability of smart solutions is an important determining factor. Key issues are the easiness and reliability of operation, the cost of maintenance, the access to technologies as well as to technical assistance on the market, the high implementation price of the technologies and the fear that because of less human care, some problems remain hidden inside the herd. For this reason, most frequently used applications were the least expensive solutions which provide the most obvious information, such as live pictures about the buildings and the animals, and real time data on the climate and air quality within the livestock buildings.

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Conditions of applying advanced information technologies in livestock farming

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Abstract

Information and communication technologies (ICTs) help livestock farmers in paying closer attention to their animal, thus optimising the operation of their farm, as well as better meeting environmental obligations and social expectations set for the livestock industries. Despite all well-known benefits, the uptake of advanced technologies is slow in the livestock industries, mainly due to socio-economic and cultural barriers. To explore this issue in depth, (as part of the LivestockSense project), focus group discussions (FGDs) were conducted in five European and one Middle Eastern country with 83 invited participants representing the value chain of smart technologies in pig and poultry farming. Focus groups are underutilised as a method in research examining livestock stakeholders' attitudes towards ICT tools, despite the fact that it is seen to provide useful and practical insights into the context of ICT tool use. In order to draw on a wide spectrum of expertise, this study used a multi-actor strategy that included policy makers, livestock producers, technology providers, and ICT developers. Four main themes were covered by the focus groups: (1) implications regarding the application of ICTs on farms; (2) general description of ICT-users; (3) main barriers (lock-ins) of the adoption of ICTs; and (4) incentives that might motivate the spread of ICTs. An important outcome of the research was, that the knowledge of clear, identified investment and maintenance costs, cost-effectiveness and proven profitability is an essential condition for promoting these smart technologies, which must be well adapted to practice and end users' requirements.

Keywords: ICTs, precision livestock farming, focus group discussions, barriers of adoption, multi-actor approach.

Introduction

The need for a more sustainable development pathway in agricultural and food systems is a well-evidenced scientific consensus (Abbasi et al., 2022). Digitalisation, as an integral element of this development pathway, offers solutions to fulfil the needs to feed the growing human population, while addressing economic, environmental, and social impacts of intensive food production (Basso and Antle, 2020). In primary industries, digitalisation relates to on-farm tools, such sensors for data capture, automation and robotics, Internet of Things, cloud computing and data analytics (Eastwood et al., 2021).

Under the new European policy mechanism, national CAP Strategic Plans also aim to promote strategic and comprehensive approach towards digitalisation for agriculture and rural areas. Although national plans mainly emphasise the importance of investments in digital transition to reduce the digital divide between rural and not rural areas, they also include a number of features that support knowledge transfer and skills development of rural area actors (European Commission, 2023). Furthermore, digital transition, which goes hand in hand with the green transition, is also key topic area in the EU's primary research and development programme (European Commission, 2020a). The agri-food sector is no exception in this regard, as demonstrated by the numerous research and innovation actions (AgriBIT, AgROBOfood, DEMETER, DESIRA, SmartAgriHubs) that clearly highlight the importance of future role of digitalisation in European initiatives targeting food system transition and sustainable growth.

European agriculture is becoming digitalized, but – despite these ambitious and abundant development efforts – , it is also clear that the adoption rate of new technologies is still very limited (European Commission, 2020b). The influence of digitization in agriculture is less than it could be compared to other economic sectors, which shows that there is still much room for improvement in terms of the general use of digital solutions. Moreover, there is also a great variety among countries in terms of adoption rate of new technologies, that is often linked to the opportunities, awareness and motivation of farmers'. However, there is very limited knowledge available on these aspects of adoption, especially in cross-country focused assessments (Klerkx et al., 2019).


Although the number of studies attempting to evaluate the factors that influence agricultural stakeholders' decisions to implement digital technologies has increased, there is still much to investigate and comprehend in this area (Ingram and Maye, 2020; Klerkx et al., 2019; Krampe et al., 2021). Klerkx et al.'s (2019) review on the contribution of social sciences to study digital agriculture revealed that studies focusing on adoption, uses and adaptation of digital technologies on farm can be grounded into two categories: 1) individual determinants affecting the uptake of digital farming technologies, 2) impacts on farm and farming practices by digital technologies. They highlight that there has been a diverse set of methodologies supporting the examination of these aspects of digitalization. In addition to modelling approaches of the costs and benefits and the quantitative methods to test the impacts of different factors on adoption, there have been examples of inquiries based on qualitative methods as well. The LivestockSense¹ project aimed to identify/remove social barriers for technology adoption to achieve a wider use of information and communication technologies (ICTs) on farm by using mixed social science methods, such as quantitative surveys and qualitative studies, including in-depth interviews and focus group discussions.

In this increasingly multi-faceted methodological approach, little attention has been paid to participatory methods, for instance focus group discussions with a diverse range of participants. However, such initiatives have the potential to collectively address complex issues together with stakeholders from different backgrounds. Focus group discussions with multiple stakeholders were a key part of the methodology of the LivestockSense project. Stakeholders involved in livestock production were convened in all the 6 partner countries to discuss country specific issues of the adoption of digital technology in the pig and poultry sectors. The findings of this research are unique in the wider discourse on digital agriculture because, to the best of our knowledge, no other study has used this methodological approach.

Materials and Methods

Focus group discussion (FGD) is a direct qualitative research procedure, in which a facilitated discussion takes place between a moderator and selected small groups of participants. The role of the FGD is to gain insight into a specific topic based on the conversation of the representatives of the target market (Malhotra, 2010). The aim of conducting FGD was to get an in-depth, multi-aspect view on the issue of slow ICT uptake by the livestock industry, identify key characteristics of farmers' attitudes towards ICT tools and recommend actions to foster quicker spread of ICT adoption. To achieve this, parallel focus groups were planned for the pig and poultry sectors (chicken meat and commercial egg production), respectively, by inviting representatives from science, policy and business communities with experience about ICT tools used in pig and/or poultry farming into each group (Figure 1).



Figure 1: Composition of individual focus groups

Participants were recruited within the LivestockSense project in five European (Denmark, Estonia, Hungary, Poland, Sweden) and one Middle Eastern countries (Israel) by the project partners. In total, 83 invited participants and 41 hosts participated in the different FGDs, with the hosting institutions ensuring the presence of moderators and assistants in each FGD, and the representatives of science in most of the cases. As regards the sectoral distribution of the FGDs, in total 7 pig FGDs and 7 poultry FGDs were established (Table 1).

Focus Group Discussions (FGDs) were conducted between December 2022 and February 2023, using online, in-

¹ https://livestocksense.eu/



person, or hybrid formats, each adhering to the same pre-defined protocol. The FGDs started with welcoming the participants, and introducing the LivestockSense project as well as the objectives of FGDs. This was followed by a brief introduction of the moderators, assistants, and group participants. During the discussion phase, participants engaged with an introductory question to set the context, and subsequently, three core questions were addressed, as outlined in Table 2. Given that the purpose of the FGDs was to identify and address social barriers for technology adoption and promote the wider use of ICT on farms within the LivestockSense project, the questions were specifically tailored to align with these aims. Each FGD lasted approximately 2 hours in each participating country.

Participating Type of		Participants		Distribution of participants				Distrib FC	ution of 3Ds
country	meeting Invited Hosts Moderator/ Scie		Science	Policy	Business	Pig	Poultry		
Estonia	in person	11	3	2	1	7	4	1	0
Denmark	online	9	5	3	3	3	5	1	1
Hungary	in person	21	6	6	4	4	13	2	1
Poland	in person	20	8	8	4	4	12	2	2
Israel	in person	9	8	2	6	1	8	0	1
Sweden	in person	6	4	4	2	1	3	1	0
	online	7	7	7	2	1	4	0	2
Total		83	41	32	22	21	49	7	7

Table 1: Participants of the FGDs by country

During the discussions, moderators' assistants took notes, and with participants' consent, voice recordings were made. The FGDs' output comprised country reports, meticulously prepared following a pre-defined format. These reports included the date and location of the meetings, the number of participants from the predetermined stakeholder groups (science, policy, business), the meeting agenda, and a comprehensive account of the discussions, categorized by sectors (pig and poultry) and stakeholder groups.

The qualitative data from the individual country reports were systematically organized by questions and sectors, with clear indications of their origin. Data with similar content were grouped together and labeled according to the themes they addressed. To evaluate their significance, the data were ranked based on the number of mentions of specific key words and issues across countries, resulting in a ranking that reflected their importance. Ultimately, the sector-based organization was amalgamated into a concise and comprehensive summary of the overall outcomes.

	Table 2:	Ouestions	addressed	during	the FGDs
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Topics	Starting questions	Probes
Introductory question	What are the implications of applying ICT technologies at pig / broiler / layer farms?	In which aspect of pig/ broiler/ layer production are they used usually? Motivations and purposes of using smart technologies?
Characteristic of advanced ICT adopters	Could you give a general description about those pig/poultry farms, which can be considered as the users of smart technologies?	What makes them different compared to non- user farms? Characterize not just the farm but the attitudes of the farm manager(s).
Barriers of adoption	What factors do you think are the <u>main</u> barriers (lock-ins) of the adoption of ICT tools in pig / broiler / layer production?	On-farm and external issues as well.
Solutions for removing barriers	What incentives (enabling factors) might motivate the spread of smart technologies in your opinion?	

Results

In the beginning of the FGDs, as a warming up exercise, participants were asked to list the implications of applying ICT technologies at pig, broiler, and layer farms. The participants recognized in five countries (Estonia, Hungary, Israel, Poland and Sweden), that implementing ICT technologies can have a '*positive impact on animal welfare*'. By continuously '*measuring barn temperature, humidity and air quality*', these technologies create *better 'indoor environments and climate conditions*' ensuring that animals are kept in comfortable and stress-free surroundings. This leads to improved well-being and health outcomes for the animals, ultimately benefiting the farming operations.

As second and third most important implications mentioned were issues, such as ICT technologies 'ensure early alarm and error detection', so that farmers can 'immediately react and intervene' in case of any issues, ensuring the well-being of the animals. Furthermore, ICT technologies 'enable precise feeding, minimizing feed waste and individualizing the feeding process' based on specific needs. The implementation of ICT technologies also contributes to economic and environmental sustainability by 'improving the profitability' of farming, through 'increasing efficiency of production' and 'optimizing costs' and by 'decreasing the environmental impact' of farming practices. In addition, ICT technologies enable 'better biosecurity measures', allowing for 'individual health control' and early detection of potential health issues. By monitoring and analysing data on animal health parameters, farmers can identify patterns and take preventive measures, minimizing the spread of diseases and ensuring a 'healthier livestock' population. The positive impact of ICT technologies on the 'work environment and time management of farm staff' was a frequently emphasized issue too, which means, that the issues mentioned above came up in three and four out of six countries. The implementation of ICT technologies helps pig and poultry farms 'meet the quality requirements and expectations of various stakeholders, including processors, traders, consumers, and legislation'. By enabling 'automatic weighing' and 'daily registration of weight in relation to feed intake', ICT technologies ensure a more homogeneous animal population in terms of weight and in case of pig fattening a more accurate sorting of finishers, according to the weight requirements of the slaughterhouse (Figure 2).

The examination of the implications mentioned by countries made clear that Danish stakeholders held different opinion regarding ICT adoption compared to the other participating countries. The Danish FGD report indicated that the agriculture sector in Denmark is operating at a much more advanced level of ICT usage than the other countries in this study. Thus, the benefits mentioned earlier, with the exception of weight monitoring, appeared to be a natural and established part of their practices. For them, the focus has shifted from technology adoption issues to more advanced considerations such as rational data use (processing and handling), the frequency of information flow (expected to be a daily routine), and targeted technology design. They emphasized the need to 'design the necessary technology, not the other way around, where the technology is designed and then you find a problem that fits the technology'.



Figure 2: Main implications of applying ICT technologies at pig, broiler, and layer farms - mentions by countries

3.1. General description about the users of smart technologies

Participants in all six countries agreed that the primary users of smart technologies in pig and poultry farms are 'younger farmers who are not approaching retirement age'. This indicates that the adoption of smart technologies is more widespread among the younger generation of farmers who are technologically inclined and open to innovative solutions, since they 'accept more easily new technologies and see the advantages of ICT'. Except for the Israeli participants, all other countries acknowledged, that 'large farms' are the main adopters of ICTs. The 'risk of disease outbreaks increases with larger farms', making it essential for such farms to invest in advanced technologies to mitigate these risks effectively. Additionally, the participants noted that these farms are 'creditworthy, productive', and have 'good viability', which enables them to allocate funds for 'investing' in smart technologies.

Furthermore, participants from Hungary, Poland, and Sweden mentioned additional characteristics related to personal attitudes and skills, like 'farmers and staff members' associated with these farms exhibit a 'strong interest in



technology and possess a certain level of digital maturity'. This means that the users of smart technologies are proactive in seeking technological advancements and are comfortable with using digital tools and solutions to enhance their farming operations. Moreover, these farmers are focused on 'creating added value' and are 'inclined towards innovation'. This suggests that they are receptive to novel ideas and are willing to explore innovative approaches to stay competitive in the industry. Another significant characteristic identified is that farmers using smart technologies demonstrate a high level of 'interest in their production process' and practice 'conscious farming'. Smart technologies likely assist them in monitoring and managing their operations with greater precision, enabling them to optimize resource utilization and minimize negative effects on the environment.

Lastly, participants in the FGDs held in Hungary, Israel and Sweden, emphasized the importance of 'good technological endowments', including 'reliable internet connections' for successful implementation and utilization of smart technologies in farm operations. This aspect was also raised by the Estonian, Danish and Polish participants in the 'barriers of ICT adoption' section (chapter 3.2), confirming the critical role of robust technological infrastructure and connectivity in successful implementation and utilization of smart technologies in farm operations (Figure 3).

In terms of the countries involved, it can be concluded that in Denmark and Israel, only the age of farmers was mentioned as a human factor in contrast with the other participating countries. This implies that in these two countries, digital maturity and openness towards ICTs are strongly associated with age. On the other hand, good technological conditions were only mentioned as user characteristics in three countries, while all other countries referred to this issue as a barrier to ICT adoption. Consequently, it can be concluded that the good technological supply of a farm is on similar importance like the age of the farmer. These findings provide valuable insights into the target audience for smart technology providers in the pig and poultry farming industry and offer guidance for developing and implementing strategies to promote smart technology adoption in these sectors.



Figure 3: Main characteristics of the users of ICTs in pig and poultry farming

3.2. Main barriers of the adoption of ICT tools in pig/poultry production

Factors related to financial attributes were the most frequently mentioned barriers. Participants commonly expressed the '*lack of information about the cost-benefit*' of new digital technologies. Lack of knowledge about economic returns contributes to the difficulty of '*gaining access to resources (e.g. loans)*', but also increases farmers' perception of the risks associated with the use of digital technologies, making their decisions about the adoption of these already "*expensive*" tools even more difficult. Adaptability, another frequent factor, is primarily dependent on the connectivity between existing farming infrastructure (e.g., farm buildings) and new technologies. In many instances, 'old farm infrastructure is unsuitable for installing cameras, sensors, and other devices'. This undoubtedly slows adoption if any digital development first necessitates new buildings, thereby increasing investment costs.

Another frequently cited factor was the '*lack of service support*', which implies a certain level of experience with digital tools. It is important to note, that the user experience of insufficient service provision by technology providers can act as a hindrance to the uptake of additional technologies.

The 'lack of a workforce skilled and trained' in using digital tools is another limiting factor. This emphasises the fact that, while the necessity for manual labour is reduced by the use of digital technologies, the demand for highly skilled labour is increased. As a result, the issue of workforce supply is no longer one of quantity but rather of quality. This is closely tied to another interesting finding from the discussions, which is related to the fact that the adoption of digital tools does not always imply a qualitative improvement when used by untrained individuals. In reality, improper use may make it more difficult to see the advantages of employing these technologies.

The focus group discussions also revealed a number of attitude factors. Farmers' reluctance to experiment with and use new technology might be a significant impediment to the digital shift. Another attitude similar to that is the belief that *'already successfully operating farming activities cannot be improved further, even with the use of modern*



technology'. In addition, there is often a *'lack of trust'* regarding new and unproven tools. This mindset is fundamentally based on the status quo bias, which holds that any change is perceived as uncertain or potentially harmful (Figure 4).



Figure 4: Main barriers of the adoption of ICT tools in pig and poultry production

3.3. Incentives that might motivate the spread of smart technologies

The suggested incentives harmonize well with the main barriers previously introduced. Out of all, the most frequently mentioned incentives targeted financial and technological aspects. This primarily entails the need for clarification of the still unknown costs and benefits of advanced technologies, which is a key step to achieve financial supports to reduce the financial burden and encourage farmers to invest in these technologies. In the absence of financial supports, targeted 'subsidies' can be an alternative to foster technology uptake as emphasized in several FGDs (Estonia, Hungary, Poland and Sweden). From a technological perspective, ensuring tailored 'adaptation of ICT technologies to the needs of end-users' highlights the need for customized solutions that address the unique challenges and preferences of farmers. This should be accompanied by 'intensive technology support after purchasing the products' as pointed out by the Hungarian, Polish and Swedish FGD participants. This support could include assistance with installation, troubleshooting, and ongoing technical support. The availability of reliable and responsive support services helps farmers effectively integrate and maximize the benefits of smart technologies, minimizing any potential challenges or obstacles they may face during implementation.

The most effective way to change non-users' negative or neutral attitudes resulting from a lack of knowledge, is by sharing information, providing training and educational opportunities, and promoting the real benefits, including the limitations of the technologies. Based on the FGDs, the most important in this regard is to make 'comprehensive information about the technologies available' through demonstrations, forums, exhibitions, and various media platforms. Encouraging 'interactions with fellow farmers, advisors and veterinarians' is also vital. Providing access to real-world examples, such as 'visits to demonstration farms' where running systems can be evaluated, can facilitate decision-making and increase confidence in adopting smart technologies. Participants from the Hungarian and Polish FGDs pointed out the need for 'training programs that focus on practical education'. Furthermore, 'improving communication channels between business, training institutions, and scientific communities', including cooperation between farmers and developers, was highlighted as essential. Enhancing collaboration and information sharing between these entities can lead to the development and dissemination of 'relevant and credible technologies that are cost-effective' for farmers, as underscored by the Polish and Swedish participants (Figure 5).

Upon examining the differences between the countries, a notable divergence in the views of Danish participants came to light again. It became obvious, that the use of certain types of ICTs is widespread in the Danish pig and poultry industry. Consequently, the barrier to the further spread of the technology was not financial or attitudinal, but rather technological in nature. More precisely, participants expressed request for improving the practical usability of the



technologies, focusing on effectively utilising data, and customizing technologies to meet user requirements as much as possible. The following point summarize their propositions:

'Data must be given value, that value must be shown and quantified';

'There is value in that data, but we have not shown how the value is there';

'Being able to benchmark against other productions, [...], analyzes that make it easier to document and meet environmental and other requirements';

Medicine registration: 'Our constant challenge is to handle the technology inside the stables';

'Some technologies are missing for quick and easy identification of the animals';

One participant mentioned problems with 'ID chips in the ears of the pigs' which should be solved by the industry.



■EE ■DK ■HU ■ISR ■PL □SE

Figure 5: Main incentives that might motivate the spread of ICTs in pig and poultry production

Discussion

This survey comprehensively examined the reasons of slow ICT uptake in the pig and poultry industry. It provided valuable insights into the perception of different stakeholders in the PLF value chain, including farmers, ICT developers, researchers, as well as representatives of farmers organizations and the government. The study employed focus group discussions to explore the implications of applying ICT technologies in pig and poultry farms, the characteristics of technology users, the barriers of technology uptake and incentives to promote the spread of smart technologies.

Participants primarily mentioned positive implications of ICT adoption, emphasizing improved animal welfare and health through better indoor environment along with the potential for early alarm and error detection. These benefits contribute to reduced environmental impact, cost savings, and higher profitability due to enhanced production efficiency. The findings are align with a numerous literature that declare these aspects as key drivers of the use of PLF systems (Abeni et al., 2019; Akinyemi et al., 2023; Banhazi et al., 2022; Gómez et al., 2021; Hartung et al., 2017; Krampe et al., 2021; Schillings et al., 2021). However, none of the FGDs mentioned any threats associated with smart technologies, such as adverse effects on animal behaviour, health or comfort due to stress from insufficient adaptation to the system or false management actions taken because of incomplete information, as listed by Tuyttens et al. (2022).

Users of ICT technologies were predominantly characterized as young farmers with a keen interest in technology, which is consistent with the findings of Botsiou et al. (2018), i.e. young farmers are more frequently ICT adopters. In contrast, Balogh et al. (2020) observed no age-related effect in a survey among crop producers. FGD participants also found that large farms, with good financial viability and investment capacity, were more likely to apply PLF technologies. This can be confirmed by the results of a study made across crop producers in 7 European countries by Kernecker et al. (2017), who reported higher ICT adoption with increasing farm size. The role of human attitudes in ICT purchase decisions is an aspect that has been rarely investigated, despite the fact that several personal qualities were mentioned by the FGD participants as characteristics of potential users. These qualities include being innovative, conscious farmers with a strong interest in digital technology and possessing a certain level of digital maturity. Botsiou et al. (2018) and Chuang et al. (2020) associated farmers' digital maturity and interests with factors such as age, education level and technology knowledge. These existing and acquired characteristics together influence farmers' perceptions of smart technologies. Last, but not least, good technological infrastructure and reliable internet connections



have emerged as significant determinants of PLF adopters in line with several studies that highlight them as crucial prerequisites and major obstacles to ICT adoption (Akinyemi et al., 2023; Banhazi et al., 2022; Guarino et al., 2017; Nääs et al., 2022; Neethirajan and Kemp, 2021).

The unknown or uncertain cost-benefit ratio was identified by the participants as the main barrier to the adoption of ICT tools. This information was found to be crucial when deciding whether to implement a technology, based on the results of Abeni et al. (2019) and Borchers and Bewley (2015). In addition, if the technology itself is considered to be too expensive (due to high investment costs), as observed in case of PLF systems according to the results of the FGDs and the survey by Hartung et al. (2017) and Krampe et al. (2021), and is coupled with a lack of available financial support, it can indeed become a significant impediment to technology dissemination. The participants emphasized the issue of unsuitable farm infrastructure for ICTs, including IT technologies in this part of the discussion again, as mentioned earlier. Lack of knowledge, skills and interest are exactly the opposites of the characteristics found in ICT users. These human shortcomings lower the adoption level of smart technologies as highlighted by Akinyemi et al. (2023) and Chuang et al. (2020). Moreover, PLF systems are susceptible to hardware and software failures (Hartung et al., 2017; Maselyne et al., 2022; Tikász et al., 2022; Tuyttens et al., 2022), necessitating the availability of readily available service support. However, the participants from different FGDs pointed out the general lack of available maintenance services, especially in the pig and poultry industry, which is most likely associated with the fact that these technologies are often provided by micro-SMEs. These small organisations often do not have the capacity to provide timely and cost-effective maintenance services, despite their obvious goodwill. Additional government support, targeted subsidies might help increasing the maintenance and general service provision capacity of these smaller entities.

To eliminate the barriers of ICT adoption, the participants of this survey listed financial, technological and attitudinal incentives. As the main barrier to the uptake of PLF technologies was the unknown or uncertain cost-benefit ratio, the participants emphasized the need for clear identification of costs and cost-effectiveness, along with proven profitability. However, it was also recognised during follow-up discussions that evaluating the benefits of these technologies is inherently difficult. To obtain the benefits, farmers have to act on the information received. These ICT tools typically do not have the capacity to automate the implementation of the required management action; they merely provide the information that could be used by the farm management to formulate appropriate actions. Thus, if the management is not acting upon the info received; it is unlikely that any additional benefits will be gained. Therefore, this stalemate has to be somehow resolved, otherwise farmers will remain reluctant to act on the info received because the unproven benefits. The FGD participants also called for increased financial support and subsidies to facilitate adoption. They pointed out that ICT developers should focus on solutions that are well suited to farming conditions and meet the specific needs of farmers. By doing so, excessive malfunctions and demands for technology support can be minimized, which, in turn, mitigates growing distrust in these technologies. Admittedly, it is now recognised that often these problems occur because these ICT based technologies are demonstrated on farms that do not always meet the criteria of farms (described in this article) that would maximise their likely success of trouble-free operation.

Achieving this requires enhanced collaboration between farmers, scientists and engineers to develop robust technologies, demonstrate their usefulness and inspire consumer confidence (Borchers and Bewley, 2015; Neethirajan and Kemp, 2021). Furthermore, the survey identified a clear need for maintenance services to fully realize the potential of PLF technologies and provide real value for farmers (Jago et al., 2013). Additionally, information-sharing, education and training were emphasized as critical means of changing the negative or neutral attitudes and perceptions of non-users. Based on Borchers and Bewley (2015) and Jago et al. (2013) educating users on the effective utilization of these technologies and interpreting the information generated by them is essential for successful adoption.

Conclusions

Focus group discussions involving stakeholders from the pig and poultry precision farming value chain in five European and one Middle Eastern country yielded promising results in exploring the multifaceted reasons for the slow uptake of ICT in the livestock industry. Participants highlighted numerous positive implications of applying ICT technologies, including improved animal welfare through better indoor environment, early detection of issues, precise feeding, and increased profitability of production. The study identified younger farmers and larger farms with a creditworthy and productive profile as the primary users of smart technologies. It emphasized the importance of digital maturity of farm staff and good technical conditions of the farm, including internet connection. Financial factors, adaptability issues, lack of skilled workforce, and negative attitudes were cited as barriers to ICT adoption. However, incentives such as clarifying costs and benefits, tailored technology solutions, and extensive support services could promote technology uptake. Additionally, the findings underlined the importance of comprehensive information dissemination, practical education, and collaboration among stakeholders to encourage technology adoption. Overall, these insights offer valuable guidance for policymakers, technology providers, and farmers to foster the broader use of ICT technologies in the pig and poultry farming industry.

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Influence of Thermal Stress on Feeding Behaviour of Growing-Finishing Pigs: A Preliminary Study

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Abstract

Animal feeding behaviour is controlled by hunger and satiety mechanisms, however, it can be influenced by external factors such as treatments and diets; feeding and housing systems; health and breed; and thermal environment. Heat stress is the main concern in pig production since pigs do not have functional sweat glands. In order to reduce heat production in a situation of thermal stress, pigs present a decrease in their activity, an increase in water intake and a reduction in feed intake. Adjustment of voluntary feed intake is one of the most important adaptation processes to modify metabolic heat production in response to ambient temperature. Heat stress may cause a decrease in voluntary feed intake in growing-finishing pigs at the level of 50%. In addition to reducing feed intake, pigs can change their feeding behaviour. It is not entirely clear how these changes in feed intake are mediated by underlying feeding behaviours. In order to understand the interaction between voluntary feed intake and the feeding behaviour, three experiments, each with 8 females Piétrain x TN60, were carried out in an environmental controlled room where the air temperature (T) and relative humidity (RH) were permanently monitored. The feeding behaviour was evaluated through an electronic feed station that, through an RFID system, allowed individual monitoring and control of the food supplied and ingested and the number and duration of visits. The results highlighted the influence of the environmental conditions on the feed intake and feeding behaviour.

Keywords: thermal stress; animal welfare; pig; feeding behaviour

Introduction

By monitoring feeding behaviour, it is possible to assess some of the theories that were at the origin of the principles of animal welfare (absence of thirst and hunger) and even indicate the presence of some diseases, in case these patterns undergo changes (Rushen et al., 2012; Zhuang et al., 2022). Feeding behaviour is controlled by hunger and satiety mechanisms, however, it can be influenced by external factors such as treatments and diets; feeding and housing systems; health and breed; and thermal environment (Maselyne et al., 2015).

Heat stress is the main concern in pig production since pigs cannot sweat. If in a cold situation the animal tries to use the metabolic heat associated with production (extra-heat) for thermoregulation, in a hot situation the objective is to eliminate this heat (Cruz, 1997).

When the temperature exceeds the point above which the equilibrium between heat production and heat loss can be maintained, the maximum heat loss by evaporation is reached and respiratory evaporation (panting) proves inadequate to lose enough heat to maintain the body temperature constant (Huynh et al., 2005; Huynh et al., 2007). Thus, as a response to the high temperature, several behavioural patterns are observed in pigs.

Adjustment of voluntary feed intake is one of the most important adaptation processes to modify metabolic heat production in response to ambient temperature (Cruz, 1997; Mayorga et al., 2019; Renaudeau et al., 2012). The severity of reduction in feed intake behaviour depends on genotype, sex, breed, age, body weight, physiological state, diet composition, feeding regime, group size and environmental factors (Godyń et al., 2020; Renaudeau et al., 2012; Santos et al., 2018).

According to the literature, high ambient temperature compared with thermoneutral environmental conditions (\approx 30 ° C vs \approx 20° C) may cause a decrease in voluntary feed intake in growing-finishing pigs at the level of 50% (Godyn et al., 2020; Huynh et al., 2005; Ma et al., 2019; Pearce et al., 2015).

In addition to reducing feed intake, pigs can change their feeding behaviour (Bus et al., 2021; Santos et al., 2018). It is not entirely clear how these changes in feed intake are mediated by underlying feeding behaviours. However, there is general agreement that the daily duration of feeding decreases with increasing temperature (Collin et al., 2001; Fraga et al., 2019; Gertheiss et al., 2015).



Materials and Methods

Structures and equipment

The experimental work was developed in an environmental control room at the University of Évora. A pen with an area of around 12,0 m2 was installed in the environmental control room. The pen had a manure pit and was equipped with an automatic feed station and two nipple drinking bowl. The floor was partially concrete cover with anti-slip tactile.

Environmental control was carried out through ventilation, heating and cooling systems. Ventilation system was compound by two vertical extractors fans. The air came into the facility through a false ceiling to protect the animals and left through the extractors (negative pressure). The heating system consisted of a conventional gas heater. The cooling of the facility was made by a nebulization system.

The environmental control room was equipped with temperature and relative humidity sensors, as well as an electronic feed station.

Experimental design

In the experimental phase, three trials were carried out in the environmental control room. Three different conditions were set: Winter (W) – cold stress (trial 1), Thermoneutrality (TN) – thermal neutrality (trial 2) and Summer (S) – hot stress (trial 3) (Table 1).

Table 1. Experimental environment set points.

Environmental Conditions	Winter (W)	Thermoneutrality (TN)	Summer (S)
Temperature (°C)	10 ± 2	18 ± 2	30 ± 2
Relative Humidity (%)	80	70	60

In each trail 8 female pigs of Piétrain x Topigs Norsvin (TN60) genotype were used whit an initial body weight around of 48 ± 3 kg. Each animal had 1,5 m2 of area in the pen. The animals were identified with an RFID ear tags system and each trail started after 15 days of habituation period in TN conditions (Tmean = 18 ± 2 °C and RHmean = 70%) and finished when the animals reached a commercial slaughter weight of around 95-105kg live weight.

Data collection

The environmental variables measured were temperature (T) and relative humidity (RH). This data collection was made continuously and in real time through an environmental control system (Webisense) and a data collector (Nidus).

The productive data measured were initial and final body weight (BW) and feed intake (FI). These data were recorded using the electronic feed station, which through the RFID ear tag system, allowed to monitor and control individually, in each feeder access, the amount of food supplied and ingested (grams); number and time of visits to the feed station (h:m:s); and animal's weight (grams). This precision livestock farming tool allowed to calculate the average daily gain (ADG) and feed conversion rate (FCR).

Results and Discussion

The air temperature, RH, voluntary feed intake and feeding behaviour data collected during the entire experimental periods were analysed through a descriptive statistical analysis.

Inside environmental conditions recorded in the experimental trials are presented in the Table 2.

Table 2. Environmental cond	inions recorde	eu in the experin	mental trials.			
	Winter (W)		Thermone	utrality (TN)	Summer (S)	
	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%
Average	12.5	74.5	20.7	74.0	28.9	63.1
Standard deviation (SD)	2.1	6.2	1.5	12.0	1.6	6.9
Maximum (max)	19.4	95.4	24.9	97.3	33.3	90.1
Minimum (min)	8.3	54.5	15.9	43.8	23.2	25.3

Table 2. Environmental conditions recorded in the experimental trials.



The average T and RH recorded inside the environmental control room were in accordance with the work goals and represented real winter, thermoneutrality and summer conditions.

Productive data recorded in the experimental trials are presented in Table 3:

Experimental trial	Final BW (kg)	FI (kg/day)	ADG (kg/day)	FCR (kg/kg)
W	96.0	2.701	0.792	3.41
TN	103.4	2.560	0.930	2.75
S	98.7	2.310	0.859	2.69

Table 3. Productive data recorded in the experimental trials.

Through the analysis of these results, it is possible to conclude that environmental conditions influenced:

- (i) The pattern of voluntary food intake: during the summer (heat stress), the average daily intake rate decreased due to the negative impact of high ambient temperatures on food consumption, especially in swine, which have significant difficulty dissipating heat in such environmental conditions. Conversely, during winter conditions, food intake increased. This can be explained by the fact that in cold stress conditions, the animals' heat loss to the environment increases. Therefore, the additional heat production to compensate for this loss is achieved through an increased consumption of feed.
- (ii) Average daily live weight gain: In general, animals grew faster in the thermoneutral condition because, in this situation, almost all the dietary energy consumed is directed towards meeting maintenance and growth needs. The ADG was higher in summer when compared to the winter condition. This can be explained by the fact that animals in winter conditions had to expend a portion of the energy from their food for temperature maintenance, reducing the amount of energy available for increasing body weight.
- (iii) Feed conversion rate: Its value was higher in winter conditions due to the fact that the amount of available metabolizable energy for growth was reduced as a result of increased maintenance needs, which influence the FCR (Cruz, 1997). Although the values obtained in summer and thermoneutrality conditions were very similar, animals exhibited better feed efficiency during the summer. This can be explained by the fact that animals in thermoneutrality conditions were housed for a longer period (an additional 7 days), and consequently, they were slaughtered at a higher live weight. This factor has an influence on the feed conversion ratio, as beyond a certain growth stage, increased live weight negatively affects feed efficiency.

Experimental trial	FI (kg/day)	Visits (nr/day)	FI / visit (g/visit)
W	2.701	14	193
TN	2.560	13	197
S	2.310	13	178

Table 4. Feeding behaviour of pigs in the experimental trials.

When analysing the pigs' feeding behaviour in this study, it is evident that, concerning the average number of visits to the feeding trough, no differences were observed based on environmental conditions. However, upon examining Graph 1, a noticeable trend emerges, showing that animals subjected to summer conditions considerably increase the number of visits to the feeding trough as they grow.

Regarding food consumption per visit, it becomes apparent that animals consumed more in thermoneutral conditions, with little variation compared to the winter situation. The lowest consumption was recorded during the summer condition. The analysis of Graph 1 reveals a contrasting trend, where animals in winter conditions tend to increase food consumption per visit as they grow, while the opposite trend is observed in the summer situation.

Although this approach is still preliminary, it aligns with existing literature, which suggests that animals tend to reduce food intake as temperatures rise and increase it as temperatures decrease. These results provide some valuable insights, especially regarding the impact of high temperatures on pigs during the growth and fattening phase. They can explain that, even though the animals reduce food consumption in the summer throughout their growth, they do so by adjusting their feeding behaviour, resulting in an increased number of visits to the feeding trough with a lower intake of food per visit.





Graph 1. Pigs' feeding behaviour according to different environmental conditions.

Conclusions

This work, being a preliminary study, serves to identify the need to understand how environmental conditions influence the feeding behaviour of growing and finishing pigs. Although no analytical statistical treatment has been applied, these preliminary results highlight certain trends in this behaviour, where environmental conditions affect intake and feeding behaviour. However, there is a substantial need to work on and analyse these data in a more detailed and robust way in order to make a significant contribution to scientific progress in this research area. The next steps are related to analysing the interactions between feeding behaviour parameters, animal growth and recorded temperatures, as well as incorporating the duration (in seconds) per visit to the feeding trough in these analyses.

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Assessment of Weight Loss on Pigs in Pre-Fattening Stage in Function of Temperature and Humidity Index (THI) Using Low-Cost Sensor Network

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Abstract

The growth rate of pre-fattening stage pigs in confinement depends on their genetic characteristics and the environmental conditions in which they are found, determining their welfare and productivity. Real-time measurement of environmental variables allows the prevention of stress conditions that could affect production, thermal comfort and animal welfare. This research was carried out in a typological natural ventilated facility located in Antioquia State Colombia. A customised low-cost sensor network was developed for real-time monitoring of temperature, relative humidity, light intensity and wind speed, which allows instant computing of the temperature and humidity index (THI) inside the piggery in which the animals are found. Pigs in pre-fattening stage were separated in two groups, males and females, selected randomly. The influence of THI on the weight gain of the groups was analyzed using three repetitions of the experiment. The impact of THI on the weight gain of males and females was analyzed independently. Descriptive statistics, Pearson correlation coefficient and linear models were employed to analyses the relation between the environmental and physiological variables. It was found that both animal groups were repeatedly subjected to stress conditions, which could negatively impact their weight gain and wellness. The use of low-cost sensor networks for monitoring environmental variables in real time is very reliable, providing relevant and timely information for decision-making, in relation to either gain or loss of weight to the pigs in function of microclimate conditions inside the facilities.

Keywords: Bioclimatic, animal welfare, stress, weight gain, instrumentation.

Introduction

Colombian swine farming has grown in recent decades, with a 7.2% of increases between the years 2021 to 2022 (Porkcolombia, 2022), being an important productive activity in the country, where the agriculture contributes the 6% to the GDP (Ammendolea, 2022). Due to favorable climatic conditions and increasing pork consumption, the country has a growing demand for pork products. The increase of pork products consumption reached 13 kg per capita in 2022 (Porkcolombia, 2022). Furthermore, this numbers can be associated to the constant renewal of production practices, improvement in genetics, compliance with quality standards, biosafety and animal welfare, even dough there is a lack of technology improvement in small and medium producers.

Despite animals being adapted to the climatic conditions in which they live, there are certain occasions when animals are subjected to unfavorable periods and suffer stress due to fluctuations in temperatures or a combination of factors, which generate physiological modifications in their development and changes in behavior (Arias et al., 2008). The most relevant climatic factors that influence the ability of animals to maintain their thermal comfort zone are ambient temperature, relative humidity, direct or reflected solar radiation, and air movement (Oyhanart et al., 2017). The bioclimatic conditions in which production occurs are determining factors in the life stage of the animals, since these can favor or affect their development. Unfavorable conditions or bad practices in environmental management and/or animal management can affect reproductive cycles, energy expenditure, health, feed intake, and daily weight gain in animals. Due to the this, each system should evaluate these variables in their production, to establish their impact over the animal and the production system, with the goal of obtaining maximum performance and productivity (Echevarría and Miazzo, 2002).

Infrastructure design is of the utmost importance for proper handling of the animal. This varies according to the productive model that is going to be adopted, looking for characteristics that are functional, economical and appropriate for the animal and the producer, according to the climatic conditions (Oleas et al., 2012). Intensive production facilities require adequate ventilation systems, which allow regulating the humidity and the heat produced by the pigs, as well as the gases coming from the manure and the dust particles generated (Gamba-Castro, 2018). In temperate-warm climate zones, it is recommended that the facilities be open since the biggest problem that can be found in the species is the difficulty in regulating temperature (Gómez, Rojas, 2007).

In pig production, specific care is required for each productive stage, enssuring a good animal performance, which implies, constant monitoring of the productive parameters. The pre-faiting stage, is a period where the animals enter



after weaning with a weight over 5 - 7 kg and leave it with a weight over 27 - 32 kg. This weight must be obtained in 6 - 7 weeks according to the production methodology and animal supplier. In this stage, the air temperature requirement varies according to the weight of the piglets, with animals between 6-15 kg a temperature of 26-32°C is recomended while for animals between 15-35 kg a temperature between 18 to 26° C is recomended (Gamba-Castro, 2018).

In this research, the influence of the Temperature and Humidity Index (THI) on the weight gain of pigs in the prefattening stage is studied, seeking in particular if there is a relationship between the THI and the weight gain of males and female piglets in this stage, looking differences in the impact of the climatic conditions in the productive performance of females or males pigs in pre-fattening stage.

Materials and Methods

Tests

Two groups of Pigs in pre-fattening stage, of 10 pigs each one, were used for the tests. The groups were divided into males and females, selected aleatorily at seven days after weaning. Three repetitions of the test were carried out with a separation of 30 days between them. All the repetitions started seven days after weaning, this is 30 days after birth, with a duration of 41-42 days. A natural ventilated piggery was employed where two separated cages of 2x2m, slat floor and steel bars, each one, were used. Cages were separated 1m one another and were elevated 0.5 m of the floor. At libitum water and concentrate were supplied for each cage. The health of the animals was monitored by a zootechnician.

The temperature inside the piggery was controlled manually through the opening of the fixed windows shades, which stays open between 7:00 and 17:00h. The tests were carried out at the Universidad Nacional de Colombia Agrarian Station, located in 6°07'56"N 75°27'17"W at 2.154 m above sea level, in Colombia. The Agrarian Station has an average temperature of 16.2 °C, mean RH of 82 % and rainfall average of 2,645mm.

The pigs were marked with ink on their backs in order to differentiate them. They were marking from 1-10 on each one of the groups. Pigs were weighed three times a week using a pig measurement scale (0-1000kg). They were weighed individually at noon, where the order of the selection was random. Customised senor network.

A custom-made low-cost, environmental sensor network was developed for this research. It was designed and constructed as an open source IoT tool based on the ESP family microprocessor, for monitoring the air temperature, relative humidity, pressure, radiation and wind. The IoT monitoring tool has three modules for measuring internal variables (inside the piggery), external variables (outside the piggery) and a camera module. This last one was based on a Raspberry Pi 4B processor and a camera Arducam OV5647 5MP (Visible camara), for computing purposes.

Each module has its own micro-SD memory storage. The data of the network can be accessed in real time by Bluetooth or by the intranet. For communicating the modules, the ESPNow communication protocol was employed. The environmental modules send the information wireless to the Raspberry Pi module employing the protocol MQTT through an open-source message broker Eclipse Mosquitto. Wireless communication and data transmission were employed between all the modules.

The internal module employed an ESP32 microprocessor for measuring air temperature (SHT31, -40 to 90°C, Sensirion), relative humidity (SHT31, 0 to 100%, Sensirion), pressure (BMP280, 300 to 1100hPa, Bosh), light intensity (MAX44009, 0.045 to 188.000 lux, Maxim) and wind velocity (WindSensor Rev. P, 0-67ms⁻¹) inside the piggery. For the external module an ESP8266 microprocessor was used for measuring air temperature (SHT31, -40 to 90°C, Sensirion), relative humidity (SHT31, 0 to 100%, Sensirion), pressure (BMP280, 300 to 1100hPa, Bosh), global radiation (LP02-1, 0 to 2000 Wm⁻², Hukseflux), wind speed and direction (Anemometer 1733, 0.5-50 ms⁻¹, Adafruit).

The sensor network was composed of two camera modules, two internal measurement modules, one external measurement module and a router. Each cage has one camera located in the ceiling, 3.2m above the slat floor and one internal module located in the middle of the cage at 1.5m above the slat floor. The router was installed inside the piggery, while the external module was installed over the piggery ceiling at 3.5m over de floor. A schematic of the sensor location can be seen in Figure 2.

Data and video were saved every 30 s along the tests. The THI were computed in real time to stablish the welfare of the animals.

THI

The Temperature and humidity Index (THI) that represents the combined effect of air temperature and humidity on animal comfort in livestock production facilities was computed in real time. In this research the equation proposed by Cao, et al (2021) Eq. (1) will be used, because it was obtained for similar conditions as our tests and being one of the most up-to-date equations for this propose. Where *THI* is the Temperature and Humidity Index (Dimensionless), *T* is the temperature (°C) and *RH* is the Relative Humidity (%)



$$THI = 0.8T + \left(\frac{RH(T - 14.4)}{100}\right) + 46.4 \tag{1}$$

Results and Discussion

Pigs were weighed twice a week during the trials, for a total of 19 measurements during each trial. Figure 1 shows the growing curves of each one of the pigs, taken between October 25^{th} of 2021 and December the 6^{th} of 2021, for the last trial.



Figure 1. Growing curves of pigs between October 25th of 2021 and December the 6th of 2021 (last cycle). A. Females and B. Males

It can be seen increasing growth curves for males and females, with similar slopes for both cases. It is observed that the females reached a higher weight at the end of the trials. The mean of the growth curves of the ten pigs for each case (males and females) it can be appreciated. Through the trend line, it is confirmed that the females present a greater weight gain during the trial with a slope of 1.8 kg/day, compared to 1.7kg/day of the males, with very similar intercepts for both cases. The weight mean of females was 23,2 kg while the males was 21,7kg, with standard deviation of 10,1kg for females and 9,3 kg for males, showing a higher variability in the weight of the females, these variations are equivalent to 5,6-5,7 days of growing. The ideal growth curve, given by the animal supplier (PIC 337), can be seen in red, with a slope of 1.2 Kg/day, below the daily weight gains achieved by the tested pigs, with males being the closer to ideal behavior, the variation of the weight of the pigs using the ideal curve during 5.7 days would be 6.84kg. It was found that, at the end of the cycle, the weight of the females was 41.4K and of the males 38.7 kg, with a difference of 2.7kg, which is less than the standard deviations of females and males.



Figure 2. Relation between the ideal weight curve and the wight gain of females and males

It can be seen a linear relationship between the ideal growth curve and the growth curves of males and females. The male growth curve being the closest to the ideal curve, where the weight gain of the males in the experiment is 1,3 times greater than the ideal gain and that the growth rate of the females is 1.4 times greater than the weight gain provided by the animal supplier. The concentrated consumption of the males was 395 kg during the whole period with a total weight gain of 292kg, for a feed conversion of 1.27kg/kg. For females the total consumption was 437 kg, with a weight gain of

342kg, for a feed conversion of 1.35, the feed conversion of males being better than the females. Taking into account that the ideal growth model has a weight gain of 1.2Kg/day, with a expected feed conversion of 1.63, it can be seen that the pigs in the cycle have better conversion and higher growing rates than what the supplier indicates. It is noteworthy that females reach a higher average weight and growth rate given a less efficient food conversion than males, where the weight gain of females is 15% higher than males, with a 9% higher feed consumption.



Figure 3. Temperature and Humidity Index

The THI was calculated using the Cao's equation for temperatures and humidities taken near to the weighing scale when the animals were weighted. As can be seen in Table 1, the THI mean was 76.3 with an Standard Deviation of 2.3, for the air temperature the mean was 25.9 °C and for the relative humidity the mean was 81,3%%. The minimum temperature was 22 °C and the maximum was 29 °C, these values are in the rage recommended by the supplier for the development of the animals in this stage, being quite in the upper limit for pigs over 15kg.

	Table 1. main statics variables of the las cycle								
Variable	т	ТА	% RH	THI	Weight f	Weight m			
Mean	37,1	25,9	81,3	76,3	23,2	21,7			
Variance	1,6	3,4	122,5	5,5	102,4	87,3			
SD	1,3	1,9	11,1	2,3	10,1	9,3			
Max	39,3	29,0	100	80,2	41,4	38,7			
Min	34,2	22,0	60,8	71,2	10,2	9,5			

The threshold employed to define different rages of heat stress in pigs employing the Cao's equation are: suitable for THI below 74, mild from THI between 74-78, moderate for THI between 78-82 and severe for THI over 82 (Cao et al., 2021). These thresholds can be seen in Figure3 as horizontal lines. It can be appreciated in Figure 3 that THI goes from suitable to moderate, with a big portion of the values in mild stress level, reaching moderate stress index in the first and second-last weeks.





Figure 4. Relation of the THI and the weight gain in females and males pigs

Finally, the linear relationship between the weight gain of male and female pigs with the THI was studied. As seen in Figure 4, the Pierson coefficient shows a low linear correlation of the variables, close to 20% for males and 17% for females. This shows that, although it is known that the climatic conditions influence weight gain and that being subjected to conditions of mile and moderate stress affects the productivity of the animals, other factors intervene in the weight gain process that are not taken into account in this one variable lineal model. Therefore, it would be necessary to consider additional variables and different models for this propose. On the other hand, the data show that for males, weight gain is more influenced by THI than female weight gain, given its higher Pierson correlation.

Conclusions

Given the impact of the climatic variables on pig production, it is necessary for the producers to carry out the analysis of their production systems, in order to establish the correlation between production and climatic variables. The analysis of productive variables of pigs in the pre-fattening stage was carried out for standard production conditions, in a productive system with a low level of technology. It was found that both, females and males, have higher weight gains than what was established by the animal supplier. Also, they presented a better feed conversion than the established by the supplier, with the performance of females being better than males. Although, pigs were repeatedly subjected to heat stress conditions, a linear relationship between pig weight gain and THI could not be established. In this sense, a greater correlation between the THI and the weight gain of the males was evidenced, which could explain the lower weight gain of the males during this trial, but given the low levels of correlation, it is necessary to carry out experiments where more variables are involved to be conclusive in this regard. The use of low-cost sensor networks for monitoring environmental variables in real time is very reliable, providing relevant and timely information for decision-making, in relation to either gain or loss of weight to the pigs in function of microclimate conditions inside the facilities.

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Processing Corn Silage Yield Data from Forage Harvesters

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Abstract

Self-Propelled (SP) Forage Harvesters equipped with yield monitor systems have started to operate in Spain in the last five years. These yield monitor systems have been adopted by contractors that hire their machinery services to farmers. After four seasons recording yield data files with corn silage, we analyse in this paper what are doing contractors with the information collected. The main objective is to adopt precision farming practices for planting and fertilising the corn silage crop. But to be able to offer Variable Rate Application (VRA) to the farmers, contractors need to process the raw yield data files and obtain reliable prescription maps for controlling the corn planters or the fertiliser spreaders during the work.

The way in which contractors collect the information is easy to do in practice, but processing raw yield data is not so easy for them. Online tools like John Deere Operations Center (JDOC) or Field View are the most popular crop data management software applications used by the machinery services companies. But these commercially available solutions have their limitations and users do not know which data of the files are considered to create yield or prescription maps.

The objective of this study is to analyse which data of the files need to be cleaned for obtaining quality corn silage yield maps. Errors are introduced in raw yield monitor data due to georeferencing, sensor, and/or operational errors. The fact of working in small plots in the geographical area of the study, may be another source of yield inaccuracies. Corn silage data from 100 fields were downloaded from the JDOC of one agricultural contracting services company in Northwest Spain. In all fields corn silage yield data files have been collected from 3 to 5 seasons in the 2018-2022 period. Different methods of data cleaning were compared.

Keywords: Precision Farming, Corn Silage, Yield Maps, Data Cleaning, Forage Harvester.

Introduction

Self-propelled forage harvesters, popularly known as forage choppers, have become the machines most used by contractors and cooperatives in the forage harvesting seasons that take place in livestock farms in northwestern Spain. In Spain, the average number of new units registered in the Official Register of Agricultural Machinery (ROMA) in the last eight years (2015-2022) has been 22 machines per year, of which approximately half (48%) are registered in Galicia region at the northwest of the country. The number of new units registered in the ROMA each year is small compared to the main European markets. For example, more than 500 new units are sold annually in Germany and more than 300 in France. In this type of machinery, the market for second-hand units is much larger than that of new units in Spain. In 2022, out of a total of 98 machines registered in the ROMA, only 18 (18.4%) were new units, with the rest (80 units) changes of ownership or imports of used machines (MAPA, 2023).

In the last five years, newly acquired self-propelled forage harvesters have begun to have sensors that measure forage production and moisture content, so georeferencing this data with the positions calculated by a GNSS receiver located above the cabin, allow yield maps to be obtained. Various sensors for measuring yield in forage harvesters were tested between the late 90s and early 2000s. Finally, the solution adopted by all commercial models of forage choppers was the feedroll displacement system (Digman and Shinners, 2012).

Two types of sensors are used to measure moisture content, capacitive and near-infrared reflectance (NIR) spectroscopy (Long et al., 2016). The latter have a much higher cost and can also determine other qualitative properties of forage (protein, starch, sugar, fiber, ashes ...). Depending on the brand of the forage chopper, this information is stored in the machine's computer system in a different format. In the Spanish market, 59% of the new units sold in the last 8 years are of the Jaguar model of the Claas company. New Holland with 26%, John Deere with 11% and Krone with 4% are the other three manufacturers with new units registered between 2015 and 2022, but with much lower market shares.

The yield maps obtained by the harvesters can be used to optimize seed and fertilizer doses using Variable Rate Application (VRA) techniques. For this, it is necessary to load prescription maps, obtained from the processing of yield maps, into the computers of the tractors that control the spreaders and planters. As the best-selling tractor brands do not match those of forage choppers (in 2022 Claas only had a 2.5% market share in tractors), the problem of file compatibility between tractors and forage choppers needs to be solved to be able to use Precision Agriculture



techniques in forage crops.

Although some initiatives have been commercialized in the market to facilitate the exchange of the most relevant data of agricultural machinery between different commercial brands, these are limited to machine positions, speeds, working status and fuel levels (John Deere, 2021). Documentation files, such as yield data, are not yet compatible between the different digital platforms associated with commercial companies.

On the other hand, in the files with the raw yield data generated by the harvesters, a series of errors are detected due to georeferencing, the sensors used and operational factors (Kharel et al., 2019). Reliable yield maps require cleaning up the raw files to debug errors and to be able to precisely define differentiated management zones in the fields. The commercial software applications most used by contractors that make prescription maps from yield data with forage crops, do not offer clear information on how they perform this error debugging and, therefore, on what data they remove from the raw files obtained by the harvesters.

This paper presents the first results obtained from the analysis of the data of two contractor companies that want to start offering VRA techniques in the corn silage crop from the yield maps documented with the self-propelled forage harvesters. Both companies use the John Deere Operations Center (JDOC) for the documentation of their mechanized operations because they use John Deere tractors in the services provided to the farmers. However, for corn silage harvesting operations, both use self-propelled harvesters from the Claas brand, so they need to translate the harvest data files generated in the chopper into a JDOC-compatible format. This process must be as simple and automated as possible, in order to make it compatible with the commercial activity of these agricultural contractor companies during the forage harvesting seasons.

Materials and Methods

The data used in the present work were collected in two agricultural contractors based in northwestern Spain. The two carry out mechanized operations in livestock areas in which forage harvesting is the most demanded service, for which they have in their fleet three self-propelled forage harvesters each, all models Jaguar 970 and 980 of the Claas brand. The two also use a fleet of John Deere tractors equipped with monitors that document operations in files that are then uploaded to the cloud portal John Deere Operations Center (JDOC). Each of the two contractors harvest around 1000 ha of corn silage annually over many small plots.

To measure the harvested yield and the moisture content of the forage, the sensor that measures the displacement between the feed rollers (which is already mounted as standard on the choppers) was activated and the capacitive sensor for measuring the moisture content in the discharge tube was installed. For collecting harvest data, the forage harvesters were equipped in their cabins with John Deere monitors (4600 and 4640). These JD monitors were connected to the Can-Bus of the Claas harvesters by means of a bridge (Agra-GPS Ltd). This bridge allowed to obtain the yield data files in jdl (John Deere Link) format and to upload then these files to the JDOC portal. In one contractor the data were downloaded from the monitors manually by means of a modem directly to the cloud. For data georeferencing, all harvesters were equipped with John Deere Starfire 6000 and 7000 GNSS receivers connected to the monitors.

For downloading the files with the harvest data from the JDOC of each contractor, the AgFiniti cloud-based platform (Ag Leader Technology) was used. This cloud-based platform connects with the JDOC and automatically downloads the files that each contractor uploads to it. AgFiniti data was automatically synced to SMS Advanced (Spatial Management System – Ag Leader Technology) software and the raw yield data of each field and season were imported from AgFiniti into SMS. With SMS, a first edition of the files was carried out, consisting of correctly ordering the fields by grower, farm, field and year, as well as reviewing their boundaries, separating plots that appeared together in the same file, merging pieces of fields that appeared separated in different files and eliminating the data with a moisture content of less than 46% (Long et al. 2016). After that, the files were exported in Ag Leader Advanced (ALA.txt) text format to be cleaned with the Yield Editor 2.07 software (Sudduth et al., 2012), which has a series of filters and tools to clean the typical errors that appear in the raw yield maps.

Data files with problems in the numerical format of the measurement interval duration column of each recorded data were corrected using Microsoft's Access software. In total, 372 files were processed from 100 different fields belonging to 36 different livestock farms in the provinces of Lugo and Asturias (Northwestern Spain). In all plots, corn silage production data were obtained with a minimum of three harvested seasons between 2018 and 2022, resulting in between 3 and 5 different files per field. Field size ranged from 1.8 to 19.2 ha, with an average of 3.5 ha.

Results and Discussion

Equipment installed in the self-propelled forage harvesters

The sensors and equipment installed in the self-propelled forage harvesters allowed to collect the files with the georeferenced yield data in a satisfactory way. In addition, the Agra-GPS bridge installed between the Claas forage



chopper, and the John Deere 4640 monitor worked correctly. The collected information was correctly uploaded to the JDOC. This solution facilitates the management and subsequent analysis of data by allowing a single platform to be used for all information, regardless of whether the files come from the work carried out with tractors or harvesters. For the technician of the contractor company, it is more comfortable to work with only one software application instead of having to learn the management of two different ones that, although they allow to export their files from one to another, complicate the learning process and their daily use.

Downloading files from the JDOC

Once the contractor grants the appropriate access to establish the connection between its JDOC and the AgFiniti platform, all files that have been uploaded to the JDOC since the year it is set in the configuration was automatically downloaded. From there, each new file that the contractor uploads to the JDOC is automatically and immediately copied to the AgFiniti platform. This process worked satisfactorily and allowed AgFiniti to be used as a gateway to download the files to the SMS software.

The download of the harvest files in the SMS program from AgFiniti was also successful, although with problems to correctly sort the data in the correct grower, farm and field. We believe this was mainly due to shortcomings of the original database created by the contractor in the JDOC. During the season, when working with multiple operators, errors occur such as documenting the information of the same field with different field names, grouping different fields in the same file or using identical field and farm names for different growers, which then make it difficult for the SMS software to correctly identify the files. The methodical organization of the database is a requirement to be scrupulously respected to have the information correctly ordered and to be able to manage it properly for decision making.

This incorrect placement of some files forced a first edition of them in the SMS. The main actions consisted of placing the harvest data in the correct grower and field, separating fields that appeared together in the same file or merging pieces of the same field that appeared in different files. Through these editing works, it was possible to obtain 365 complete data files (datasets) from the automatic download from the JDOC through the synchronization of AgFiniti and SMS. Only 7 files (1.9%) needed to be downloaded manually from the JDOC as they were not found in the SMS. Probably these files were also correctly downloaded by the automatic SMS synchronization procedure with AgFiniti, but due to the problems of placement in an incorrect grower and field, they could not be found.

Another issue concerning the SMS-AgFiniti synchronization was the storage limits of this two-software combination. Ag Leader company informs that with one license of SMS Advanced these limits are 7284 ha and 100 Gb file storage. In our case, none of the two contractors reach these hectare or file storage limits. But we detect a problem with the number of files stored in the AgFiniti platform. As the two contractors work with up to 90 farms per year that have a high number of small fields (average field size usually below 1.5 ha), the different mechanised operations performed every season on each field (planting, fertilising, spraying, harvesting...) generate a high number of files. We detect that when the number of files stored in AgFiniti reached a value around 20.000, the synchronization was affected, and we were unable to download more files from AgFiniti to SMS. To fix this problem we must reduce the number of files stored in AgFiniti and the synchronization started to work again.

Cleaning yield data files

Once all the raw harvest data files were organized in the SMS program, they were cleaned to eliminate errors using the processing and cleaning protocol established by Kharel et al. (2018). To this purpose, all data files were exported in the Ag Leader Advanced (ALA) text file (txt) format. This is one of the only two formats supported by the Yield Editor software, the software used to apply filters to clean the errors that appear in raw data.

In this export process, an issue was detected with the numerical format of the time data of the logging interval at which each yield point was collected. The harvesters worked by recording the yield data with a frequency of 1 Hz (1 data per second), but in the column of the data file in which this attribute was reflected the numerical value was a decimal figure that did not always match the exact 1 second value. In Table 1 we see the first 10 rows of part of a data file exported in csv format where in column seven we appreciate these decimal values of the logging interval in seconds. We suspect that this problem may be caused by the translation from Claas to JD data file format made by the bridge used, but further research is needed to confirm or not this theory.

When this same data file is exported in ALA txt format, the result is showed in Table 2, where in the fourth column we see that the previous decimal values of the logging interval have been converted into whole numbers, which generates many values equal to zero. This means that when the yield per hectare is calculated, if we multiply the flow measured in the feed rollers by a measurement time equal to zero, it results in a yield also equal to zero. For this reason, these files in ALA txt format had to be corrected by replacing the zeros with logging intervals of 1 second to be processed by the Yield Editor software. But the rounding performed with all the values of the duration of the logging interval by the ALA txt format, will cause that the yield data per hectare will not coincide with those calculated with the decimal values. As a result, the yields calculated by the Yield Editor software differ from those calculated both in the JDOC and in the SMS software. This circumstance, in addition to the limitations of only accepting two very specific file formats (ALA txt and John Deere Greenstar txt) and not accepting datasets with the data in metric system units, make the use of Yield Editor as a reference method for file cleaning not the most user-friendly software in our geographical



area. Vega et al. (2019) also found that software like Yield Editor slows down the cleaning process of large map collections and makes the cleaning process automation difficult.

Longitude (°)	Latitude (°)	Field	Product	Obj. Id	Date	Duration (s)
-7.2383179	43.48997345	Monte	Corn silage	13	9/22/2020	1
-7.23833145	43.48996829	Monte	Corn silage	14	9/22/2020	1
-7.23834361	43.48996196	Monte	Corn silage	15	9/22/2020	0.999
-7.23835439	43.48995515	Monte	Corn silage	16	9/22/2020	1.001
-7.23836744	43.48994973	Monte	Corn silage	17	9/22/2020	0.999
-7.23838079	43.48994589	Monte	Corn silage	18	9/22/2020	1.001
-7.23839766	43.48994066	Monte	Corn silage	19	9/22/2020	1.001
-7.23841491	43.48993646	Monte	Corn silage	20	9/22/2020	0.999
-7.23842848	43.48993251	Monte	Corn silage	21	9/22/2020	1
-7.23844234	43.48992849	Monte	Corn silage	22	9/22/2020	1

Table 1. Dataset in csv format

Table 2. Dataset in Ag Leader Advanced txt format

Longitude (°)	Latitude (°)	Flow (lb/s)	GPS Time (s)	Duration (s)
-7.238318	43.489973	67.37	1600786807	0
-7.238331	43.489968	81.34	1600786808	0
-7.238344	43.489962	79.89	1600786809	0
-7.238354	43.489955	43.94	1600786810	1
-7.238367	43.48995	56.31	1600786811	0
-7.238381	43.489946	73.73	1600786812	1
-7.238398	43.489941	76.42	1600786813	1
-7.238415	43.489936	139.54	1600786814	0
-7.238428	43.489933	166.19	1600786815	0
-7.238442	43.489928	112.25	1600786816	1

Despite these limitations detected, the errors in the raw data files have been cleaned using the filters provided by the Yield Editor program. The automatic cleaning offered by version 2.07 of Yield Editor called AYCE (Automated Yield Cleaning Expert), is taken as a reference for the development of alternative procedures that simplify this work for contractors. These tests showed the importance of working with error-free files to determine the different management zones of a field to perform, for example, VRA operations.





Figure 1. Yield maps (dry yield in t/ha) with three management zones created with raw yield data (left), with manual cleaning (middle) and with automatic cleaning (right)

In Figure 1 we can see an example of establishing three management zones (low, medium and high yield potential) in a field of 3.75 ha (2020 harvest season) from raw data and from clean data with manual and automatic cleaning performed with Yield Editor. Contour maps were obtained with SMS Advanced software using Inverse Distance Weighting (IDW) interpolation method. The area classified as low yield potential in the southern area of the field changes to medium potential after the cleaning process. In the north, on the other hand, the area of high yield potential is reduced by eliminating anomalous data of excessive yields. In this example, we have first eliminated data points of corn silage with a moisture content of less than 46% following the protocol of Kharel et al. (2018). Then, in manual cleaning, the data with yields whose values deviate by +/- 2 standard deviations (STD) from the mean have been deleted, thus disappearing anomalous values with very high or very low yields. Finally, an automatic cleaning with AYCE has been carried out by applying the following filters: flow delay, minimum and maximum speeds, minimum and maximum yields, overlaps and +/- 3 STD.

The consequence of this cleaning can be clearly seen in the ranges of the legends of the zones with low and high yield potential of the three maps in Figure 1. Future work will analyse the influence of field size on the number of STDs to be considered to filter yield data, which we assume will increase with increasing plot size. The smaller and more irregular the fields, the more the maneuvers per unit of area increase and, probably, also the points of low yields that appear in headlands and areas near the boundaries. This is consistent with the results obtained by Amiama et al. (2008) which showed that the effective working capacity of self-propelled forage harvesters tends to increase when the area of the field increases.

To simplify the cleaning process, we have developed our own software for Corn Silage Data Cleaning (CSDC) using the MatLab programming platform (The MathWorks Inc). Two filters were applied in the cleaning with CSDC: first all the yield data with a moisture content below 46% was deleted and then only the data comprised in +/- 1 STD around the mean value was selected to build the map with the three management zones. CSDC software works with files in generic txt format and with units in the metric system. In Figure 2 we can see the yield map of the same field and harvesting season than in Figure 2 obtained with the first version of CSDC software using interpolation of data on rectangular grid. Also in Figure 2 we can see the contour map created with SMS Advanced using IDW interpolation with the data cleaned using the same two filters.





Figure 2. Yield map (dry yield in t/ha) with three management zones created with CSDC software (right) and with SMS Advanced (left) with two filters (Moisture < 46% and +/- 1 STD)

Table 3 shows the results of the cleaning process with the raw yield data. The combination of deleting the data with a moisture content below 46% together with manual or automatic cleaning with the Yield Editor (YE) program eliminated 23% (manual) to 29% (automatic) of the data, increasing the average yield and decreasing the average dry matter (DM) content. The cleaning method with CSDC software deleted 25% of the data and showed similar yields and DM content than using YE.

Archivo	Data number	WY t/ha	DM t/ha	DM %	Deleted data	Deleted %
Raw data	3076	31.62	13.22	45.89	0	0%
Moisture filter < 46%	2428	33.95	13.62	40.65	648	21%
YE Manual cleaning	2383	33.88	13.59	40.64	693	23%
YE Automatic cleaning	2198	34.03	13.64	40.51	878	29%
CSDC cleaning	2316	33.85	13.63	40.81	760	25%

Table 3. Cleaning processes performed (WY: wet yield, DM: dry matter)

The effect of the cleaning process on the dispersion of data can be seen on Figure 3, where the measurement technology of self-propelled forage harvesters generates larger deviations in raw data from the mean value. This feature suggests the importance of data cleaning with corn silage yield files for setting of yield potentials (Kharel et al., 2019). In the field of Figures 1, 2 and 3, dry yield values ranged from 0 t/ha up to 347.32 t/ha in the raw data file (mean value of 13.22 t/ha) of year 2020.





Figure 3. Dispersion of corn silage dry yield (t/ha) raw data (left), data after filter 1 applied (moisture < 46 %, middle) and data after filters 1 and 2 applied (moisture < 46% and +/- 1 STD, right). Yield data from the same field and harvesting season than Figures 1 and 2.

Conclusions

The first analyses of yield data collected by self-propelled forage harvesters in northwestern Spain showed the great potential that their correct interpretation can have for the optimization of the application of inputs in the fields. Larger deviations in dry yield from the mean value were found in the raw data files. It is very important to clean the raw data files for delineation of accurate management zones with corn silage. The protocol for cleaning data files must be adapted to the farm typology in the geographical area of this study, where forage production is based on many small size fields. Further research is needed to test the CSDC software with more yield data from different fields and farms.

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Application of Artificial Neural Networks and Genetic Algorithm for the Prediction of Grain Loss from a Medium-sized Combine Harvester

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Abstract

One of the most important factors which is used to evaluate the performance of a combine harvester during harvest is the amount of grain loss. Inappropriate settings and calibration of a combine harvester operational factors could result in significant grain loss during machine operation. The performance factors that contribute to grain loss must be determined to effectively reduce the loss and increase the yield. The measurement and monitoring of grain loss from a combine harvester are very important; however, this method is usually time-consuming, tedious, and labour-intensive. Therefore, the operating settings of a combine harvester must be optimized to achieve the best configuration for minimizing grain loss. The experiment was conducted using a central composite design (CCD) with different speeds, header heights, cleaning fan speeds, and feed rates over 30 runs. An artificial neural network (ANN) model was developed to predict the grain loss and yielded an excellent R² value of 0.9892, MAE of 1.7291, and RMSE of 3.6794. The ANN model was then used to optimize the operating parameters of the combine harvester using a genetic algorithm (GA) to determine the predicted minimum grain loss during harvest. The optimized parameters using the ANN-GA resulted in a minimum grain loss of 17.12 kg/ha. The results showed that optimization using ANN-GA could yield a better prediction accuracy for grain loss during harvest.

Introduction

The operational characteristics of a combine harvester are significant for obtaining useful information regarding the performance of the machine in harvesting rice crops, enhancing grain quality, reducing losses, and lowering production costs (Elsoragaby et al., 2019). Among these parameters, one of the major concerns is the reduction in grain loss, which directly affects farmers' income. However, it was observed that operators of combine harvesters ignore the impacts of these factors, and farmers often overlook the importance of these variables (Mokhtor et al., 2020). According to Al-sammarraie and Alhadithi (2021), inappropriate settings and calibration of a combine harvester performance could result in significant losses during machine operation. The performance factors that contribute to grain loss must be determined to effectively reduce the loss and increase farmers' output. By improving machine performance and field conditions, the utilization of combine harvesters in rice harvesting can effectively reduce post-harvest losses. Therefore, achieving optimal a combine harvester performance is crucial for establishing a sustainable and efficient process to maximize yield and minimize losses during harvesting.

Measurement and monitoring of grain loss from a combine harvester is very important; however, this method was usually time consuming, tedious, and labour-intensive (Paulsen et al., 2014; Al-sammarraie and Alhadithi, 2021; Wang et al., 2021). In contrast, assessment of the performance characteristics of the machine is feasible. On the other hand, rice industries can easily utilize these data to guide machine operators in improving the operational process. Therefore, predicting grain losses from measurable machine factors enables combine harvester to be effectively controlled thus improve subsequent harvesting operation conditions to minimize losses.

Several researchers have applied various methods to determine and model the performance of combine harvesters using statistical multivariate model analyses (Otieno, 2018; Doungpueng et al., 2020; Šotnar et al., 2018). However, among the performance parameters, the prediction of grain losses has historically proven to be complex because of the consistent adjustment of machine factors with linear and non-linear interactions. These issues cannot be resolved using linear multivariate correlations.

In recent years, partial least squares regression and other regression methods have been used to predict grain losses (Huang et al., 2017; Mirzazadeh et al., 2022; Jarolmasjed et al., 2013; Chaab et al., 2020). These methods have certain limitations in examining special problems and are ineffective in many other studies (Nazzal and Tatari, 2013). Therefore, reliable prediction methods can be very useful for determining the optimal operational factors of a combine harvester that can reduce grain loss. This results in the adoption of intelligent prediction models, such as artificial neural networks (Hiregoudar et al., 2011). This method of prediction can help achieve proper and prompt management of combine harvester operational factors by addressing the uncertainty in the process.

An artificial neural network (ANN) is a computational model inspired by the structure and functionality of the



human brain (Abbasi et al., 2011). It consists of interconnected nodes, called neurons, which are organized into layers. The input layer receives the input data, which are then processed through the hidden layers, and finally, the output layer produces the desired prediction or result. The advantage of using Artificial Neural Networks (ANN) is its ability to learn and recognize complicated non-linear functions (Rahimi et al., 2015). ANN models can imitate biological neural networks in the human brain and can be used in various engineering fields (Ramezanpour and Farajpour, 2022). In the context of predicting applications, ANN can be particularly useful for determining the optimal design of a system or process. It can also effectively learn complex relationships and predict variables that are useful for subsequent applications (Pater, 2016). In addition, ANN is also suitable for analysing and predicting grain loss from a combine harvester during field operation because they can achieve high prediction accuracy and outperform empirical correlations when it comes to estimating future grain loss. ANN can be trained using algorithms such as backpropagation (BP) and can be improved using genetic algorithms (GA) to avoid local minima and achieve global convergence quickly and correctly (Abbasi et al., 2011).

A genetic algorithm (GA) is a randomized method based on the survival of the fittest generation by applying special operations like natural phenomena such as selection, genetic operation, and replacement. It involves creating an initial population of randomly generated chromosomes, which represent potential solutions to a problem. The chromosomes evolve over successive generations through genetic operations such as reproduction, crossover, and mutation (Ramezanpour and Farajpour, 2022). The fitness of each chromosome was evaluated, and individuals with higher fitness were selected as parents to produce new individuals for the next generation. This process allows the GA to optimize important parameters of ANN structures, such as the number of hidden layers, number of processing elements, learning rates, and momentum coefficients. By applying GAs to ANN, researchers can develop models that accurately predict important parameters in various industries such as the bakery industry. Thus, the objective of this study was to apply ANN and GA (ANN-GA) to predict grain loss and optimize the operation factors of a combine harvester during harvesting by determining the optimal machine speed, height of the header, cleaning fan speed, during combine harvester operation in order to develop a reliable model for the process of rice harvesting and optimize the operational parameters of the combine harvester. The goal of this study was to reduce losses, which are the most critical factor contributing to higher post-harvest losses in Malaysia. Farmers face significant challenges in reducing these losses due to improper machine adjustment, field conditions, and untimely harvest. Inappropriate settings and calibration of the units within the machine can lead to significant losses, reducing farmers' income. The study could lead to improved post-harvest yield, higher income for farmers, and increased food security in the country.

Materials and Methods

Experimental design

The experiment was designed using a central composite design (CCD) with four numerical factors and one response. The numerical variables included the combine harvester speed (X_1) , height of the header (X_2) , cleaning fan speed levels (X_3) , and feed rate (X_4) , and the response was grain loss (kg/ha). Thirty experiments were conducted for different combinations of machine factors. The design matrix for the prediction of grain loss and optimization of performance factors with experimental values and the corresponding predicted values is presented in Table 1.

Table 1: Experimental design matrix									
				F	Experimental Values	ANN Predicted Values			
Run	\mathbf{X}_1	X_2	X_3	X_4	Grain loss (kg/ha)	Grain loss (kg/ha)			
1	2400	350	4	3	50.72	51.00			
2	2131.5	250	3	4.5	69.57	68.45			
3	1863	350	4	6	43.77	42.41			
4	2400	150	4	6	36.52	35.65			
5	2400	150	2	3	22.03	21.68			
6	1863	150	4	3	26.52	29.05			
7	1863	350	2	3	43.48	43.51			
8	1863	150	2	6	31.88	32.48			
9	2131.5	250	3	4.5	67.10	68.45			
10	2400	350	2	6	24.06	41.83			
11	1863	150	4	6	26.96	27.62			
12	2400	350	2	3	25.80	26.48			
13	2131.5	250	3	4.5	67.83	68.45			
14	1863	150	2	3	33.48	33.83			
15	1863	350	4	3	44.93	44.85			
16	1863	350	2	6	42.90	44.08			
17	2400	350	4	6	49.42	50.92			



18	2131.5	250	3	4.5	68.41	68.45
19	2400	150	2	6	23.48	23.66
20	2400	150	4	3	35.65	34.28
21	1594.5	250	3	4.5	35.36	36.63
22	2131.5	250	3	1.5	69.71	69.50
23	2131.5	250	3	4.5	68.84	68.45
24	2668.5	250	3	4.5	22.03	17.95
25	2131.5	250	3	7.5	70.00	63.52
26	2131.5	250	1	4.5	24.06	23.53
27	2131.5	250	5	4.5	29.86	28.03
28	2131.5	450	3	4.5	35.07	37.15
29	2131.5	50	3	4.5	17.68	18.73
30	2131.5	250	3	4.5	67.39	68.45

Measurement of grain loss

This study was conducted using a medium-sized combine harvester, World Star (WS 7.0 plus), to measure grain loss during rice harvesting. The combine harvester is the latest model deployed for rice harvesting in Malaysia. To determine the grain loss using this type of the combine harvester, a conventional method of measuring grain loss was employed (Srivastava et al., 2013; Amponsah et al., 2017). In this method, a woven sack was placed at the rear of the combine harvester at the start of each swath distance to collect effluents from the machine, as shown in Figure 1. At the end of the swath distance, the combine harvester was stopped and the sack was removed from the rear of the machine. The swath distance used in the study for each run was 30 m, and the width of the combine harvester header was used as the cut width for each experimental run. This operation was repeated according to the number of experiments obtained from the design matrix using different operational factors of the combine harvester. After the experiment was completed, the samples of the materials collected inside the woven sacks were separated to remove grains from non-grain materials. The collected grains were weighed, recorded as losses, and further utilized to determine the amount of grain loss per unit area, as presented in Equation (1).

 $Grain loss = \frac{Average weight of grain collected behind the combine harvester (kg)}{Area covered by the combine harvester (ha)}$

(1)



Figure 1. Experimental run for measuring grain loss.

Artificial neural networks for grain loss prediction

ANN feed-forward (FF) back-propagation (BP) multilayer perceptron (MLP) algorithm was used in this study to provide a nonlinear mapping between the input and output variables of the experimental data obtained from the combine harvester operation. The ANN model had four (4) input layers, ten (10) hidden layers, and one (1) output layer, as shown in Figure 2. The input layer comprises the combine harvester speed (rpm), height of the header (mm), cleaning fan speed levels, and feed rate (kg/s), whereas the output layer is the grain loss (kg/ha).





Fig. 2: structure of the neural network used in the study

The input layer is typically passed through the hidden layer by a set of weights and biases, which are variable parameters for the network. The neurons in the hidden layer sum up the weighted inputs and bias, while the input of the output layer comes from the output produced by the hidden layer, as shown in Figure 3. The number of neurons in the hidden layers determines the performance of the ANN model because a very small number of neurons in the hidden layers may limit the ANN's ability to model the process accurately and the network may not train well, whereas an excessive number of neurons may cause the network to memorize the data rather than train it.



Fig. 3: the architecture of the ANN obtained from the neural network tool.

Back Propagation (BP) is a distributed and parallel model that employs supervised learning for the training dataset to minimize errors between the output and input variables using the expressions given in equations (3) and (4) reported by Ramezanpour and Farajpour, (2022).

$$\text{Error} = \frac{1}{n} \sum_{n=1}^{n} (y_s - \bar{y}_s)^2$$
(3)

Where n is the number of observations in the study, y and \bar{y} are the observed and predicted variables respectively.

$$\bar{\mathbf{y}} = f[\sum_{i=1}^{p} w_i g(\sum_{i=1}^{k} w_{ij} X_i + w_{jo}) + w_o]$$
(4)

where p and k are the number of neurons in the hidden layer and output variables, respectively. X_i is the ith output variable, w_j is the weighted input data into the jth hidden neuron, f is the activation function for the output neurons, w_{ji} is the weight of the direct relationship of the input neuron I to the hidden neuron j, w_{jo} is the bias for the jth node, wo is the bias connected to the neuron output, and g is the activation function for the hidden neuron.

The optimal number of neurons in this study was obtained by trial and error when training the dataset to obtain the best model output, whereas the bias and weights were adjusted using the Levenberg–Marquardt algorithm. The model was developed by splitting the datasets into three groups:72 percent for training, 13 percent for testing, and 13 percent for validation. The ANN model was trained until the error between the experimental and the predicted response values was minimal. The trained network model was validated using a validation dataset (experimental data that were not used for training).



2.4 Analysis of the Developed Grain Loss Models

The performance of the ANN prediction model was determined using the coefficient of determination (R^2) when the intercept was zero, the mean absolute error (MAE), and the root mean square error (RMSE). If $R^2 = 1$, the experimental and predicted values are closely related. The random association between outputs and targets is represented by "0." The MAE is the sum of the absolute difference between the experimental and predicted values divided by the total number of data points, and RMSE is the square root of the sum of the differences between the predicted and experimental values divided by the total number of data points. The model fits better if R^2 is close to one, while MAE and RMSE become smaller. The relationships for the performance of the model are given in Equations (4) – (6):

$$R^{2} = \frac{\sum_{i=1}^{n} (Y_{pi})^{2}}{\sum_{i=1}^{n} (Y_{ei})^{2}}$$
(4)

$$MAE = \frac{\sum_{i=1}^{n} |Y_{pi} - Y_{ei}|}{n}$$
(5)

$$RMSE = \sqrt[2]{\frac{(Y_{pi} - Y_{ei})^2}{n}}$$
(6)

Where n is the number of data points in the experiment, Y_{pi} represents the values predicted by the models, and Yei represents the experimental values.

Genetic algorithm of ANN model

The procedure for optimizing the input variables of the ANN model in this study was based on previous studies (Çelekli et al., 2013; Karimi and Dastranj, 2014; Pater, 2016; Rahimi et al., 2015; Ramezanpour and Farajpour, 2022). The genetic algorithm (GA) started by randomly selecting an initial population of individuals, where each individual represents a possible set of ANN weights. The fitness of each individual was determined by evaluating the ANN outputs and comparing them with the experimental data to calculate the error. Individuals with lower error values were ranked higher in fitness. The best individual was selected for survival using the elitism mechanism. The roulette-wheel selection method was used to choose parents for generating offspring, with individuals of higher fitness having a higher probability of being selected. The crossover operation combines the genetic material from two parent individuals to create new offspring with random exchanges in the genetic material to maintain the diversity in the population. The best individuals from each generation are selected as parents to generate the next generation. After a defined number of cycles, the GA training was completed. A set of weights from the best individual of the last generation was selected as the optimal.

The GA weas employed to optimize four operating factors of a medium-sized combine harvester to minimize grain loss during harvesting operation. The codes for the algorithm were written using MATLAB software. The following GA parameters were applied in this study: 120 population size, 0.01 mutation probability, 0.5 crossover probability, and 100 number of generations. Mukherjee and Chakraborty, (2019) recommend a medium-sized population to avoid local optima without compromising process speed; a higher crossover probability for a better searching period; and a low mutation probability to minimize needless delays in convergence.

Results and Discussion

ANN and GA were used to predict grain loss and optimize a medium-sized combine harvester operation according to four machine operational factors. According to the model results shown in Figure 5, the model showed higher predictive accuracy in training, testing, and validation. The results show training and validation correlations of 0.99817 and 0.99226, respectively. This indicates that the model has a high correlation between the training and validation sets. The higher the correlation, the better the performance of the model.





Figure 5. Neural network training, prediction, and validation result for prediction of the grain losses.

Figure 6 shows a graph of the experimental and ANN-predicted values. The graph illustrates that the ANN model can accurately predict experimental outcomes over a wide range of values. This is because the points on the graph are closely aligned with the line of best fit, indicating a strong correlation between the predicted and actual values. This suggests that the ANN model is robust and can be used to predict the performance of medium-sized combine harvesters under various conditions. The results of the model's performance parameters showed that the R², MAE, and RMSE values for the ANN model's predictions were 0.9892, 1.7291, and 3.6794, respectively. This shows that the model is reliable and can be used to make accurate predictions about grain loss in wheat crops. Therefore, the predictive accuracy of the model is confirmed with a higher coefficient of determination and lower errors.



Figure 6. Plot of ANN predicted values against Experimental values

Based on the results of the optimization process using the ANN-GA model, the model accurately predicted that a combine harvester speed of 2153.5 rpm, header height of 250 mm, level 3 cleaning fan speed, and feed rate of 3 kg/s would result in a minimum grain loss in a medium-sized combine harvester. Therefore, the optimized ANN-GA can predict outputs with credible performance.

Conclusion

A study of a medium-sized combine harvester using ANN and GA found that the ANN model is highly effective in predicting grain loss. It demonstrated that the ANN-GA optimization approach minimized grain loss by 17.12 kg/ha, indicating that it can be employed as an effective tool to improve harvesting performance with minimum losses. The results suggest that ANN-GA optimization can be utilized in future harvesting using other types of combine harvesters



to optimize their operational parameters based on the outcomes of this study.

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The Role and Importance of Digital Transition in Portuguese Agriculture Sector

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Abstract

In Portugal, agriculture has proven to be a sector that ensures national sovereignty, as it has demonstrated its importance and resilience during times of crisis. One of the key factors contributing to the success of this activity has been the investment in new technological solutions that enhance productivity while promoting a more efficient use of production factors and natural resources. The current direction towards a healthier and more sustainable European food system, as part of the European Green Deal, biodiversity strategies, and the 'Farm to Fork' approach. However, meeting this challenge is only achievable through a solid foundation of knowledge, research, and skills, as outlined in the targets of the Innovation Agenda for Agriculture 2030, aligned with the Digital Transition Action Plan. This plan focuses on digital empowerment of individuals, digital transformation of companies, and digitization of the public sector.

The agricultural sector faces significant challenges in the digital transformation process, which can only be overcome through collaborative efforts that identify threats and opportunities within the sector. It is essential to support capacity building, entrepreneurship, and the adoption of new practices and processes on the ground to meet the proposed goals.

This paper provides examples of the implementation of digitalization in agricultural activities and identify threats and opportunities, as well as strengths and weaknesses of the current course of digital transition processes in the sector.

Keywords: precision farming, artificial intelligence, blockchain, competitiveness

Introduction

The farming tends to manage every factor of production in varying measures, treating small areas inside the lot as separate surfaces. By doing so, the economic margin of crops can be increased, reducing the input of the technical means. Furthermore, the environmental impact and the quantity of the production factors used, such as pesticides and fertilizers, are significantly reduced (D'Antonio et al., 2015). There are many definitions for digital transition. In a simple way it can be defined as the integration of digital technology into all areas of a business, fundamentally changing how it operates and deliver value to customers, promoting efficiency, sustainability, and competitiveness. Through digitalization, stakeholders can benefit from a more streamlined value chain, with closer collaboration and improved communication between producers, processors, distributors, and retailers. From artificial intelligence and robotics to the Internet of Things and 5G, the latest technologies can offer invaluable support for farmers and agribusinesses (EC, 2023; Zhang &Fan, 2023).

The quantity and quality of digital technologies available to farmers have advanced considerably since the 1990s – when use of computer- and internet-based technologies for management of crop and livestock operations began to develop. Many factors – including increases in computational power, faster internet and greater connectivity, declining technology costs, and the rise of big data paired with advanced analytics – are driving the current wave of digitalization (Kenney et al., 2020). Increased concerns about global food security have accelerated the need for next-generation industrial farms and intensive production methods in agriculture. At the forefront of this modern agricultural era, digital technologies offered by Industry 4.0 initiative are suggesting a myriad of creative solutions.

Three layers of actors are seen as being at the center of the digitalization of agriculture: farmers, technology providers, and "intermediaries" (McFadden et al., 2022) such are university extension and government advisory agents, science communicators and farm advisors, experts in digital technologies and a key instrument in modern farm entrepreneurial management when responsive to farmers' needs.

Although its importance the evidence from nationally representative surveys is not yet clear in many countries, exception made too high to very-high income countries with relatively large agricultural sectors and advanced infrastructure for carrying out complex surveying tasks (McFadden et al., 2022).

For Portugal the importance of digitization is as related to the importance of agricultural activity. In the 2019 Agricultural Census, the Used Agricultural Area increased by 8.1% compared to 2009, now occupying 3.9 million hectares (43% of the territorial area). This is evident in the weight that the agri-food sector, including the agricultural sector, holds in the national economy. Portugal ranks as the 41st largest global exporter in the agri-food industry and, in 2018, it accounted for 11.3% of the country's total exports. Although Mediterranean climate and natural edaphic


conditions of the Portuguese territory are far to be considered to best to agriculture activity (Carvalho &Bash, 2008). Apart from the Alentejo region, most of the territory have some of the lowest average farm size in Europe (< 10 hectares per exploration) and represents 2/3 of the average economic size, so digitization must be synonymous of competitiveness.

Under this panorama digitization and precision agriculture technologies are often associated with mechanization, particularly with the use of georeferenced data (from satellites, drones, sensors, etc.) that allow targeted and zone-specific management and interventions (such as the application of fertilizers or pesticides, irrigation, seeding/planting, etc.). Although it remains a marginal reality, with only 0.3% of farms reporting the availability of such data and 0.2% performing differentiated cultural operations based on georeferenced data analysis, the areas and livestock associated with these farms (and potentially benefiting from these technologies) are more substantial: 4.2% of the agricultural land and 1.6% of the livestock belong to farms with access to this data (with 2.3% and 0.8%, respectively, stating its use for defining cultural operations) (INE, 2021).

Portuguese case studies

There are many examples of the digital transition in the Portuguese Agriculture sector provided by the adoption of precision agriculture technologies. Evidence shows examples related to soil and water monitoring, crop monitoring, and livestock monitoring mainly that related to extensive livestock systems, and farm machinery management.

Soil and water monitoring is based in the adoption of geoelectric soil surveys to manage smart soil sampling methodologies that properly define different soil management zones. On the contrary of the classic soil sampling methodology that takes time and labour, geoelectric surveys using contact or induction sensors allow a fast and objective picture of the arable and sub arable surfaces that easily can be sampled and correlated to different physic, chemical or soil biological characteristics. This approach helps the farmer to mainly delineate and are support decision to act in compaction areas, fertilization zones and irrigation rates (Figure 1). In question to irrigation rates, soil apparent electrical conductivity is positively correlated with soil moisture and texture (Friedman, 2005) allowing the adequate location of soil moisture sensors and so correcting irrigation rates. The digitization of the process become real by the information at distance of the need of irrigation in a certain moment.



Figure 1. Geoelectric soil map where different classes of soil apparent electrical conductivity being related to soil texture define the proper location of soil moisture sensors (https://mechsmartforages.ipportalegre.pt/)

Crop monitoring is based on the objective of crop spatial uniformity or segmented yield. Crop spatial uniformity is adopted by commodities farmers, namely those that produce cereals and fodder crops. The importance of digitization is based on the capacity of monitor the crop mainly by remote sensors so that it can be possible to correct vegetative growth differences observed along the crop cycle. Different vegetative indices can be used. NDVI - Normalized Difference Vegetation Index and NDWI - Normalized Difference Water Index are probably those with more generic application in most crops and platforms (Figure 2).





Figure 2. Sequence of a fodder crop evaluation using NDVI and NDWI by remote sensing in a plot of 30 ha (https://mechsmartforages.ipportalegre.pt/)

The segmented approach is used in the gross valued that can be added to special crops by the differences found in crop parameters and the different products that can be obtained. One example is precision viticulture where the maturity of grapes is usually based on three parameters: sugar content, titratable acidity, and pH. All these parameters change over time, and the rate at which they change depends on conditions during the growing season, and crop monitorization defines different zones to different batches and so becoming possible different wine blends.

Digitization in livestock is increasing among ruminant extensive systems due to the adoption of GNSS collars in cattle that provide the opportunity to build geofences and obtain data from location, transects and daily activity or even body parameters such is thermal comfort. Once again, the digitization is provided by the information at the status of the animals and or alarms detected to faster decide in an emergence. The combination with drones, depending on the type of sensor RGB or multispectral is also adopted to faster find lost animals, look for their behaviour or simply evaluate the biomass under pasture.



Figure 3. Location and status of a livestock group using GNSS devices (https://isomapforragem.ipportalegre.pt/)

Farm machinery management is seen as the decision-making process by farmers or machine service providers, primarily concerning resource allocation, scheduling, routing, and vehicle and material monitoring. This management also involves overseeing the use and maintenance of machinery and associated administrative functions, including task coordination and information dissemination (Sorensen & Bochtis, 2009). The adoption of telemetry systems is becoming more frequently among the Portuguese farmers due to new available technological platforms available form tractors brands and outsourcing services. Once again, the aim is to provide in real time information of what is happening in a certain moment so it can be accepted or correct it to optimize machinery yield (Figure 4).





Figure 4. Operating principle of a telematics platform used in the management of agricultural machinery fleet (Silva, 2021).

Opportunities and constraints

The digitisation and new technologies will help ensure the modernisation of the Common Agricultural Policy (CAP), which is of crucial importance in enhancing the long-term competitiveness, sustainability, and resilience of the primary sector of the European Union. It is noteworthy that the increased use of digital technologies will have a positive impact on the quality of life in rural areas and is expected to attract a younger generation to engage in agricultural and rural entrepreneurship (GPP, 2019). Strategies are implemented in such a way that information is never isolated but always interconnected with various sources of data (e.g., public data, operational business data, meteorological data, machine data, sensor data). The aim is to enhance resource efficiency to achieve sustainable food production, known as 'sustainable intensification,' which can be based on further development of Precision Agriculture for Smart Farming (Balafoutis et al., 2017). In any case of the present examples data can be send at distance, alarms may be created, and in same platforms decision support is possible to give to the farmer so that he can implement a fast and accuracy solution for what is detected in the moment. Platforms are open or contracting depending on the quantity of options available. Digital transition with the automation processes, traceability and blockchain become possible a more transparent and proximity between farmers and consumers.

On the other hand, predictive models must be improved in many cases and constraints such the farm scale capacity to the adoption of digital tools, tradition vs acceptance, the average age of the farmer and low digital skills, price and data interoperability, rural broadband, cyber security, and data ownership must be taking in account to implement digitization processes in a more fast and efficient way.

Conclusions

Digital transition in the agriculture sector in Portugal is in practice by different crop and livestock farmers upon the difficulties that still must be solved in the shorter time as possible. Digitization is an important competitiveness factor to the Agricultural Portuguese due to natural and physical constraints and the need of a more transparent and proximity from the farmer to the consumer, developing new skills among the young generations in the rural areas and so going through the present CAP aims.

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Image analysis of Hedge Almond Orchard to monitor flowering – an account of four years

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Abstract

The analysis of almond trees in hedgerows in a hedge almond orchard from four years ago in Soleta cultivar, planted in September 2014, in Herdade da Torre das Figueiras – Monforte - Portugal (39° 04' N; 07° 29' W), was continued with a trial to evaluate different pruning treatments. The flowering intensity was evaluated as a function of four pruning treatments, which influenced the number and length of branches. The flowering was evaluated in four years (2019 to 2022), with image analysis. For each tree, a vertical photograph of the crown was taken perpendicularly to the tree line, using a contrasting background. A total of 360 trees were surveyed each year. The flowering area was quantified per tree using image analysis software. There were differences between the years in the level of flowering, which revealed a clear alternation. The flowering level of 2019 and 2021 had the highest values with a drop in the next years (2020 and 2022). Similar behavior was registered at the level of almond production. This shows that flowering monitoring can be a good indicator of the expected almond production each year. In manual pruning treatment, the shoots extremely developed lengthwise, were removed, therefore the trees registered less flower density. This work shows the advantage of image analysis to evaluate the flowering density and variability between years for hedge almond orchards.

Keywords: Pruning, Soleta cultivar, Variance analysis, Portugal, Image analysis

Introduction

With the almond plantation expanding, the new orchards are designed under more intensive systems (Mirás-Avalos, et al., 2023). In the Mediterranean basin, after the expansion of the super high density (SHD) or hedge olive orchards, some hedge almond orchards have also been planted. This training system could reduce harvesting costs due to the use of the same machinery as in vineyards and olive orchards (Torrents, 2015), but require the adequacy of the canopy dimensions to the over-the-row harvesting machine. SHD must have factors such as spacing, tree architecture, and a proper row orientation to ensure a more efficient sun exposure, yield, and harvesting, being the photosynthetic active radiation interception a key role in flower bud differentiation (Maldera, et al., 2023)

To control canopy dimension, Torrents (2015) suggested the use of mechanical pruning with topping and hedging since the first year of plantation. Manual pruning should only be used to eliminate dried shoots or vigorous branches (Torrents, 2015). In addition, Torres-Sánchez, et al. (2018) said that an appropriate pruning would be essential to avoid problems related to machinery during harvesting and to the access to all fruits. In almond trees, the spurs, that is the very short proleptic shoots, are primordial to fruiting in mature trees (Kester et al., 1996 cit. in Valdebenito et al., 2017). Thus, it is of the utmost importance to study the management practices' effects, in particular pruning, on flowering and fruiting. To attain a regular fruiting yield, it is necessary a high number of flowers annually (Kester, 1959 cit. in Casanova et al., 2019), since almond tree yield, according to Tombesi et al. (2016) is primarily related to the flower number and less to the fruit set.

The image analysis has been used to study winter pruning systems in the vineyard (McFarlane et al., 1997) and for the quantitative monitoring of pesticides application with hydrosensitive paper (Panneton, 2002; Marques Da Silva et al., 2017). However, no references were found to the use of image analysis in the quantification of almond tree flowering as well as on the effect of pruning on flowering.

The goals of this study are twofold; the quantification of the almond tree flowering area and their interannual variability and the effect of pruning on flowering.

Materials and Methods

Orchard

The trial was established in a commercial hedge almond orchard planted in September 2014 at Herdade da Torre das Figueiras-Monforte-Portalegre-Portugal (39° 04' N and 07° 29'W). The orchard was ridge planting in a 5m x 1.5m



spacing with an east-west orientation. The cultivars 'Soleta', 'Belona', 'Guara', and 'Lauranne' grafted on RootPac 20 or Densipac® (www.rootpac.com) rootstock (Prunus besseyi x Prunus cerasifera) were used. Plants with 6 months of nursery from Agromillora Catallana were used. Trees were tutored to ensure central axis formation, assuring that the height of the beginning of the crown was at least 0.5 m from the ground.

Pruning treatments

The trial was established in the orchard plot of the 'Soleta' cultivar. A randomized complete block design, with four pruning treatments and three replications (in a total of 12 plots) and 95 almond trees in each plot. The pruning treatments were (Figure 1): T0 – farmer pruning, with mechanical topping and hedging at the beginning of June every year from 2018 to 2022, winter manual pruning in 2018 and manual pruning complement in June 2019 and after harvest in 2020; T1 – winter manual pruning every year from 2018 to 2022; T2 – post-harvest mechanical pruning (topping and hedging) in September 2018 to 2021, winter manual pruning in 2018, 2020 and 2022; T3 – summer mechanical pruning (topping and hedging) at the end of July in 2018 to 2022 and winter manual pruning in 2018, 2020 and 2022.

Treatament	Pruning season	2018 (Year 4)	2019 (Year 5)	2020 (Year 6)	2021 (Year 7)	2022 (Year 8)	
	Winter	Manual pruning					
TO	Summer (June)	Topping + Hedging	Topping + Hedging	Topping + Hedging	Topping + Hedging	Topping + Hedging	
			Manual complement				
	Post harvest			Manual complement			
T1	Winter	Manual pruning	Manual pruning	Manual pruning	Manual P.	Manual P.	
	Winter	Manual pruning		Manual pruning		Manual P.	
T2	Summer						
	Post harvest	Topping +	Topping +	Topping +	Topping +		
		Hedging	Hedging	Hedging	Hedging		
	Winter	Manual pruning		Manual pruning		Manual P.	
Т3	Summer (July)	Topping + Hedging	Topping + Hedging	Topping + Hedging	Topping + Hedging	Topping + Hedging	
	Post harvest						

Figure 8. Schematic representation of pruning interventions between 2018-2022

Methodology

For the evaluation of flowering in each pruning treatment, three sub-plots of 10 trees were randomly selected in each pruning row. The flowering surveys were done from 2019 to 2022 when the orchard was in full bloom (February). A photograph was taken of each sampled tree (a total of 360 trees). A photographic camera Cannon model EOS 1100D was used. The photographs were taken with the maximum aperture (position 4), without flash, with a focal distance of 25 mm, with a resolution of 72 ppp. Each photograph was taken perpendicularly to the tree line in the south direction at a distance to the tree of 3.5 m, at the height of the eyes of the operator (about 1.6 m), without a tripod. To reduce the effect of the background (which included other almond trees and its flowering) a black canvas of 1.65 x 1.65m fixed in two wooden sticks of 2m long was placed behind each tree, in days with uniform light.

The images were processed in two steps. First, the images were cut by the limit of the black canvas. The second step



was the identification of the flowers as a function of a minimum and maximum threshold of the color histogram. The area of flowering was calculated as a percentage of the number of pixels with flowers in relation to the total number of pixels of the original image after cutting. The evaluation was done in pixels to reduce the bias derived from the pixel conversion in metric units. The image analysis was done in the Snipping Tool of Windows and SigmaScan Pro 5.0.

To quantify the tree yield, each row was harvested, weighing the mass of almonds caught by the harvester and monitoring the losses of almonds to the ground by sampling (Dias et al, 2021).

Data normality and homogeneity of variance were evaluated with the Shapiro-Wilk normality test and Levene test. As the assumptions for normal distribution and homogeneity of variance were not met, the comparison of flowering between pruning treatment and year was carried out with non-parametric statistical tests of Kruskall-Wallis and of Bonferroni (for multiple comparisons). The statistical analysis was done in IBM SPSS Statistics, version 24.0 (IBM Corp., 2019) with a level of significance of 0.5.

Results and Discussion

The results of the processing images are shown in Figure 2. The image processing was able to capture the flower level. In Figure 3 are presented the flowering level and the yield of each year in this study. The flowering level and the yield had similar behavior, with significant differences (p<0.05) between years in both parameters, though the results did not show a direct correlation between these two parameters. Although it was not possible to establish a correlation between the level of flowering and the production of almonds, higher productions were recorded in years with more flowering (Figure 3). Results showed significant differences between the year 2019 with 2020 and 2022 and between 2020 and 2021 in the production of almonds per tree.

At flower density level the distribution of every year is different except between 2020 and 2022. The higher number of flowers in the first year (2019) led to a decrease of flower buds in the second one, and the same behavior occurred from 2021 to 2022. For almond trees, as in perennial species, several authors (Reidel et al., 2004 cit. in Valdebenito et al., 2017; Tombesi et al., 2011) referred that flowering level is dependent on the previous year flowering and that its interannual variability is large.







Figure 2. Photographs of the flowering of a tree (A) and the resulting area after image processing (B).



Figure 3. Flowering density per year and production

The crown dimension and the flower level are related to the number of flower buds, which are linked to the photoassimilates the tree can stored in the previous years. If the tree gives priority to flowering, there will be less bud formation. Reidel et al. (2004 cit. in Valdebenito et al., 2017) referred that the probability of death of the spurs that bear fruits when compared with those that do not was 80%, so, the increase of flowers is likely to increase fruit production. Also, flowering and fruiting need high amounts of carbohydrates, which might result in the depletion of the trees' reserves. This will result in the reduction of the number of flowering buds and flowers and/or the death of the spurs (Tombesi et al., 2011).

Annual pruning is essential in almond hedge orchards to maintain the crown dimension compatible with the harvesting equipment but can reduce the flowering level. The results of this study showed a trend toward the fluctuation of high and low flowering levels (Dias et al., 2021). The winter manual pruning interventions should be carried out in the years where the flower potential intensity prediction is higher, as the tree buds will produce less spurs than flowers and with this effect the crown dimensions will be controlled efficiently.

Figure 4 shows the level of flowering recorded each year for each treatment. There were significant differences (p<0.05) between treatments in all years. T0 in 2019 had the highest level of flowering, significantly different from all treatments except T3. In 2020, T2 registered the highest value, and T1 the lowest value, differing significantly from the other treatments. The other treatments did not differ from each other. In 2021, T0 recorded the highest percentage of flowers, with no significant differences between T1 and T3 and between T3 and T2. In 2022, there were significant differences between all treatments except T2 and T0, with the highest percentage of flowers being obtained in T3.

The T1 treatment had significant differences every year for all the other treatments, except for T3 in 2021. The analysis per year and per pruning treatment revealed that T1 had the lowest flowering intensity and variability in



general, and specially in 2022 (Figure 4). This result can be explained by the manual annual pruning in 2018, which resulted in larger reductions of the crown dimension than the other pruning treatments and thus on the flowering. The behavior of T2 and T3 alternated between the years, without showing a consistent trend. There were significant differences between the other treatments over the surveyed years.





Figure 5 shows examples of photos after processing for each of the treatments in a year with a high level of flowering, while figure 6 shows a low level of flowering. As it can be seen in Figure 5 and Figure 6 the level of flower percentage per tree decreased from 2019 to 2020. There was no clear trend between treatments, whereas a clear trend was observed between. However, the results of T1 always recorded the lowest level of flowering in all years. This may be associated with the type of pruning. In this treatment, pruning consisted of selective cuttings that reduced the density of branches on the lateral faces of the crown, while in the other treatments, uniform cuts were carried out mechanically on the lateral faces of the crown promote greater branching. The cuts made mechanically in the faces of the hedge (T0, T2, and T3) can contribute to higher density of branches with short length and higher density of flower buds per crown (Dias et al., 2021).

In the years with lower flower percentage, was also performed a manual pruning at winter, and the number of branches was reduced. However, the buds of the trees did not evolve into flowers at the same flowering level as the year before, resulting in a year where the vegetative growth was increased. Overall, T1 resulted, for every year and most of the evaluated trees, in a lower flowering level intensity. When pruners remove from the tree the longer shoots developed lengthwise, they are also reducing the density of the crown. This could explain the lower flower level found in T1as seen by Dias et al. (2021).





Figure 5. Treatments in a high flowering level year (2019)



Figure 6. Treatments in a low flowering level year (2020)

Figure 7 shows the productive level obtained in each year by the different treatments, with no significant differences between the treatments in any of the years (p>0.05). However, it should be noted that the T1 treatment recorded the lowest productions, in accordance with what had occurred in terms of flowering density. These results show that to correlate the flowering level with almond production, it would be necessary to ensure the individual production of each tree in a similar way to what happened in terms of flowering records.





Figure 7. Almond production per tree (Kg)

Conclusions

Image analysis to monitor and study flower levels is an inexpensive technique, which revealed annual alternation between high and low density through the years. Hand counts for flower density are difficult to obtain in a single day for large numbers of almond trees, due to high number of flowers (Underwood, et al. (2016) cit. in (López-Granados, et al., 2019). So, this method of 2D observation is an easy and straightforward method to evaluate the flower density, and also to denote significant differences between treatments. It was observed a trend toward the reduction of flowering intensity from 2019 to 2020, and from 2021 to 2022, where this behavior was observed too with manual counting by Casanova, et al. (2019). The differences in production followed the behavior of each year relatively to flower density, but, did not had significant differences between treatments as also reported by Thorp, et al. (2021). Therefore, flower density does not seem to be a direct predictor to estimate fruit yield. This shows a higher correlation to crown volume than to flower density when 3D models are used in the assessment, according to Underwood, et al. (2016). The 3D models can be an alternative for the flowering assessment, due to the higher correlation to crown volume than to flower density (Underwood, et al, 2016). However, the methodology for 3D models is more complex than that developed at 2D in this study. There were significant differences between treatments. The manual pruning showed a lower flower level. This was the treatment where the shoots with long lengthwise were removed, so there were few branches with the production ability, whereas, the other treatments pruned mechanical originated a higher density of branches as shorter branches, which resulted in higher flowering level as reported by Negrón, et al. (2015).

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Effects on ammonia emission of dairy stables by implementing an hourly Dutch measurement and calculation method

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Abstract

The ammonia emission by dairy stables in the Netherlands is currently done on a basis of 24-hour averages. The emission calculation is based on the CO_2 mass balance and wet-chemical ammonia measurements, as described in WUR report 1032 [1]. EnviVice is investigating the effects on the ammonia emission if the 24-hour average is replaced by hourly averages. This hourly method is already proposed in the VERA protocol [2] and the CIGR calculation rules [3]. To be able to investigate the effects of the hourly method, EnviVice has performed multiple parallel measurements over the past 3 years. Implementing both the 24-hour method and the hourly method at the same time. During these measurements, EnviVice used an ammonia analyzer based on photoacoustic to determine the hourly averages. This analyzer was also compared to the wet chemical method (Standard Reference Method) in an orthogonal regression test based on WUR report 1285 [4]. Furthermore, EnviVice used a grid point approach to ensure a volume proportional sample.

The latest results show that emission values can be up to 39% higher if the hourly method is used instead of the 24hour average. The key figure for ammonia emission for dairy cows was increased from 11 to 13 kilograms NH₃ per cow per year in 2014 (see WUR report 744 [5]). This increase was implemented on emission calculations of 24-hour averages. The hourly method estimates that this increase is insufficient and that the key figure should be raised further.

Introduction

EnviVice has performed ammonia emission measurements on three naturally ventilated dairy stables, both with a rubber low-emission floor. The measurement setup is based on the standard measurement setup for dairy stables in the Netherlands, see WUR 1032 [ref]. The standard measurement technique for ammonia in the Netherlands is the wetchemical method. Due to the small ammonia concentration in dairy stables, 0.2 to 5 ppm [4], a relatively long measurement time is needed. Consequently, this means that the ammonia concentration is determined by one duplicate 24-hour measurement. The GIGR calculation rules [3] and VERA test protocol for housing [2] also describe an hourly method, in which 24 hourly ammonia concentration are measured and averaged. To investigate the difference between the standard and hourly method EnviVice executed continuous ammonia measurements using a photoacoustic laser manufactured by Synspec (LSE-monitor) parallel to the standard measurements. Furthermore, EnviVice investigated the correlation and trueness between the wet-chemical and photoacoustic laser method, to determine if the photoacoustic laser is suitable for ammonia measurements in stables. In total 152 measurements are performed, 6 at each of the three dairy stables. The 6 measurements are equally spaced in time over the year 2022/2023, to cohere to the standard measurement protocol [1].

The motivation for EnviVice to investigate the difference between the 24-hour and hourly method is the volumetric flow rate calculation, based on the CO2 mass balance. The volumetric flow rate is inversely proportional to the difference of the CO2 concentration inside the stable and outside the stable. In Figure 1, the volumetric flow rate is plotted against the difference in CO2 concentrations using the agricultural parameters of stable 1, session 6. The figure clearly shows the steep increase in volumetric flow rate for low CO2 differences. This low concentration behavior of the volumetric flow rate induces errors when averaging over 24 hours. For example, if during one measurement of 24 hours, 2 subsequent hours provide CO2 differences of 80 and 150 ppm. If the CO2 difference is first averaged before the volumetric flow rate is calculated, the calculation would return 586158 m3/h 3. However, if the volumetric flow rate is calculated to the adveraged afterwards, the calculation would return 645995 m3/h, an increase of around 10%. Subsequent hours are chosen as an example to suppress the effects of animal activity, see materials and methods. The situation sketched above can occur on windy days, where strong and weak winds alternate. EnviVice also believes this phenomenon to influence the emission itself. Emission is the product of volumetric flow rate and ammonia concentration of stables 1 and 2 is plotted against the difference in CO2.

 $^{^{2}}$ 15 measurements are performed as one of the stables is still under investigation and only has been measured 3 times.

³ Still using the agricultural parameters of stable 1, session 6





Figure 9: The volumetric flow rate against the difference in CO_2 (outside - inside) using the agricultural parameters from stable 1, session 6.



Figure 10: Measured Ammonia concentration (LSE-monitor) vs. Difference in CO₂ concentration (inside -outside). The points included are from stables 1 and 2.



Figure 2 shows that the ammonia concentration and difference in CO_2 share a linear relationship. This has the following effect on the emission factor calculation. The volumetric flow rate is equal to,

$$Q_{stable} = \frac{H * c(h)}{\Delta C_{CO_2}}$$
 (1)

With H, the total heat production corrected for by temperature, see VERA calculations [2], c(h) a correction factor that depends on agricultural parameters and may depend on the hour of the day (only for hourly calculation) and Δ CCO2 the difference between the inside and outside CO2 concentration. Figure 2 provides us with a relation between the ammonia concentration and CO2 difference,

$$C_{NH_3} = a * \Delta C_{CO_2} + b \quad (2)$$

With a and b the slope and intersect obtained from figure 2 respectively. The emission factor can be calculated as follows,

$$E_{NH_3} = Q_{stable} * C_{NH_3} = H * c(h) * a + \frac{H * c(h) * b}{\Delta C_{CO_2}}$$
(3)

This shows that the emission factor is still inversely proportional to $\Delta CCO2$. It must be said that if the intersect were equal to 0 (b=0), the proportionality would not exist. This is however not the case as can be seen from figure 2. Furthermore, it must be said that equation (2) is found by analysis of data and not derived from theory. It is therefore an estimation and further research should be conducted to find evidence for the relation.

The inverse proportionality of the emission on the difference in CO2 gives rise to an error when averaging. It is better to calculate the emission on hourly basis and then average than to average the CO2 concentration and determine the emission one time. Again, suppose two subsequent hourly readings give CO2 differences of 80 and 150 ppm. Using equation (2), it is possible to estimate the ammonia concentration, which would be 0,5761 and 0,8491 for 80 and 150 ppm of difference respectively. Averaging both the ammonia concentration and CO2 difference and calculating the emission gives 14,3 kg/animal/year. Calculating the emission for the 2 hours separately and then averaging results in 14,8 kg/animal/year.4 The error produced also becomes larger the further away the two readings are and the lower the value of the readings is, due to the inversely proportional nature of the emission curve. EnviVice performed measurements to try and uncover this effect in real stable measurements.

Materials and Methods

The measurement setup in both stables agrees with the setup described in the standard measurement protocol, WUR 1032 [1]. This means that the sample is collected via a measurement duct in the top of the stable. This duct is placed at least 3 meters above the ammonia producing floor and contains one critical opening (orifice) with an upstream filter per 10 meters. The last requirement ensures that a volume representative sample is taken. The measurement duct is connected to the flasks of the wet-chemical method, the photoacoustic laser (LSE-monitor) and the continuous CO2-monitor (Siemens Ultramat23). Additionally, the CO2 concentration outside is measured by the second channel of Ultramat23. Other parameters that are monitored are the inside (stable) and outside temperature as well as the inside and outside relative air humidity. The parameters are needed to convert the ammonia emission to a standardized ammonia emission factor, which is described in the standard measurement protocol [1]. The outside CO2 concentration is needed to determine the volumetric flow rate via the CO2 mass balance method, which is explained in the GIGR calculation rules [3]. It is important that this outside measurement point is chosen upwind of the stable. This is done to prevent raised CO2-concentration from the stable to interfere with the measurement. An overview of the performed measurements with their specific instruments is given in Table 1.

The analysis and calculation of the 24-hour emission is described in WUR report 1032 and is not discussed in detail. The hourly method does require some extra steps with respect to the 24-hour method. As stated in the introduction EnviVice will check the correlation and trueness between the wet-chemical method and the LSE-monitor. This is done

⁴ All these calculation are again performed using the agricultural parameters of stable 1



in the following way. Both the LSE and the wet-chemical flasks are connected to the same measurement duct, therefore both measurement instruments receive the same sample over 24 hours. The LSE-monitor provides a continuous sample (value every 60 seconds) and is therefore averaged over 24 hours. The 24-hour averages of the wet-chemical and photoacoustic method of the 12 measurements are compared to each other in a orthogonal linear regression test. This test is also described in WUR report 1285 [4]. This test provides the linear correlation between two methods. The null hypothesis in this test is that the regression line should have slope 1, intersect 0 and a correlation coefficient of 1, which would mean the methods are identical. For the calculation rules of orthogonal linear regression, refer to WUR report 1285 [4] and NEN-EN 14793.

Table 4: Measured Components/Parameters with their respective sampling and measurement methods. Also included is the norm which describes the measurement of the component/parameter.

Component/Parameter	Sampling Method	Measurement Method	norm
NH ₃	Collection via measurement	24-hour method: absorption in	24-hour method:
	duct in stable	0.05 M H ₂ SO ₄	24-NEN 2826 /
		Hourly method: photoacoustic	NEN 8014
		laser LSE monitor by Synspec,	Hourly method: -
		range: $0 - 8$ ppm NH ₃ , detection	
		limit 0.02 ppm NH_3	
CO ₂ inside	collection via measurement	Siemens Ultramat23	NEN-ISO 12039
	duct in stable.	Channel 1: range 0-5000 ppm CO ₂	
CO ₂ outside	24-hour method: collection via	Siemens Ultramat23	NEN-ISO 12039
	measurement point placed upwind of the stable	Channel 2: range 0-5000 ppm CO ₂	
Temperature (inside	Measurement point in stable	thermocouple	ISO 8756
and outside)			
Relative air humidity	Measurement point near CO ₂	Dewpoint sensor	-
(inside and outside)	outside collection point		
Atmospheric pressure		barometer	
(ambient)			NEN EN 13284-1

Another point of attention for the hourly method is the correction for relative animal activity, which influences the CO2 production calculation in the GIGR calculation rules. Since the CO2 production by animals linearly influences the calculated volumetric flow rate and thus ammonia emission, it is important to carry out this correction. The correct way to calculate the volumetric flow rate considering the relative animal activity can be found in the GIGR calculation rules 4th edition [3]. The rest of the emission calculation is nearly identical to the 24-method. The only difference being that this time 24 individual hourly averages are calculated, which are than averaged to obtain the final ammonia emission



factor of the stable.

Results

First the results of the correlation test between the wet-chemical method and LSE-monitor are discussed. The graph belonging to the orthogonal linear regression test is shown in figure 3. The resulting line had a slope of 1.25, an intersect of -0.08 and a correlation coefficient (R2) of 0.98. From the correlation coefficient and graph it can be determined that a strong correlation between the concentrations of the LSE-monitor and wet-chemical method exists. The equation relating the 24-hour concentrations of the wet-chemical and LSE-monitor is,

 $C_{LSE} = 1.25 C_{WC} - 0.08$

With CLSE the concentration measured by the LSE-monitor and CWC the concentration measured by the wetchemical method. This relation will be used to convert LSE-monitor concentration to wet-chemical concentrations, the reason for this conversion is presented in the discussion.



Figure 11: Orthogonal Linear Regression test using the parallel 24-hour ammonia concentrations of the LSE-monitor and wetchemical method. The red line shows the orthogonal linear regression line, the solid black line shows the null hypothesis (y=x). The dashed black lines show a deviation of 20% from y=x, or a 0.2 deviation below a concentration of 1 mg/m³, 20°C.

The results for the 24-hour and hourly method emissions are presented per stable in table 2 below. Not all sessions for stable 1 and 2 are usable for this project. The main reason for this is that some technical failures resulted in unusable readings of the LSE-monitor. 24-hour averages were still retrieved by the wet-chemical method, but they cannot be compared to the hourly method and are therefore not shown here. As already mentioned in the introduction stable 3 is still under investigation and therefore does not have values for sessions 4 till 6.

Stable 2 showed the smallest difference between emission calculated by the 24-hour and hourly method. With the



largest deviation being 5 %. Stables 1 and 2 on the other hand both showed significant deviation, as high as 39% for session 3 of stable 3. In figure 4 the absolute difference in emission between the two methods is plotted against the average 24-hour CO2 difference. It is observed that the spread in the absolute difference tends to become larger for a lower CO2 difference. This is to be expected, see the introduction.

Stable 1 1 3 4 5 6 Session: 24-hour method NH₃ emission (kg/animal/year) 6.6 11.6 10.0 14.7 11.7 Hourly method emission (kg/animal/year) 6,5 14,2 11,0 18,3 12,3 Hourly method emission with animal activity correction (kg/animal/year) 6,5 13,3 9,9 17,0 11,5 difference in % between hourly and 24-hour method⁵ -2% 15% -1% 16% -1% Stable 2 Session: 3 4 5 6 24-hour method emission (kg/animal/year) 10,0 10,0 11,7 19,1 Hourly method emission (kg/animal/year) 10,1 10,4 11,8 21,0 Hourly method emission with animal activity correction (kg/animal/year) 9.6 11.2 19.7 10,1 difference in % between hourly and 24-hour method 1% -4% -5% 3% Stable 3 Session: 1 2 3 24-hour method emission (kg/animal/year) 13.1 6.0 10.4 Hourly method emission (kg/animal/year) 14,7 7,5 13,5 7,1 Hourly method emission with animal activity correction (kg/animal/year) 14,4 14,5 difference in % between hourly and 24-hour method 10% 19% 39%

Table 5: Determined emission of stables 1,2, and 3 using both the 24-hour and hourly method.

⁵ The difference is calculated between 24-hour method emission and the hourly method with animal activity correction emission.





Figure 4: A plot of the absolute difference in emission againt the CO2 difference. Showing the larger spread at lower CO2 differences.

Discussion

During the analysis of the data the following choices were made. First the choice was made to use the relation between the NH3 concentration of wet-chemical method and LSE-monitor. The relation was used to convert LSE-monitor concentrations to wet-chemical concentrations. This is done with the following formula,

$$C_{WC} = \frac{C_{LSE} + 0.08}{1.25}$$

The LSE-monitor concentration is converted to wet-chemical concentration as the wet-chemical method is seen as the standard in the Netherlands.

Another choice that is made, is to average hourly LSE-monitor NH3 concentrations to retrieve the 24-hour average NH3 concentrations. There are multiple reasons for this. First, it makes the comparison between the methods more accurate. It rules out the influence of the measurement method on the ammonia concentration determination. Furthermore, during measurements at stable 1, some hours could not be included as cows left the stable for milking sessions. This means that no CO2 is produced in these hours, which forbids the use of the CO2 mass balance method. With the LSE-monitor these hours can be excluded. However, this cannot be done with the wet-chemical method as this requires 24 hours of continuous measuring.

Conclusions

Concludingly the hourly and 24-hour method for the determination of the ammonia emission of dairy stables do not result in the same value for the ammonia emission. It is observed that the two methods can deviate as much as 39%. As expected, the spread in the deviation between the methods gets higher for decreasing CO2 differences (inside-outside concentration). This increased spread at lower CO2 differences is probably the result of the inverse proportionality between the volumetric flow rate and the CO2 difference. The exact reason for the magnitude of the deviation is still unknown. However, EnviVice believes that it might be due to weather conditions. On calm days the CO2 difference will likely be stable and will only be influenced by the animals in the stable. The animal activity correction is than sufficient to reduce the effect of variable CO2 production. On windy days, this is not the case. It is believed that strong winds, which dilute the CO2 concentration in the stable, can cause large differences in the CO2 concentration over the



24-hours. The animal activity correction does not correct for this effect. Therefore, EnviVice believes that larger deviation between the methods is likely caused by strong winds and/or small CO2 concentration in the stable.

EnviVice will further investigate the difference in results between the hourly and 24-hour method. However, at this point it can already be concluded that the hourly method is more robust than the 24-hour method. The 24-hour is prone to failure if low CO2 differences are measured.

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Design of an Application for Analysing the Progression of Musculoskeletal Diseases in Slaughterhouses

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Abstract

Work-related musculoskeletal disorders (WRMSD) are common in Brazilian slaughterhouses. This study aimed to develop an application for predicting the risk of aggravating WRMSD in slaughterhouse workers. The algorithms used to develop the software were developed from a dataset retrieved from an open-source governmental database. The dataset involved organizational aspects and demographic, physical, and health issues. We applied the data mining method to process data using the Random Forest algorithm to find the rules that predicted WRMSD risk aggravation. The variables age, sex, working time, change of function due to health issues, change of working place, and pain symptoms were the most critical attributes to determine the risk of WRMSD progression. The software was developed with PHP programming language, version 8.0, and it uses HTML5 and CSS3 for styling data on the screen. The MySQL database was used for data storage. Data from the worker is input into a dataset containing information on the workers' variable-related questions. The output was the risk of aggravating WRMSD (low, average, and high).

Keywords: Computer application, predicting WRMSD, software development.

Introduction

Brazil has emerged as a prominent global player in the production and distribution of meat, encompassing beef, pork, and poultry. As the Brazilian Association of Slaughterhouses (ABRAFRIGO, 2023) stated, the country exported approximately 2.53 million tons of meat in 2021, yielding revenues exceeding US\$ 10 billion. The significance of the meat industry within the Brazilian economy cannot be overstated, as it serves as a vital source of employment and income across various regions of the country. Moreover, meat exports are pivotal in generating foreign exchange, substantially contributing to the nation's trade balance and overall gross domestic product (GDP) (Garcia, 2021). The evolution of poultry production to meet the requirements of the export market has resulted in significant changes to the work dynamics of workers in various ways (Gurgel and Marinho, 2019).

The slaughterhouse meat processing routine is still similar to that developed at the end of the 19th century (Varussa, 2016). In this industry segment, the production process is characteristic, which requires workers to work long hours standing up, with repetitive movements, following the rhythm and speed established by the company's production line, which can result in health problems (Rosso and Cardoso, 2015). As a result of increased production efficiency, many workers may get sick (Dario and Lourenço, 2018; Santos and Oliveira, 2018).

Slaughterhouse workers often encounter a significant issue called work-related musculoskeletal disorders (WRMSDs), which encompass injuries or damage to the soft tissues (Jaffar et al., 2011). Musculoskeletal disorders (MSDs) are injuries and conditions that affect the muscles, tendons, ligaments, joints, and the nervous system (Tang, 2022). Among occupational health and safety (OHS) concerns globally, WRMSDs are recognized as one of the most prevalent and costly problems (MacDonald and Oakman, 2022).

Artificial Intelligence (AI) can significantly prevent and mitigate WRMSDs. There has been previous research in this field, and AI can address WRMSDs in a few ways, as stated in Table 1.

Area of the application	Characterization	Reference
Ergonomic Assessments	AI algorithms can evaluate workers' movements, postures, and repetitive tasks by analysing data from sensors, motion capture devices, or wearable technology. This data-driven approach allows for the early detection of hazards and helps design safer workstations and processes.	Dimitropoulos et al. (2021); Donisi et al. (2022).

Table 6. Examples of the studied use of artificial intelligence in helping mitigate WRMSDs.



Predictive Analytics	AI algorithms can analyse large amounts of data, including historical injury records, worker demographics, and environmental factors, to identify patterns and predict the likelihood of WRMSDs. This enables proactive and targeted ergonomic interventions for high-risk individuals or job roles, ultimately reducing injuries.	Howard (2019); Agbehadji et al. (2020)
Real-time Feedback and Training	AI can provide real-time feedback to workers on their posture, movements, and ergonomics. Wearable AI-enabled devices can monitor workers' actions and provide immediate alerts or suggestions to maintain proper body mechanics and reduce strain.	Gaur et al. (2019); Chouragade (2023).
Robotic Assistance	AI-powered robotics can alleviate the physical burden on workers by automating repetitive or physically demanding tasks. Taking over duties that pose a high risk of WRMSDs, such as heavy lifting or repetitive motions, allows workers to focus on less physically demanding or complex responsibilities.	Romanov et al. (2022); Kim et al. (2023)
Data-driven Workforce Management	AI can assist in optimizing work schedules, workload distribution, and task allocation based on real-time data and worker capabilities. By considering individual worker capacities and ergonomic factors, AI algorithms can ensure that workload is distributed fairly and safely, reducing the risk of over-effort and WRMSDs.	Villalobos and Mac Cawley (2022).

In the present study, we aimed to develop an AI-based application to investigate the progression of WRMSDs in slaughterhouses using three decision trees that were found by applying data mining to a Brazilian Health Ministry opensource database of slaughterhouse worker's subjects reported with WRMSDs (Brazil, 2016).

Materials and Methods

The database was processed using XAMPP, a package with the main open-source servers supporting the PHP language. The software is released under the GNU license. It acts as a free web server, interprets dynamic pages, and is available for the main operating systems. The available screens were designed using CSS (to define colours, positioning, and layout aspects in page design). The database management system used MYSQL, the structure query language (SQL).

The application was designed to run on a server. We developed the application in a local Apache server (XAMPP) to run the application on the machine where the server is installed. A MySQL DBMS (Database Management System) was installed along with the server.

The programming language used was PHP and PDO (PHP Data Objects), a PHP module assembled under the Object-Oriented Paradigm, which aims to standardize how PHP communicates with a relational database. In the code structure, HTML5 was used to structure the code, and CSS3 for styling and layout for displaying data on the screen.

The schematic of the input, processing data, and output of the application is presented in Figure 1.



Figure 12. Schematic view of the data input, processing, and data output.



The risk of exacerbating work-related musculoskeletal disorders (WRMSDs) in slaughterhouses was determined by several factors, including age, duration of work (in days), job changes due to chronic health issues, changes in the workplace, gender, symptoms of pain, and daily working hours. The decision tree models generated outputs indicating whether the risk was high, average, or low.

To develop these models, data mining techniques were employed using the database of work-related musculoskeletal disorders (WRMSDs) available on the website of the Health Ministry. Slaughterhouses are required to report WRMSD occurrences in this database, which serves as the primary source of information for the system. The mandatory notification of diseases and health problems listed in the national register (Brazil, 2016) provides the foundation for the system's operation and data collection process.

Figure 2 displays the application flowchart starting at the database input, connection, and processing phase. The decision tree rules were applied, and each tree's risk value was calculated based on the retrieved data. Afterward, the data is structured and displayed on the screen, ending the processing.

For the validation process, we randomly selected ten subjects, being five males and five females, with different ages and within a diverse range of variable characteristics.



Figure 13. Application flowchart with the development steps.

The information flow within the system operates through the following steps: (1) The application establishes a connection with the database; (2) The application retrieves the selected data from the database; (3) The data undergoes rule application, wherein the values of each decision tree are calculated based on the received data, following the constraints of the three decision trees; and (4) The structured data is displayed on the screen. Additionally, the application incorporates CRUD (Create, Read, Update, and Delete) operations to interact with the database, enabling data management within the system.

Results and Discussion

Figure 3 shows the screen for the database control, and in Figure 4 we present the database update or insertion of a new worker.



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Figure 14. Output screen for the database control.

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0	
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Figure 15. Print screen of the input to a new worker and editing.

In Figure 5, the screenshot displays the variables, including workers' actions, age, working time (in days), change of function due to health issues, change of workplace, gender, symptoms of pain, and work hours during the day. The data presented in the screenshot pertain to the input variables and forecast the risk of exacerbating work-related musculoskeletal disorders (WRMSDs) in the three last columns.

Female workers in the study ranged from 21 to 52 years old, while male workers ranged from 25 to 42 years old. For example, the application assessed a 33-year-old female participant with a health leave of 2700 days and reported pain symptoms as having a low risk of aggravating work-related musculoskeletal disorders (WRMSDs). In contrast, the application categorized a 42-year-old male participant with 180 days of health leave as having an average risk of aggravating WRMSDs. It is important to note that multiple variables influence the risk assessment, and the final prediction is a non-linear combination of these factors based on the decision tree models developed using data mining techniques.



Aç	ões	ID	Nome	Idade	Sexo	Dor?	Mudança Local?	Mudança Função?	Dias Trabalhados	Dias Atestado	Carga Horária	Risco - Árvore 1	Risco - Árvore 2	Risco - Árvore 3
×			COLABORADOR 1	33		Sim	Não	Não		2700	510 Minutos/Dia	Baixo	Baixo	Baixo
×			COLABORADOR 2	29		Sim	Não	Não		60	510 Minutos/Dia	Baixo	Baixo	Baixo
×			COLABORADOR 5	21		Sim	Não	Não			510 Minutos/Dia	Baixo	Baixo	Baixo
×		202	COLABORADOR 191	42		Sim	Não	Sim	1440	15	510 Minutos/Dia	Médio	Médio	Médio
×		207	COLABORADOR 196	25		Sim	Não	Sim	1440		510 Minutos/Dia	Médio	Médio	Médio
×		212	COLABORADOR 200	37		Sim	Sim	Sim	1440		360 Minutos/Dia	Médio	Médio	Médio
×		260	COLABORADOR 245	28		Sim	Não	Não	2520	180	510 Minutos/Dia	Alto	Alto	Alto
×		261	COLABORADOR 246	32		Sim	Sim	Não	2520		510 Minutos/Dia	Alto	Alto	Alto
		262	COLABORADOR 247	52	٠	Sim	Não	Não	2520	0	360 Minutos/Dia	Alto	Alto	Alto

Sim=yes; não=no; dia=day; carga horária=hourly workload

Figure 16. Print screen of the worker's actions, the attribute variables used in evaluating the risk, and the risk of aggravating the slaughterhouse WRMSDs (low - in blue, average - in green, and high - in red).

By simulating the randomly selected subjects, the assessment helps tailor preventive measures and interventions based on the identified risks. When doing the simulation using ten randomly chosen subjects, we found data presented in Figure 6. When one decision tree results in a high risk, we considered the risk of aggravating WRMSD as a high risk.

Açõe	5	D	Nome	Nome Risco - Árvore 1 Risco - Árvore 2		Risco - Árvore 3	
	3	349	INDIVIDUO 1	Baixo	Baixo	Baixo	L
×)	0 3	350	INDIVIDUO 2	Baixo	Baixo	Baixo	L
		351	INDIVIDUO 3	Baixo	Baixo	Baixo	L
	8	352	INDIVIDUO 4	Baixo	Alto	Alto	Hi
	8 3	353	INDIVIDUO 5	Baixo	Baixo	Baixo	Lo
	8	354	INDIVIDUO 6	Baixo	Baixo	Baixo	Lo
	8	355	INDIVIDUO 7	Alto	Médio	Médio	Hi
	8	356	INDIVIDUO 8	Baixo	Baixo	Baixo	Lo
	8	357	INDIVIDUO 9	Baixo	Baixo	Baixo	Lo
	8	358	INDIVIDUO 10	Balxo	Alto	Médio	Hi

Alto=high, médio=average, and Alto=high.

Figure 17. The application output (in Portuguese) with ten randomly selected subjects for validating the model.

Even though age was one of the attributes that determined a high risk, we had one female subject aged 57 years with a low risk. Both male and female subjects aged 65 years had a high risk of aggravating WRMSDs. We had two subjects (30 < age < 50 years) with pain symptoms; however, their risk was prognostic as low and average. Various factors, including repetitive movements, awkward postures, forceful exertions, and prolonged periods of physical activity, can cause WRMDS. While pain can be a symptom of WRMDS, it does not directly lead to these disorders' development (Sundstrup et al., 2020).

To reduce damage to the health of employees in the slaughterhouse industry, on April 18, 2013, Ordinance No. 555 approved a regulatory rule that establishes minimum requirements for the assessment, control, and monitoring of risks faced by workers in slaughtering and processing meat and meat products to promote their health, safety and quality of life (NR 36; Brazil, 2018). NR 36 addresses several aspects, the main ones being related to breaks during working hours, which are regulated as follows: For shifts from 6:20h to 7:40h, a minimum break of 30 minutes is required for rest. For shifts from 7:40h to 9:10h, the break increases to 40 minutes; for shifts of 9:10h, 60-minute breaks are required. The norm also addresses job rotations and training, as well as establishing actions to control ammonia and carbon dioxide concentration levels in work environments.

Previous literature (Tang, 2022) provides substantial evidence highlighting the necessity of adopting a comprehensive systems-based approach to manage work-related musculoskeletal disorders (WMSDs) effectively. However, there is a notable disparity in translating this evidence into practical risk management strategies. Continuing to rely on a linear and hazard-focused approach to address the significant challenge of WMSDs will not lead to significant reductions in the problem. This approach overlooks the intricate factors that contribute to the development of WMSDs, thus hindering progress in mitigating their impact.



Expert systems can accumulate data over time and utilize machine learning algorithms to improve their effectiveness in mitigating WRMSDs (Donisi et al., 2022). By analyzing the collected data on age, sex, working time, and injury patterns, the developed application can identify trends and refine its recommendations and risk assessment algorithms to adapt to changing conditions and individual needs.

Previous studies indicate the feasibility of using machine learning algorithms in ergonomics (Dimitropoulos et al., 2021; Baduge et al., 2022). Therefore, machine learning techniques offer valuable capabilities for analyzing complex data sets, identifying patterns, and making predictions, which can significantly contribute to ergonomic assessments and interventions. Villalobos and Mac Cowley (2022) illustrate the potential of ergonomic machine learning algorithms to improve risk assessments in slaughterhouses, develop personalized interventions, and provide real-time monitoring and feedback. By leveraging the power of machine learning, ergonomic interventions can be more precise, proactive, and tailored to individual needs, ultimately enhancing workplace safety and reducing the occurrence of musculoskeletal disorders.

Most risk of WRMSDs assessment methodologies rely on standard survey-based, time- and labor-intensive methods. Using machine learning technology algorithms, we proposed a way to identify the risk of aggravation of WRMSDs (assuming previous symptoms), providing a more reliable way to prevent health leaves.

Conclusions

We developed an application to help mitigate the risk of augmenting WRMSDs in slaughterhouses in Brazil. By utilizing expert systems solutions, workers can be provided tailored interventions and recommendations based on their specific characteristics and work requirements.

This approach might help reduce the risk of aggravating WRMSDs and create a safer working environment for employees.

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Use of Marine Macroalgae Extracts to Protect Corn Crop from Water Stress

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Abstract

Crops require considerable volumes of water to satisfy their water requirements and complete their production cycles. However, due to climate change, increasingly impacting the daily lives of the entire world population, this natural resource, considered "infinite" will be greatly affected. Based on this premise, sustainable forms of cultivation are necessary to overcome this obstacle. The present study aimed to analyze the efficacy of the use of aqueous extracts of sargassum (S. vulgare), in protecting corn from water stress. To this end, trials were conducted, under water deficit conditions, with an application of sargassum extracts. The crop response to stress was monitored using the vegetation index, Crop Water Stress Index Simplified - CWSIsi. This index was obtained with the aid of a multispectral camera, with a thermal band, attached to an Unmanned Aerial Vehicle (UAV). The use of UAV has advantages in the speed and reliability of data acquisition, and because it is considered a non-invasive method of plant analysis. The results demonstrate that seaweed extract exerts a promising bio-protective action against water stress in corn. The average index results in the treatment variant with algae extract under water stress were very close to the non-stressed control. The application of bio-protective substances to crops may present advantages in the control of climatic constraints, such as drought, allowing them to be produced more sustainably, and using less water resources. The reduction in the amount of water used by the plants, as well as the use of new technologies, can also generate benefits for producers in the financial aspect, as well as for society in general when analyzed from the point of view of climate change. Keywords: Precision Agriculture, CWSIsi, UAV, Climate Change.

Introduction

The scarcity of water resources is currently one of the main challenges when thinking about water management for use in agricultural areas. Climate change as well as the misuse of water resources by today's society has caused considerable changes in them, especially favoring the decrease in volume as well as decrease in quality. Based on this premise, studies on the maximization of agricultural production per unit of water used will increasingly gain space in the scientific-technical environment (Zhang et al., 2019a).

According to Zhang et al. (2019b), the current demand for food will double by 2050 due to population growth. To meet this demand Atkinson et al. (2018) report that an increase of approximately 40% in cereal production will be required, and water needs will increase by 40 - 50%. To overcome this possible constraint Zhang et al. (2019b) reinforce the need for plant breeding associated with increasing their potential yields, whereby crops can produce the maximum of their capacities using the minimum possible water.

Studies related to the use of biostimulants are beginning to gain space in the scientific environment since they can provide some positive characteristics to crops. According to Saavedra et al. (2020), biostimulants can increase natural processes in plants, such as generating a greater stimulus for nutrient absorption as well as promoting tolerance to abiotic stress. Teklic et al. (2020) report that biostimulants can be produced from different raw materials, such as algae, composts, and humic substances, among others.

Currently, there are two major methods for assessing crop water stress; the first consists of analyzing the water content present in the soil and the other uses intrinsic crop parameters (Ihuoma and Madramootoo, 2017). However, despite being widely used, these methods are time-consuming, labor-intensive, and considerably expensive, and often do not consider the spatial variability of the crop (Li et al., 2010).

With the advancement of technology, the use of unmanned aerial vehicles (UAVs) becomes very useful, which, despite being a high-priced technology, has been increasingly used in studies related to crop phenotyping in the field (Zhang et al., 2019b). Several advantages make the use of UAVs increasingly prominent in environmental studies, such as the great ease of transportation of the equipment, its high flexibility, short operational cycle, and namely its high spatiotemporal resolution. However, to obtain interesting results that can be used in different studies related to vegetation, good-quality cameras must be used. Currently, multispectral cameras already have a specific thermal band,



widely used in studies related to crop water stress.

Measuring the temperature of the vegetation cover is a method that gives relatively quick results on plant stress levels. Idso et al. (1981) formulated the Crop Water Stress Index (CWSI), considered an indirect method whose premise is that crop transpiration causes cooling in the leaves, however, as the crop undergoes some state of stress, its transpiration is considerably reduced, with an increase in the leaf temperature of the crop because of incident solar absorption (Jackson et al., 1988). Bian et al. (2019) simplified the process of obtaining data to use the previously proposed equation, in which they use only the data obtained with the thermal band, considering the highest and lowest values to obtain the CWSI, the authors defined this simplification as Simplified Crop Water Stress Index (CWSIsi).

The present study aimed to analyze the efficacy of the use of aqueous extracts of sargassum (S. vulgare), in protecting corn from water stress using the Simplified Crop Water Stress Index (CWSIsi).

Materials and Methods

Study Area

The present study was conducted at Quinta de São Roque (32° 39'37" N, 16° 55'15" W, altitude 198 m) of the University of Madeira, Funchal - Portugal in 2022. The soil of the study area is classified as Chromic Cambisol, with a clayey texture. According to the Köppen classification, the study area is classified as having a temperate climate with hot and dry summers (Csa), with average, maximum, and minimum temperatures of 18.5 °C, 26.4 °C, and 11.1 °C and average annual accumulated precipitation of approximately 653 mm (Macedo et al., 2023).

Field Test

Corn was initially planted in peat plates on 04/04/2022 and was transplanted into Quinta de São Roque on 22/04/2023. On 05/05/2022, the 1st application of algae extract applied directly to the root system was carried out on 10 plants in each row, and on 05/20/2022 the 2nd application of extract was made on the same plants. In the 1st and 3rd row, the extract was applied to 10 consecutive plants starting from the 6th plant (inclusive) and counting from the beginning of the row. In the 2nd and 4th rows, the extract was applied on 10 consecutive plants, starting from the 6th plant (inclusive) and counting from the end of the row. Differential irrigation was started on 23/05/2022. The first 2 rows from the wall were considered stressed (half irrigation) and rows 3 and 4 were controlled (full irrigation). (Figure 1).



Figure 1. Experimental design of the present study (27/06/2022).

Agronomic analysis

The first analysis carried out in the field was carried out on 27/06/2022 and consisted of analyzing plant height (cm)



and the number of leaves. The second analysis carried out on 29/07/2022 analyzed the following parameters: plant height (cm), number of leaves, number of ears, number of secondary shoots, fresh weight of ears (g), fresh weight of plants (g), total fresh weight (g), dry weight of plants (g), number of seeds, total weight of seeds (g), and the weight of 100 seeds (g).

Vant Platform

A DJI Matrix 210 RTK V2 multirotor quadcopter was used for image acquisition, through flight at 30 m above the field surface. The UAV was equipped with a gimbal, mounting a Micasense Altum multispectral and thermal imager. It collects images in 5 spectral bands (blue, green, red edge, and near-infrared) along with the thermal LWIR, with a size of only 8.2 cm \times 6.7 cm \times 6.45 cm and a weight of 407 g. The Altum multispectral camera can collect images with a ground sample distance (GSD) of 5.2 cm at a height of 120 m above ground, with a view field of 48 degrees \times 37 degrees for the multispectral channels.

Data Acquisition

The data collection in this study was carried out only once when the plants were at the beginning of flowering (R1). Details of each flight mission are listed in Table 1.

Table 1. Flight mission details.

Flight	Date	Growth Stage (DAS)	Wind Speed (km/h)	Images Collected	Point Density (pt/cm²)	GSD (cm·pix ⁻¹)
1	27 June 2022	130	8.7	1176	0.185	1.16

The flight mission was programmed and carried out in the proximity of solar noon to avoid differences in the quality of the images with shading. The processing of the obtained images was performed using Pix4D Mapper 4.6.4 (Pix4D, Prilly, Switzerland), a software specifically designed to process UAV images using techniques based on computer vision and photogrammetry.

Simplified Crop Water Stress Index (CWSIsi)

In this study, we used the Simplified Crop Water Stress Index from the equation adjusted by Bian et al., 2019, by the following formula:

$$CWSI_{si} = \frac{T_c - T_{wet}}{T_{dry} - T_{wet}}$$
(1)

where Tc is the average canopy temperature acquired using the UAV thermal images, T_{wet} is the lower boundary temperature of the vineyard canopy, and T_{dry} is the upper boundary temperature of the corn canopy.

Statistical Analysis

The statistical analysis was performed using Jamovi computer software version 2.3.16 (The Jamovi project, 2023). Once obtained the CWSI values as some agronomic variables, they were analyzed to verify the normality or not of the obtained samples. The Shapiro–Wilk normality test was performed, aiming to verify the normality of a random sample, i.e., whether it comes from a normal or non-normal distribution Shapiro–Wilk test.

The Pearson correlation coefficient (r) was used to evaluate the correlation between CWSI and some agronomic variables. The interpretation of Pearson's correlation coefficient can be obtained from its value, and the correlation is classified as very weak (0.00-0.19), weak (0.20-0.39), moderate (0.40-0.69), strong (0.70-0.89), and very strong (0.90-1.00) (Devore and Cordero, 2006). The root means square error (RMSE) between observations and predictions was used to evaluate the accuracy of productivity and AGB predicted by different models.

Results and Discussion

Analysis of the effect of biostimulants

Within the control plants (with normal irrigation), there were only significant differences ($p \le 0.05$) between the



plants treated with seaweed extract and those not treated with seaweed extract for the number of shoots. Within the stressed plants, there were no significant differences ($p \le 0.05$) between the plants treated with seaweed extract and those not treated with seaweed extract in any parameter.

Correlation analysis

Two correlation analyses were carried out, the first of which consisted of comparing the field results with the CWSIsi obtained on 27/06/2022. From this test, there was no evidence to reject the null hypothesis, and the values came from a normal distribution with a significance of 1% probability. However, no correlations were found between the analyzed data. For the second correlation analysis, the results obtained by CWSIsi (27/06/2022) were used against all agronomic variables performed before the corn harvest. Again, there was no evidence to reject the null hypothesis, and the values came from a normal distribution with a significance of 1% probability. No correlation was verified between the analyzed data.

CWSIsi

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For the results referring to this index to be related only to the leaf canopy of the corn crop, it was necessary to classify the image, making it possible after this procedure to generate a vegetation mask of the crop (Figure 2).

Figure 2. Simplified procedure for obtaining the CWSIsi. A. RGB; B. Vegetation Mask; C. CWSIsi

After obtaining the vegetation mask (fig. B), the CWSIsi (fig. C) was generated for the entire study area. Performing a visual analysis of the index, a certain variability in the level of crop stress is noted, especially in the upper and lower part of the test, in which the results obtained are classified with values between 0.309 to 1 (green to red hue), demonstrating that these areas are undergoing some type of water stress, at the time of obtaining the image used. The central part of the figure, on the other hand, has a dark blue hue, showing that this central area has not been causing any type of water stress for the crop.

The results of CWSIsi visually are very interesting and extremely useful for farmers, as they could act only at the points where situations with some kind of stress have been verified and could circumvent critical situations whenever possible.

To verify if there are differences between the treatments tested, for each of the different plots the average values for CWSIsi were obtained. Analyzing lines 1 and 2 (with 50% of irrigation) for the treatments without application of the



extract, the average index value was 0.179, and for the treatments in which algae extracts were applied, the average value was 0.199. In these two lines, it was found that the results for both non-use and use of seaweed extracts were very similar. However, it was noted that when the seaweed extract was used, associated with low presence of water via irrigation, the values showed that these treatments are in situations of greater water stress, since the values move away from 0 and tend to approach 1. The effect was the opposite of what was expected.

Analyzing lines 3 and 4 (with complete irrigation), the results for the treatments without extract application, the mean value obtained was 0.172, while for the treatments in which the extracts were applied the mean value was 0.152. The results with the presence of normal irrigation were opposite to those obtained for the lines with 50% irrigation. Note that the treatment with the use of the extract was the one that presented the lowest results of all those that were tested and very close to 0.

This is an initial study with the use of algae extracts in crops, in which, in the future, it is expected to continue the studies testing them in different crops, with different dosages, with flights that accompany the complete development of crops among other points, since doubts about the effectiveness of algae extracts in controlling water stress need to be better understood.

Conclusions

The use of algae to combat water stress in crops should be further studied, especially in different crops, as it still causes some confusion about its real effect.

The results of CWSIsi can be extremely useful for farmers because they could act only at the points where situations with some type of stress were verified, being able to circumvent critical situations whenever possible. Reducing their expenses with certain cultural treatment, in addition to considerable gains, since crop losses would be less and less.

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Spatial distribution of bed variables and animal welfare indicators in different typologies of compost-bedded pack barn

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Abstract

The challenge for the milk industry is to maintain the focus on efficient transformations that lead to increasingly significant production results. In this sense, in confinement systems for dairy cattle, there has been a constant search for more modern and economically viable techniques that provide greater welfare and comfort to the animals, while allowing for the preservation of the environment. Among the housing options, the Compost-Bedded Pack Barn (CBP) system has shown promise for the climatic conditions in Brazil. This research aimed to compare the bedding quality and the health of the herd of cows housed in CBP with different constructive forms: CBP with closed sides and tunnel ventilation system and b) CBP with open sides and low-volume, high-speed fans. For the assessment of bedding quality, the temperature and humidity were measured. The variables used to assess animal welfare were: hygiene score and locomotion score. Based on the experimental results, it was observed that the average values of the surface temperature of the bedding were slightly higher in the open compost barn compared to closed CBP, with adequate comfort conditions for the animals to lie down. The average temperature values of the bedding at 20 cm depth in both systems were slightly lower than the lower limits recommended. The closed CBP had a significant increase in moisture content compared to the open CBP. The average values of hygiene and locomotion scores in both systems did not present statistical differences between the facilities analyzed. In general, cows housed in both evaluated systems had an adequate hygiene score and locomotion score, and the incidence of lameness was not common. It is possible, based on the obtained results, to trace strategies for the improvement in the constructive typology of the building, in the used ventilation system.

Keywords: agro-industrial facilities; compost barn; composting; dairy cow; housing system.

Introduction

One of the major concerns in the dairy farming sector worldwide is to alleviate the negative effects of inadequate breeding environments on cows during their lactation period. In addition to the adoption of modern technologies to improve the internal environment of livestock facilities, a demand exists for facilities that ensure the sustainability of animal production, highlighted by the trend of preservation of the environment and animal welfare (Damasceno, 2020).

Another challenge in future housing for dairy cows is the creation of projects that resolve conflicts in existing systems, one of which is the amount of surface area required per animal (Leso et al., 2020). More space per animal offers the possibility for more natural behavior (Galama et al., 2020). Additionally, when the lay public is introduced to the types of animal management systems, they think that living a natural life is an important part of animal welfare, reflecting their wishes for animals to live in natural environments, with space and the ability to engage in species-specific behaviors (Lassen et al., 2006).

When considering the aforementioned factors, the confinement of dairy cattle in compost-bedded pack barn (CBP) systems has shown promise for dairy farming. The system has been successfully used for several years with dairy cattle in temperate regions (Barberg et al., 2007) and, recently, in tropical and subtropical countries, such as Brazil (Pilatti et al., 2019; Oliveira et al., 2023).

In this alternative animal husbandry system, the cows remain in an extensive resting area, where they are offered a pasture-like environment in which they may lie down and stand up (Yameogo et al., 2020; Emanuelson et al., 2022). Producers use the conventional bedding system and incorporate composting methods, through the periodic addition of carbon source material and daily turning of the bedding, promoting the composting of the organic material (Shane et al., 2010; Damasceno, 2020).

Most CBP facilities are open on the sides and can be ventilated naturally or with mechanical positive pressure ventilation (Oliveira et al., 2021). Recently, some closed CBP facilities have been built in Brazil, equipped with



mechanical negative pressure ventilation systems (Andrade et al., 2022). However, as the adoption of this milk production system technology has expanded in Brazil, concerns have also arisen from producers regarding the real applicability of totally closed facilities for the construction type and climatic conditions present in the country, due to the limited research on this type of system.

Based on the above considerations, it can be stated that the compost barn system has high potential for good performance in dairy farming. However, information on the quality of bedding and herd health of dairy cattle in this system is still scarce in the literature, especially in regions of tropical and sub-tropical climate, as is the case of Brazil.

Thus, the objective of the present study was to compare the quality of bedding and herd health of cows raised in CBP with different thermal conditioning systems.

Materials and Methods

The study was carried out in a dairy production unit that uses CBP facilities for the confinement of dairy cattle. The study was carried out during the summer. Two different CBP facilities were analyzed: a) closed compost bedded pack barn (CBC) provided with negative pressure ventilation in tunnel mode, associated with the evaporative cooling (EC) system, with porous plates use.; b) compost bedded pack barn (CBO) with open sides and low-volume, high-speed fans (LVHS).

The milk production property was located in the Zona da Mata region, Minas Gerais, Brazil (670 m altitude, coordinates 20° 46' 41" S, and 42° 48' 57" W). The local climate, according to the Köppen classification, is of the Cwa-type, with cold, dry winter and hot and humid summer (Alvares et al., 2013).

The facility CBO has a northwest-southeast orientation, total dimensions of 25.0 m long \times 18.0 m wide, a gable roof, corrugated metal roof tiles, a height of 5 m, and eaves of 1.5 m. The internal spatial distribution of the CBO is composed of: a) drive-through alley with a concrete floor with an area of 100 m² (containing a single trough 25 m long), being the region where the tractor circulates for food distribution; b) feeding alley with concrete floor with an area of 100 m², with four drinking fountains in this region; c) 350 m² bedding area. 4 fans were distributed in the bed area. During the trials 25 cows were housed inside with a density in resting area of 14.0 m² head⁻¹.

The CBC has a northwest-southeast orientation, 55.0 m length \times 26.4 m width, gable roof, corrugated metal roof tiles, 5.0 m height, and 0.8 m eaves. The internal spatial distribution of the CBC is composed of (a) a 220 m² drive-through alley with a concrete floor (containing a single 55 m long trough), being the region where the tractor circulates for food distribution; (b) a 220 m² feeding alley with a concrete floor (separated from the pack area by a 1.2 m high concrete wall), with four drinking points in this region; (c) an 880 m² bed area (on compacted soil); and (d) a 132 m² service corridor with a concrete floor. During the trials 83 lactating cows were housed inside with a density in resting area of 11.0 m² head⁻¹.

On the southeast side of the CBPC, a series of five porous cellulose was used in the EC composition. A sensor positioned inside the CBP, monitored environmental conditions and was programmed to be activated when the air temperature was equal to or higher than 21 °C and relative humidity below 75%. Thus, the plates were moistened by dripping to allow the adiabatic cooling of the external air that passed through the same suction path (negative pressure). At the opposite end (northwest side) of the facility were five large exhaust fans (BigFan®, HVLS, 3.5 m in diameter, six propellers, an air volume of 150,000 m³ h⁻¹, and power of 1491.4 W). The five exhaust fans remained on continuously (24 hours day⁻¹).

The CBPC had a bed composed of a mixture of wood shavings and coffee husks, with a thickness of approximately 0.60 m. The CBO had a bed composed of wood shavings and coffee husks, with a thickness of approximately 0.30 m. The bed stirring was mechanized and occurred periodically, twice a day, usually at 6:30 a.m. and 12:00 p.m., at depth of 0.20 m. The stirring was carried out through the hybrid implement (chisel with roller) coupled to with a tractor (JOHN DEERE® 5078E, 78 hp) to incorporate animal waste into the bedding material, promote higher aeration for the composting process, and decompress the bedding. The superficial washing of the feeding aisle floor was performed by the known flushing system and occurred once daily, in the morning.

Animals in both facilities had ad libitum access to fresh water provided from a self-filling trough located in the feeding alley. In both systems, the bedding characteristics were evaluated in relation to the bed temperature at the surface and at a depth of 20 cm, to bed moisture at a depth of 20 cm.

A thirty-six point equidistant mesh was created to measure the variables. The surface temperature (TCS, °C) was measured using an infrared thermographic camera (FLIR® TG165, Wilsonville, USA, with a measurement range of - 10 to +45 °C and accuracy of \pm 1.5 °C). The focal distance of 1.00 m and emissivity (ϵ) adjusted to 0.90.

For the bed temperature at a depth of 20 cm (TC20), a digital rod-type thermometer was used, that was introduced into bed for a period of one minute or until the temperature stabilized. The 0.20 m depth temperature (t20) was measured with a rod thermometer (Pyromed® TP101, Contagem – Minas Gerais, BR, with a measurement range of – 50 to 300 °C and accuracy of \pm 0.1 °C). The rod thermometer was inserted into the bedding at each measurement point for 1 min or temperature stabilize.



Bedding samples were collected using an articulated digger in order to determine the bed moisture content and pH. The collections took place before handling of the daily bedding. The sample were packed in clear and airtight plastic packaging. Subsequently, they were placed in isothermal boxes for transport to the laboratory. The bedding samples were cooled on ice after collection and refrigerated at 1.0 °C in the laboratory. The methodology adapted from Melo (2011) and Teixeira et al. (2017) determined the moisture at a depth of 0.20 m (BM, %). The authors recommend using a 10 g sample placed in containers and drying in an oven at 105 °C for 24 h. Sample weighing was performed using an analytical balance (Shimadzu® AY220, Kyoto, Japan, with a measurement capacity of 220 ± 0.0001 g of accuracy). After drying, the samples were placed in desiccators for approximately 30 min. Finally, the container with the dry material was measured. The moisture content was determined by the ratio between the evaporated water mass and the wet bed sample, multiplied by 100.

The body score (BS) evaluation was performed considering the methodology presented by Machado et al. (2008) and was made through visual assessment of the animal's body situation using a scale with values ranging from 1 to 5, and graded every 0.25 points. The extreme numbers 1 and 5 of the scale represent an excessively lean animal and an obese one, respectively. The anatomical parts analysed in the evaluation were ribs, transverse processes of the lumbar vertebrae, tips of the ilium and ischium, and tail head.

The locomotion score (LS) was evaluated using the methodology of Sprecher et al. (1997), and by observing animals on a flat surface when they were moving or standing upright. A scale with values from 1 to 5 was used, and graded every 0.25 points. Numbers 1 and 5, the extremes of the scale, represent normal locomotion and severe lameness, respectively.

The hygiene score (HS) evaluation was performed according to the methodology proposed by Cook (2007). For the evaluation, some anatomical parts of the animal such as the leg, udder, flank and upper leg were observed. A scale of 1 to 4 was used, graded every 0.5 points. Number 1: corresponds to the absence of dirt in the evaluated regions; number 2: regions with small dirt spots; number 3: regions with the presence of some dirt plates adhered to the fur; and number 4: regions with dirt plates preventing the visualization of the fur.

Descriptive statistics was used to calculate averages, standard deviation of the average and error for the variables analysed. The averages of these variables were compared in both systems evaluated by the t-test (5.0%).

Subsequently, from the data collected of the bed, descriptive maps were generated (data is interpolated into a grid for contour plots), using the Surfer[®] software, version 13.4.

Results and Discussion

Figure 1 shows the comparison of surface temperature, depth temperature, moisture, and bedding pH collected at CBC and CBO facilities. The TCS values recorded were higher in CBO ($27.8 \pm 1.2 \text{ °C}$) and showed a statistically significant difference (P <0.05) with CBC ($24.8 \pm 2.0 \text{ °C}$) (Fig. 1, a). According to Black et al. (2013), TCS tends to present values close to the ambient air temperature.




Figure 1. Averages values and standard deviation of: a) surface temperature (TCS, in °C), b) depth temperature (TC20, in °C), c) Moisture (BM, in %) and d) pH, in the open compost-bedded pack barn (CBO) and closed compost-bedded pack barn (CBC). Averages followed by the same letters do not differ from each other at the 5% probability level by the t-test

Some authors evaluated environmental factors that influence bedding quality and observed that ambient temperature of compost barn was a significant predictor of bed temperature and humidity (Eckelkamp et al., 2016). When air is cooled, the temperature gradient between bed temperature and air increases, leading to heat loss of the bed (Black et al., 2013).

There was no statistically significant difference (P> 0.05) between the TC20 in the CBC ($38.8 \pm 6.2^{\circ}$ C) and CBO ($41.0 \pm 5.9^{\circ}$ C) (Fig. 1, b). For an ideal composting process TC20 must be between 43 to 65°C (Black et al., 2013). It was found that the average internal temperature of the bedding was below the recommended values for optimal composting.

It can be observed that the CBC system $(66.7 \pm 3.8\%)$ had a significant higher value (P <0.05) in the BM compared with CBO system (48.2 ± 8.6%) (Fig. 1, c). When BM and the microbial activity are low, which are responsible for the lower intensity of the composting process, the material is dry (<30%) and may cause respiratory tract irritation in animals. On the other hand, when BM is high, bed aeration is difficult, contributing to the anaerobic degradation process of organic matter. Thus, the ideal BM range recommended by Black et al. (2013) is 40 to 65%. These values guarantee the survival of microorganisms allowing the adequate flow of oxygen inside the bed. In CBC the humidity was above the recommended upper limit for optimal composting.

Figure 2 shows the maps of the mean values of the variables during summer. There was significant variability in the bed region of the CBO and CBP. The regions with reduced values are displayed using more bluish colors. Regions with higher values are displayed using reddish colors.





Figure. 2. Spatial distribution of the variables: surface temperature (°C) of the bed CBC (a) and CBO (b); temperature in the depth of 0.20 m (°C) of the bed CBC (c) and CBO (d); moisture at a depth of 0.20 m (°C) of the bed CBC (e) and CBO (f) in the summer.

The lack of uniformity in the distribution of the variables can be attributed to the facility's thermal environment, such as the fans arrangement, evaporative plates and deflectors, and the influence of the side closures lack of insulation. The materials used in the building and the physical barriers' thermal properties can significantly affect the ventilation rate inside the accommodation (Mondaca et al., 2019).

The averages values of hygiene score HS, BS and LS in both systems evaluated (Fig. 3) showed no significant differences (P > 0.05).

The averages HS values for CBC and CBO systems were 1.5 ± 0.8 and 1.2 ± 0.4 , respectively. Usually, cows had an excellent HS value, which is evident comparing it to the results obtained by Barberg et al. (2007), where the mean scores were 2.66 ± 0.19 .

For BS, the average values were 2.9 ± 0.1 (CBC) and 3.0 ± 0.2 (CBO). The body condition score of the animals was satisfactory, and the variations presented are acceptable due to the performance of the evaluation in animals that were at different productive levels and lactation stages.

The LS in the CBC and CBO systems were 1.3 ± 0.5 and 1.9 ± 1.1 , respectively. These values are similar to the ones found by Oliveira et al. (2019), which reported mean scores of 1.83 ± 0.25 . In general, cows housed in both the evaluated systems had a good LS, and the incidence of lameness was not common.



Figure 3. Average values and standard deviation: a) hygiene score (HS), b) body score (BS) and c) locomotion score (LS) in open compost-bedded pack barn (CBO) and closed compost-bedded pack barn (CBC) systems. Average followed by the same letters do not differ from each other at the 5% probability level by the t-test.

Conclusions

Based on the present study, it can be stated that the average values of the surface temperature of the bed were slightly higher in the CBO compared to CBC, with adequate comfort conditions for the animals to lie down. The average temperature values of the bedding at 20 cm depth in both systems were slightly lower than the lower limits recommended. The average of the BM in the CBC system was higher than the CBO. The moisture content was above the recommended upper limit for optimal composting of the bedding for the CBC.

The research on the closed CBP system so far provides preliminary impressions. As closed CBP systems are al-



ready a commercial reality in Brazil, research aimed at improving the aspects of the construction of the building, the ventilation system used, as well as the handling of the bed is required.

The dairy industry would also considerably benefit from further research into CBP systems, as this information will refine circular economy approaches to further improve efficiency while reducing their climate and environmental impacts. Sustainable alternative systems for dairy cattle production tend to be increasingly accepted by key categories such as producers, specialists and consumers.

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Development and Validation of a Real-Time Monitoring System of the Thermal Environment for Animal Production Facilities

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Abstract

The thermal environment control is a primordial condition to assure the productive efficiency in animal production facilities. Despite this, few companies operate in the development and commercialization of embedded systems (monitoring and control) for animal facilities, and those that operate in the area have costly systems that are difficult to operate. In this context, the objective of this study was to develop and validate a real-time monitoring system of the thermal environment for application in animal production facilities, using affordable electronic components, wireless communication protocols and Internet of Things (IoT). The embedded system (ES) was developed containing modules for collecting/sending data and a server, used for data storage. For validation purposes, the ES and a standard recording sensor (SRS) were installed in a room, and collections were performed for three consecutive days (every 1 min). To evaluate the data received by the server, the frequency of success (FS) and the data reception interval (DRI) were calculated. Verification of the agreement between values obtained via ES and SRS was performed using the root mean square error (RMSE). Through the results achieved, it was verified that the developed ES was able to collect and send the data of interest to a cloud server. The average receiving data FS was equal to 92.5%, while the highest DRI was 5.43 min. From the data collection modules, dry air bulb temperature values were obtained with good agreement in relation to the SRS (RMSE between 0.23 and 0.34), but relative humidity values always higher than desired (RMSE between 6.55 and 12.34). For this reason, it was necessary to adjust calibration curves for data obtained via collection modules. The ES developed has potential for use in agro-industrial facilities.

Keywords: agro-industrial facilities; thermal environment; embedded systems; internet of things.

Introduction

The projections of the United Nations indicate that the world population may increase by up to 2.0 billion people between 2022 and 2050 (UN, 2022). Therefore, it is necessary that the livestock sector continues to provide a safe supply of animal protein and contribute to food security, in addition to ensuring the generation of employment and income (FAO, 2017; Symeonaki et al., 2022).

To ensure the supply of animal origin products, current livestock has assumed an intense nature, characterized by higher levels of inputs, productivity, and production. In intensive production systems, the farms number is reduced, but it is possible for the animals' number to be increased, due to the creation in collective facilities, with the presence of thermal cooling systems and some level of automation (Saitone and Sexton 2017; Symeonaki et al. 2022). In these facilities, it is necessary that the thermal environment is maintained within certain limits, so that the health and productive and reproductive performance of the animals are not affected (Ramirez et al. 2018; Arshad et al. 2022).

Therefore, continuous and real-time monitoring of the thermal environment throughout the production cycle is a key condition to ensure productive efficiency in intensive animal production systems (Freitas et al. 2019). However, few companies act in a specialized way in the implementation of environmental monitoring systems in facilities intended for animal production and, when they do, they have costly and difficult to operate systems (Djajadi and Wijanarko 2016). Thus, there is an imperative demand for the development and adoption of modern methods, based on Smart Livestock Farming (SLF), using relatively low-cost sensors, actuators and microprocessors, high-performance software, systems based on the Internet of Things (IoT) and big data analysis (Arulmozhi et al. 2021).

In Brazil, some studies have aimed to develop and/or use thermal environment monitoring systems based on relatively low-cost sensors, actuators and microprocessors, such as those carried out by Freitas et al. (2019), Andrade et al. (2022) and Oliveira et al. (2022). However, these studies did not use wireless communication protocols and were not based on IoT, being restricted to recording data on storage devices (SD cards). In this context, the objective of this study was to develop and validate a real-time monitoring system of the thermal environment for application in facilities for animal production, using affordable electronic components, wireless communication protocols and the Internet of



Things (IoT). It can be considered that carrying out this study will be the starting point in the search for an efficient, applicable, and low-cost tool for real-time monitoring of the thermal environment in facilities intended for intensive animal production, which is incredibly important for the trade Brazilian balance.

Materials and Methods

The study was developed together with the Nucleus of Research in Ambience and Engineering of Agro-industrial Systems (AMBIAGRO) and the Agricultural Mechanization Laboratory (LMA) of the Department of Agricultural Engineering at the Federal University of Viçosa (DEA/UFV). The monitoring system was developed containing two components: modules for collecting and sending data, and a server. The server was used to store the obtained data.

The data collection modules consisted of DHT22 sensors (model AM2302; temperature measurement range from – 40.0 to 80.0°C and 0.5 °C accuracy; humidity measurement range from 0 to 100% and 2% accuracy; Aosong Electronics Co. Ltd., Guangzhou, China), that were connected to Arduino Pro-Mini boards (ATmega328P microcontroller; 5.0 v supply voltage; 16 MHz clock speed; Atmel Corporation, San Jose, USA). The Arduino Pro-Mini boards were connected to NRF24L01 Wireless Transceiver modules (3.3 v supply voltage; 1uA supply current; 2.4 Ghz frequency; Nordic Semiconductor, Cupertino, USA), which carried out the transmission of temperature and humidity data collected, as well as the ID of each "slave" collection module for a "master" module. The modules for collecting and sending data consisted of: 2 "slave" modules, containing 1 Arduino Pro-Mini, 1 NRF24L01 Wireless module and 1 DHT22 sensor module; and 1 "master" module which, in addition to 1 Arduino Pro-Mini, 1 NRF24L01 Wireless module and 1 DHT22 sensor module, had 1 ESP32 module (Model WROOM-32D; 4.5~9.0 v operating voltage; 500mA current maximum consumption; 520 Kbytes RAM memory; with WiFi 802.11 b/g/n 2.4 to 2.5 GHz, and Bluetooth BLE 4.2). In the master module, temperature, humidity and ID data were sent to the ESP 32 module by the UART (Universal Asynchronous Receiver/Transmitter) communication protocol. The development of programs for the "master" and for the "slaves" was carried out using the IDE (Integrated Development Environment), Arduino opensource software development platform (C++ language).

Through the ESP32 module, the "master" was connected to a wireless internet network (Wi-Fi) and sent data to the server in the form of a web address, by the GET method (Fielding and Reschke, 2014). The data set sent to the server consisted of the following variables: date and time the data was sent; and dry air bulb temperature (t_{db}) and relative humidity (RH) data from the master and slave modules, which had individual IDs (0, 1 and 2).

The program used to save the data on the server, developed in PHP language (Hypertext Preprocessor), was inserted in the free hosting service 000WebHost powered by HOSTINGER[®], used to store data for IoT. The data set was stored in the hosting service in TXT (text) format, and a link was generated for remote access, allowing access and processing of data by Python language, or download, when necessary.

To validate the developed system, the data collection modules were installed in a room at the Nucleus of Research in Ambience and Engineering of Agro-industrial Systems, in the Department of Agricultural Engineering of the Federal University of Viçosa (latitude $20^{\circ}46'18''$ S, longitude $42^{\circ}52'21''W$, and altitude 688 m). In that room, a commercial recording sensor was also installed (HOBO[®], model UX100-003; temperature measurement range between -20.00 and $70.00 \,^{\circ}C$, and $0.21 \,^{\circ}C$ accuracy; measurement range of relative humidity between 0 and 100%, and 3.5% accuracy). This sensor was properly calibrated, and was considered a reference standard instrument for measuring t_{db} and RH, as demonstrated in a study conducted by Freitas et al. (2019).

The collections, with the developed system and the commercial recording sensor, were carried out over three consecutive days, in December 2022. The commercial recording sensor was programmed to collect data at regular intervals of 5 minutes, $24 \text{ h} \cdot \text{day}^{-1}$. The developed monitoring system was programmed to send data at regular intervals of 1 minute. However, there could be delays in receiving the response by the server, as well as sending errors, causing irregularities in the time between submissions and/or data loss. To evaluate the performance of the monitoring system in relation to receiving data, the frequency of success receiving (*FS*, in %) was calculated:

$$FS = \left(\frac{N_{D.Received,i}}{N_{D.Expected}}\right) \cdot 100 \tag{2}$$

where $N_{D.Received,i}$ is the number of data received on experimental day *i*; and $N_{D.Expected}$ is the number of data expected in one day (1440).

To check if the failures between sending data to the server occurred in isolation or continuously, the data reception intervals (*DRI*, in minutes) were calculated:

$$DRI = T_i - T_{i-1} \tag{2}$$

where T_i is the receipt time of the i-th data at the server, in time format; and T_{i-1} is the receipt time of the data immediately preceding the i-th data sent to the server, in time format.

From the intervals of data receipt during the three collection days, the largest intervals in which there was no data receipt on each day were ranked. These intervals were used to verify whether failures in data reception by the server



occurred continuously or isolated.

The initial evaluation of the data obtained through the developed collection modules, compared to the commercial recording sensor, was carried out using descriptive statistics. For each sensor, hourly average values of t_{db} and RH were extracted, with standard deviation, and behavior curves were generated throughout the day.

To verify the agreement between the t_{db} and RH readings obtained with the developed sensor modules, in relation to the data obtained through the commercial register sensor (standard), the root mean square error—RMSE was used (Elanchezhian et al. 2020):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - p_i)^2}{n}}$$
(3)

where y_i is the i-th observation of the independent variable (t_{db} or RH obtained by standard register sensor); p_i is the i-th observation of the dependent variable (t_{db} or RH obtained by DHT22 sensor modules); and n is the observations number.

The RMSE calculations were performed for each sensor module, on each of the three collection days and, from the daily data, average data were obtained.

Finally, to relate the t_{db} and RH values obtained by standard recording sensor with the values recorded by the developed collection modules, calibration equations were obtained by linear regression analysis:

$$y_i = \beta_1 \cdot x_i + \beta_0 \tag{4}$$

where y_i is the value of the interesting variable (t_{db} or RH); x_i is the value of the interesting variable (t_{db} or RH) recorded by the DHT22 sensor; β_1 is the angular coefficient; and β_0 is the linear coefficient.

Results and Discussion

As can be seen in Table 1, of the total data expected to be received (1440), 119, 112 and 92 data were not received on experimental days 1, 2 and 3, respectively. The non-receipt of the expected data number may have occurred due to sensor reading failures, data sending failures and/or delays in receiving data by the server, which cascaded down subsequent transmissions.

Table 7. Frequency of successful data uploads to the server over each of the three experimental days.

Deromotor	Exp	Maan		
Parameter	1	2	3	Mean
Number of data received	1321	1328	1348	1332
Frequency of success receiving (%)	91.7	92.2	93.6	92.5

Failures in sensor readings can compromise the sending or the quality of the dataset, if sent to the server. Pramono et al. (2022) evaluated data readings by DHT22 sensors and reported the occurrence of reading failures (NaN – Not a Number) in 8.56% of the data read. In this study, all data sent in the three collection days were numerical readings and consistent with expected t_{db} and RH values. Therefore, it is plausible to state that the quality of the data obtained was not compromised by NaN-type reading failures.

Another factor that can compromise the amount of data sent is the delay in relation to the pre-established time. Afifie et al. (2021) developed a self-configured network in IoT sensor devices, in order to improve the quality of independent data collection and, even with the implementation of the network, verified delay values between 2 and 9 ms. In the present study, the IoT device was connected to the internet through a Wi-Fi network, through a router (Internet signal intermediary). The values of delay in sending the data were not evaluated quantitatively, but it is estimated that they were higher than those obtained by the mentioned authors. By checking the data set, it was observed that, in some cases, there were delays of seconds between consecutive submissions. Certainly, these delays were one of the factors responsible for reducing the amount of data received by the server.

When assessing whether the non-receipt of data occurred in isolation or continuously over the collection days, maximum DRI values equal to 5.43 min, 5.13 min and 4.14 min were obtained on days 1, 2 and 3, respectively. These results are an indication that failures did not occur continuously, since, during the experimental period, the lowest number of non-receipts was 92 (3rd day). It is estimated that the occurrence of short intervals without sending data to the server does not constitute a problem for the monitoring of animal production facilities, since the variables behavior that make up the thermal environment does not vary abruptly over time (Baêta and Souza 2010).

The hourly average t_{db} and RH curves (with standard deviation) obtained for each of the DHT22 sensor modules and for the commercial recorder sensor are illustrated in Figure 1. The hourly average values of t_{db} recorded by the three DHT22 sensor modules were very close to each other, as well as the values obtained using the commercial recording sensor (Figure 1a). Such results were already expected, since this sensor model provides accurate measurement of the environmental temperature, being recommended by several authors for the accurate evaluation of this climatic element



(Ahmad et al. 2021; Veerachamy et al. 2022).

For HR, however, the average hourly values obtained using the DHT22 sensors were always higher than those obtained using the standard recording sensor, with mean differences equal to 12.36, 12.53 and 5.65% being observed for the DHT22₁, DHT22₂ and DHT22₃ sensors, respectively. In fact, accurately measuring HR is a challenge that has not yet been overcome, since capacitive sensors are normally used for this purpose. The improvement of capacitive sensors is a demand of unique importance and, therefore, scientists from different countries have been working with this theme (Kaplya et al. 2020).



Figure 1. Average hourly profiles, with standard deviation, of dry air bulb temperature— t_{db} (a) and relative humidity—RH (b) throughout the day, obtained with sensors DHT22₁, DHT22₂, DHT22₃ and Hobo UX100-003 (Standard).

Table 2 lists the RMSE values obtained for the t_{db} and RH data from the developed collection modules, compared to the readings from the commercial register (standard). As can be seen from the mentioned table, the DHT22 sensors showed RMSE for t_{db} variable between 0.20 and 0.40 °C over the three experimental days, with the lowest mean RMSE value being obtained for the DHT22₁ sensor (0.23 °C). For RH, the RMSE varied between 5.54 and 12.55%, with lower values obtained for the DHT22₃ sensor (5.66%).

Table 2. Root mean squared error for dry air bulb temperature (t_{db}) and relative humidity (RH) values obtained using DHT22 sensors, in relation to the standard recording sensor (HOBO[®] UX100-003).

Experimental		t _{db}			RH	
day	DHT22 ₁	DHT22 ₂	DHT223	$DHT22_1$	DHT222	DHT22 ₃
1	0.27	0.27	0.34	12.25	12.44	5.64
2	0.21	0.27	0.27	12.40	12.55	5.81
3	0.20	0.26	0.40	12.36	12.47	5.54
Mean	0.23	0.27	0.34	12.34	12.49	5.66

When evaluating the RMSE values in relation to the errors reported by the manufacturer [0.5 °C and 2%, for t_{db} and RH, respectively (Aosong Electronics Co. Ltd. 2022)], it was found that the mean values obtained for t_{db} were within the expected range. However, for RH, the mean RMSE values were higher than the error reported by the developer of the DHT22 sensor, which is yet another indication that measuring relative humidity using the capacitive method is still a challenge for scientists of the current generation.

Shuhaimi et al. (2020) developed IoT-based embedded systems for application in the residential plants cultivation in urban environments, using DHT11 and DHT22 sensor modules. For the DHT22 sensors, the authors reported the occurrence of mean absolute error values equal to 2.66 °C and 4.28% for t_{db} and RH, respectively, in relation to the values measured with standard commercial registered sensors. In this study, the concordance assessment of readings between the DHT22 sensors and the standard commercial recorder sensor was performed using the RMSE, and the results achieved were different from those reported by the authors.

Since good agreement was not obtained between the RH values measured using the DHT22 sensors in relation to the commercial recording sensor, it is inferred that its use can be done in animal production facilities, if adjustment readings procedures are carried out (use of calibration curves). Figure 2 illustrates the t_{db} and RH calibration curves obtained for each of the DHT22 sensors used in this study.

To obtain the calibration curves, data related to the period from 07:30 a.m. at 02:30 p.m., interval in which the t_{db} and RH data were observed to show approximately linear increase and decrease, respectively. By observing the hourly behavior of temperature and relative humidity of the air obtained using the DHT22 sensors (Figure 1), it was evident that the difference between the t_{db} and RH readings is approximately constant in relation to the standard sensor, over a 24-hour period. Therefore, using a period of less than 24 hours would not harm the adjustment. It should also be noted that this definition made it possible to use the linear model to obtain the calibration curves, which are more parsimony in relation to the exponential, logarithmic and polynomial models.

Through figures 2a, 2b and 2c, it was verified that the adjusted curves for the t_{db} data showed good agreement between values measured by the sensor and corrected values (obtained via standard recording sensor). For the t_{db} adjustments, the lowest R^2 value was obtained for the DHT22₃ sensor (0.9804), while the best fit was obtained for the DHT22₁ sensor (0.995).

For RH, on the other hand, the calibration curves obtained showed less agreement between values measured by the DHT22 sensors and corrected values (Figures 2d, 2e and 2f). For such curves, the best and worst fit were also obtained for sensors DHT22₁ ($R^2 = 0.9386$) and DHT22₃ ($R^2 = 0.9039$), respectively. From these results, it is inferred that obtaining calibration curves using other models (exponential, logarithmic, polynomial, etc.) can more reliably portray the RH data behavior obtained by DHT22 sensors.



Figure 2. Calibration curves obtained for dry air bulb temperature (t_{db}) and relative humidity (RH) data collected with sensors (a,d) DHT22₁, (b,e) DHT22₂ and (c,f) DTH22₃. t_{db-Adj}—adjusted dry air bulb temperature reading; t_{db-DHT22}—dry air bulb temperature reading obtained by DHT22 sensor; RH_{Adj}—adjusted relative humidity reading; and RH_{DHT22}—relative humidity reading obtained by DHT22 sensor; and R²—coefficient of determination.

Conclusions

In this study, an embedded system was developed and validated for real-time monitoring of the thermal environment in facilities for animal production, using affordable electronic components, wireless communication protocols and the Internet of Things (IoT).

The developed environmental monitoring system proved to be capable of collecting and sending interesting data to a cloud server with a success rate of sending data greater than 90%. Through the developed system's data collection modules, values of dry air bulb temperature (t_{db}) were obtained with good agreement in relation to a commercial recording sensor (RMSE range from 0.23 to 0.34), but values of relative humidity (RH) always higher than desired



(RMSE range from 5.66 to 12.34). For this reason, it was necessary to obtain calibration curves for the data obtained by developed collection modules.

The embedded system for monitoring the thermal environment developed has potential for use in agro-industrial facilities. However, it is recommended that further studies be conducted, with the purpose of correcting failures in data transmission, testing new low-cost t_{db} and RH sensors, and evaluating these components performance in field situations.

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Validation of a Real-Time Location System for Dairy Farms. A Case Study

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Abstract

Indoor real-time location systems (IRTLS) are beginning to be used on dairy farms. In this paper a case study methodology is described for validating the accuracy of an IRTLS in a cattle barn (67,45x36m) with 19 fixed anchors and animals equipped with an electronic label attached to the ear. Wireless tags attached to the cow's ear send low-frequency signals to the fixed anchors to determine its location inside the building. Real time cow location facilitates in large herds many daily tasks that require searching for individual animals, besides cow location is an important parameter that can monitoring behaviour and measuring the time budget in dairy cows. Behaviour can be a good indicator of animal health and welfare problems so thus they can be used as an early warning system. Two different test was realized, static and dynamic test, with two labels on a stick located to 75 and 125 cm. The overall average accuracy in static test was 1,92 m with a standard deviation of 1,58 m. In dynamic test was 2,74 m with a standard deviation of 1,69 m. It seemed that the accuracy was negatively affected by position changes. The system includes a set of software for tag tracking, data processing and planning configuration tools with daily time budget spent by cows in the different areas of the building. This case study data has not been accurately enough to monitor the time budget of the cows.

Keywords: Precision Farming, Indoor Location System, Cow Track, Anchors, Dairy

Introduction

Precision dairy farming can be defined as the use of information and communication technologies for improved control of fine-scale animal and physical resource variability to optimise economic, social, and environmental dairy farm performance (Eastwood et al., 2012). Under the name of Smart Dairy Farming (SDF) or Precision Dairy Farming (PDF) are encompassed a series of sensor-based systems that can acquire data continuously, automatically and in real time of numerous parameters related to production, production quality, behavior, activity, location, health, feed consumption, body condition, time of calving and fertility of the cow. The general architecture consists of one or more sensors that capture the data, which are transferred to a base station, the base station can send them to the cloud or treat them in situ with specific software, the data is analyzed using different techniques and methods, the software will send alerts to the farmer, in some cases it can predict future events and in general will help in the management of the herd (Akbar et al., 2020; Borchers and Bewley, 2015).

Precision Technologies (TP) are becoming one of the pillars of the sustainability of the production system and represent for many, the hope of improving working conditions on farms in a way that is more attractive. They allow monitoring of animals and farms, can improve animal welfare, increase the efficiency of animal production and decrease the environmental impact of livestock production, thus improving society's perception of the sector, by demonstrating the commitment of farms to the environment and the development of strategies that improve animal welfare (Laca, 2009; Rutten et al., 2013).

One of these technologies are the indoor positioning systems (IPS) used to know the location inside the barns of dairy cows. The IPS can be used not only to know the real-time location of each animal inside the farm, but also to know the distribution of time throughout the day of each individual animal and the herd, in general, in the different areas of the barn (milking, feeding, rest, corridors, drinking troughs, etc.). The importance of time budgeting in dairy cattle is well known. In general, dairy cows spend 3 to 5 h/d eating, consuming 9 to 14 meals a day, ruminate 7 to 10 h/d, require about 10 h/d of resting time, spend about 30 min/d drinking, and 2 to 3 h/d in management and milking activities (Grant and Albright, 2001). Any factor that limits the time needed by the animal for feeding, rumination and rest, or that may cause fear, discomfort or stress, can affect production and therefore the performance of the system.

Economic aspects play a central role in the adoption of TP, being largest adoption where it allows to increase yields and reduce production costs, traditionally in situations where the availability of labor is low or expensive. Strategic planning, which allows estimating the financial impact of implementing TPs, is essential. The estimation of the financial consequences is not always predictable, a wide variety of factors influence decision-making, there are multiple options, and this makes it more difficult to make the right decision since many producers are simply unaware of the available technologies (Russel and Bewley, 2013).

It is essential to have the necessary information to discern which technology will be best suited to each case, and meet the expectations placed on them. For the technology to be useful and economically viable, physiological or animal behavior variables must be measured continuously and this information must be continuously analised with precision and ease with reliable algorithms on which decision making will be based. (Berckmans, 2006). In this work we have



developed a working methodology that allows to validate at farm level the reliability and accuracy of the IPS that are beginning to be installed in dairy farms.

Materials and Methods

The works were carried out in the experimental and teaching Campus Terra farm, of the University of Santiago de Compostela (USC), located in Castro de Riberas de Lea (Lugo) and in the Higher Polytechnic School of Engineering, in the first months of the year 2022. The experimental and teaching farm of the USC has some of the latest advances in PDF: Radio frequency identification, robotic milking system VMS 300 (DeLaval, Tumba, Sweden), online somatic cell counter (OCC), body condition scoring camera (BCS), remote monitoring of the milk tank, advanced monitoring system Smartbow (MKW electronics GmbH, Jutogasse, Austria) with real-time rumination, activity and location measurement, administration and control computer systems DelPro (DeLaval) and Smartbow.

The Smartbow (SB) system consists of a set of antennas of fixed and known position, in variable number depending on the dimensions and obstacles of the building (19 antennas in our experimental farm), ear tags carried by each of the animals - each tag contains a radio chip, accelerometer and battery inside, data from accelerometers were not used for this study – a server and computer system (Software + PC). For the system to locate the animals, the carried tag must be within reach of a minimum of three antennas to fix the position in two dimensions (x, y), or four antennas to fix the position in three dimensions (x, and Z). By triangulating the relative position of each tag in relation to the distance to the antennas, in a similar way to the operation of GPS systems used to locate vehicles outdoors, the system is capable of locating the position of the animals on the farm (Figure 1).



Figure 1. Reference screen with the real-time location of the animals (experimental and teaching farm of the Provincial Council of Lugo / USC). \otimes Antenna position

Reference coordinates.

It was not possible to access the coordinate file of the system, so to validate the precision in the location we established our own reference system, formed by a matrix with cells of 0.5m. x 0.5m. The position offered by the software was compared with the real position (figure 2), calculating the position error (h), with the simple application of the Pythagorean Theorem.





Figure 2. Sistema de referencia para determinar el error de posición (h), distancia entre posición real y posición asignada por el software (en la figura $h = \sqrt{6^2 + 3^2}$)



Static reference measurements.

We use a stick to which we attach two SB tags at different heights, and a laser measurement system (GLM 50C Bosch). One tag at 76 cm represents the typical position of an animal lying down, the other at 155 cm high represents an animal walking or standing (figure 3).



Figure 3. Two tags, at 75 and 155 cm in height respectively, were coupled to a stick for data collection of static reference measurements.

50 reference points, of fixed position and known throughout the building, were established by the areas of access of the animals (stalls, feed table, alleys, milking) In each of the points the stick was positioned, with the two tags placed, for a period of 2 minutes without performing any type of movement (static test). The time of arrival at the point (hh:mm:ss) and the time of departure (2 minutes later) were recorded, after two minutes the stick was changed to the next point and so on repeating the procedure until completing the 50 points set in the building (Figure 4).



Figure 4. Distribution of fixed and known position points for performing static reference measurements.

Simultaneously to the point-to-point data collection, the locations were recorded in the software, recording the position offered at intervals of 20 seconds for each of the reference positions (2 tags, 50 positions, 7 data per tag and position, 700 data). The data was passed to Excell (Microsoft Corp.) and the recorded data was compared with the



actual position (6 data for each of the 50 positions) using the reference coordinate matrix to calculate the position error, using a conversion factor of 0.5 to transform the calculated distances to meters. Once the distances were obtained, a descriptive statistical analysis was performed using IBM SPSS Statistics.

Dynamic test.

Simulating real conditions of cows movement through the barn, the track represented in figure 5 was followed with the tag placed at 155 cm. A total of 34 stops of variable duration (between 5 seconds and 9 minutes) were made, recording the time of arrival, the time of departure (hh: mm: ss), and the position reflected by the software at 10-second intervals for each waypoint The itinerary was designed in such a way that data were obtained from all areas of the housing through which the animals have freedom of movement.



Figure 5. Followed track in the dynamic test.

A total of 236 data were recorded taking into account the stopping times in each position. To calculate the position error, the reference matrix was used following the same procedure described for the static test. Data were linked to three zones: feed table, stalls and exercise alleys.

Results and Discussion

Static test

Of the 700 expected data, 686 were valid, 14 were lost due to several incidents in data collection. The representation of the position errors measured in the 50 reference points (figure 6), shows a high deviation with values ranging from 0 to 17 m, measured following the reference system defined in methodology.

Only 23.8 % of the data were found to be 1 meter or less from the true distance, 78.4 % of the data were at a distance less than or equal to 2.5 m (75th percentile), close enough for an operator to locate the animals without difficulty and perform the different daily handling tasks, but insufficient to define with acceptable precision the time that cows spent by different areas of the holding, which is necessary to determine precisely the time budget of individual animals and of the herd in general. The number of outliers is variable depending on the position, 33 if the data are taken for each position, 17 treating all the data together.



Figure 6. Observed values for position error at the 50 points defined in the static test.

Measured position error turned out to be 1.91 ± 1.58 meters. Grouping data and analyzing them separately for 5 areas of the farm (feed table, feeding exercise alley, central stalls, rest exercise alley, and side stalls), we can see that there are substantial differences between zones (Table 1). The area with greater precision is the feed table (1.21 ± 1.16) and feeding exercise alley, instead the greatest error is given in the area furthest from the feed table in the side stalls (2.92 ± 2.36).

These data contrast sharply with those offered by other authors (Chapa et al., 2021; Ipema et al., 2013), who observed for similar devices accuracy values of 30.5 cm with a standard deviation of 25 cm and a sensitivity greater than 70% in alleys, around 90%, or slightly higher, for stalls and feed table, and specificity values greater than 90% in alleys and greater than 80% for the rest areas. One could think of an inadequate distribution of the antennas, more focused on the feeding area, however the central stalls area has a higher error (2.15 ± 1.35) with respect to the rest alley area (1.76 ± 1.07) that is separating both lines of stalls and that have the greatest margin error, one might think that areas with a large number of metallic elements could generate some kind of distortion in the signal between the tags and the antennas, but the latter does not agree with the feed table area, where the highest precision is achieved.

		Confidence interval 95%					
Position	Ν	Mean	SD	Lower	Upper	Minimum	Maximum
Feed table	137	1,21	1,16	1,01	1,40	0,00	7,62
Feeding exercise alley	133	1,55	0,97	1,38	1,72	0,00	7,16
Central stalls	140	2,15	1,35	1,93	2,38	0,00	7,63
Rest alleys	140	1,76	1,07	1,58	1,94	0,00	6,04
Side stalls	136	2,92	2,36	2,52	3,32	0,50	17,01
Total	686	1,92	1,58	1,80	2,04	0,00	17,01

Table 1. Position error obtained by zones in the static test, (SD= standard deviation)

Dinamic test

A total of 232 valid data were obtained, 4 data were lost due to incidents in data collection. The measured position error turned out to be 2.74 ± 1.69 meters, which means a lower accuracy than that measured in the static test (1.91 ± 1.58). Observing the aggregation of data by zones (Table 2), we found that the error is lower in the feeding area (feed table) with an average value of 1.50 ± 1.57 meters and much higher, 3.01 ± 1.55 in the exercise areas (alleys). This last data contrasts with the results obtained in the static test, in which the errors of greater magnitude were observed in the rest areas (stalls).



	Confidence interval 95%						
	N	Mean	SD	Lower	Upper	Mínimum	Máximum
Fedding	29	1,50	1,57	0,91	2,10	0,00	7,16
Stalls	77	2,76	1,76	2,36	3,16	0,00	10,31
Alleys	126	3,01	1,55	2,74	3,28	0,50	8,28
Total	232	2,74	1,69	2,52	2,96	0,00	10,31

Table 2. Position error obtained by areas of the building in the dynamic test.

Only 15.9 % of the data were found to be 1 meter or less from the true distance, 50.4 % of the data were found at a distance less than or equal to 2.5 m (75th percentile), although the values differed considerably between the different farm areas (Figure 7), with differences that turned out to be significant (P<0.05). Thus, 50% of the data were found at 1 m or less for the feeding area while approaching 2.5 m for the rest area and almost reaching 3 m in the exercise area. Thus, 50% of the data were found at 1 m or less for the feeding area, while approaching 2.5 m for the rest area and almost reaching 3 m in the exercise area. We are inclined to think that frequent changes in position negatively affect accuracy and that the differences observed between the zones are multifactorial, probably due to the interaction between the distribution and number of antennas (the number of antennas should be increased), the proximity to the walls of the building and the presence of metallic elements, but more research is required in this regard to reach relevant conclusions.



Figure 7. Observed values for position error by dairy housing zones.

Conclusions

Methodology we have used is useful to validate the accuracy of the indoor real time locating systems in dairy housing, although it would be desirable that IRTLS computer systems to offer the numerical value of the reference coordinates. Using the reference system formed by a matrix with 0.5m cells. x 0.5 m global precision values of 1.91 ± 1.58 meters have been obtained for the static test and 2.74 ± 1.69 for the dynamic test, finding significant differences between the different areas of the housing that they turned out to be significant between the feeding zone (1.50 ± 1.57), the rest zone (2.76 ± 1.76) and exercise zone (3.01 ± 1.55). Regardless of the fact that some elements such as walls or metallic structures can affect the precision of the IRTLS, we consider that in the analyzed case study the number of antennas should be increased in order to reach precision values found by other authors in similar installations.

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Enhancement of Land-Use Capacity of Rural Properties Based on Geoprocessing Techniques

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Abstract

Land-intensive agricultural practices have often been performed without proper planning, which leads to inefficient utilization of such spaces, especially in societies that majorly rely on these practices. Mechanizing agricultural production emerges as a crucial factor in the management of crops when used with the right operation and environment preparations for safe usage, as it can optimize processes such as harvesting and soil preparation. Therefore, it is essential to prioritize the dynamic and intelligent identification of areas suitable for mechanization. The advancement of geoprocessing techniques and best practices in manipulating geospatial data has enabled the optimization of natural resources and a greater focus on environmental services worldwide. By employing these techniques in conjunction with data sources like Digital Elevation Models (DEMs) to determine land slope, information on soil classes, and insights into soil usage, it becomes feasible to construct an index for assessing agricultural production. Centered on enhancing the existing potential of rural properties within the economically, culturally, and environmentally diverse region of Rio de Janeiro State, Brazil, this study encompasses a range of parameters essential for implementing mechanized operations across these areas. To achieve this, the methodology was applied exclusively to the open-use areas of the registered properties. Those areas designated for biodiversity conservation were excluded from the total land area under consideration. As a result, an expansion of 926,46 km² and 1284,41 km² was identified, corresponding to 7,74% and 10,73% of the available land area, respectively. These calculations were conducted using varying image resolutions.

Keywords: Mechanized agriculture, geoprocessing, land-use optimization, agricultural production.

Introduction

The imperative of harmonizing agricultural production with acceptable environmental conservation standards becomes more pronounced as the demand for food escalates in countries regarded as major global players, shaped by climatic and environmental factors. This necessity underscores studies and research aimed at this nexus (Borlachenco & Gonçalves, 2017), which are rooted in propelling the optimization of land use in tandem with sustainable development (Alves & de Oliveira, 2022; Hu et al., 2022).

Structuring a comprehensive work plan encompassing these measures requires the strategic application of technological innovations capable of addressing this diverse range of factors. Within this framework, the adoption of precision agriculture techniques and the integration of advanced agricultural machinery can significantly enhance production, streamline processes, and offset the decreasing labour availability in the agricultural regions of southeastern Brazil (IBGE, 2010; Laurance et al., 2014; Oliveira et al., 2020; Sobroza Becker et al., 2021).

Targeted studies offer heightened process efficiency and more precise outcomes for the agricultural sector. Within this context, the investigation geared towards augmenting the production capacity of rural properties gains prominence, driven by the application of technologies in areas with latent potential (Artuzo et al., 2017; Nascimento et al., 2022).

Embedded within this technology-driven approach, precision agriculture harnesses geoprocessing techniques that leverage the manipulation of spatial data to delineate planting zones, evaluate soil conditions, and facilitate efficient production strategies (Carmo et al., 2022). As a result, the implementation of these techniques orchestrates the fusion of local attributes in the study to enhance both agricultural production and machinery utilization, while also tailoring the approach to properties of significant focus.

For this purpose, the study centred around analysing the potential for agricultural activity expansion on rural properties alongside the integration of machinery, thereby enhancing and optimizing local production processes. The evaluation parameter revolves around promoting and facilitating public initiatives, with the aim of offering substantial contributions that lead to actionable measures for advancing rural production structures.

Materials and Methods

Area of interest

Encompassing a total area of 43.750,425 square kilometres, with 6,47% classified as urban territory, the State of Rio de Janeiro, Brazil, is situated in the southeastern region of the country. Bordered by the Atlantic Ocean, the state hosts a diverse array of fauna and flora within the Atlantic Forest biome. These characteristics underscore the ongoing attention to both ecological conservation efforts and economic development. This ecological balance has been a subject of



research focus in this region (Siminski et al., 2016), aiming to strike a balance between agricultural development and mitigating extreme environmental degradation.

Within the national framework for overseeing the rural sector, a unified system governs the management of rural properties, mandating compliance with prevailing legislation and categorization based on usage. The National Rural Environmental Registry System (Sicar) publicly disseminates spatial data of registered properties, thereby fostering initiatives aimed at effectively applying and enhancing the potential of these rural holdings.

Refinement for open-use areas

When extracting data from the Rural Environmental Registry (CAR) within the Sicar database, it allows for obtaining information at the municipal level for each property. This process involves employing dedicated vector models tailored to various types of information, including property area, permanent preservation areas, native vegetation, and more.

As the entirety of the registered properties is represented in layers corresponding to the property area, it becomes imperative to determine which sections of these properties possess suitability and authorization for mechanized agricultural activities. To address this, five types of vector data have been singled out as restricted use, in alignment with the specifications outlined in their definitions, which prohibit agricultural exploitation of the land. These categories encompass Legal Reserves, Permanent Preservation Areas (PPAs), Consolidated Areas, Restricted Use Areas, and Native Vegetation.

The vector layers denoting restricted land use were consolidated to form a novel vector layer, encompassing all the zones of restricted usage within rural properties. Empowered by this dataset, the subsequent step involved determining the areas within the registered properties that are sanctioned for agricultural activities.

Implemented within a geoprocessing software, the data concerning all rural properties and the restricted areas within them underwent an overlay process. This technique enables comparative analyses of the input data, enabling the extraction of differences between them—specifically, areas that do not intersect. As a result, this method functions efficiently to generate the resulting areas available for use and potential application as zones for mechanized cultivation.

Environmental conditions for local suitability

The creation of an effective model necessitates the organization of pertinent data with substantial impact. Concerning land application, critical attributes encompass land use, terrain coverage, soil horizon classification for fertility evaluation, adaptability to diverse crop cultivation, and ensuring sufficient stability for machinery deployment.

The vector data related to soil attributes were obtained from freely accessible public databases. The identification of target areas within pastures was based on the overlay of this data with soil classes favouring both annual and perennial agricultural production, as well as the application of machinery. Consequently, a soil database developed by the Brazilian Agricultural Research Corporation (EMBRAPA) was processed to isolate the respective features associated with Argisols, Cambisols, and Latosols classes.

The resulting intersection, produced and developed using programming principles through the Python language, now awaits the fulfilment of specific conditions to ensure the secure operation of agricultural machinery. Given the scarcity of rural labour in the study locality, the effective utilization of machinery can significantly amplify the productive potential of rural properties.

Mechanized operations: ensuring fit and secure performance

In order to enhance agricultural production through the use of machinery, it is essential that the chosen terrain adheres to the principles of safe operation. When the soil types are well-suited for the implementation of such equipment, the established criteria are contingent on the topography of the land.

The investigation of the terrain initiates with the employment of Digital Elevation Models (DEMs), satellite imagery that accurately represent the elevation profile of the Earth's surface. Through the creation of image mosaics, the slope can be extracted using raster data manipulation tools. Subsequently, elevation data is refined by overlaying it with a composite vector mask layer. This step aims to gain a comprehensive understanding of the areas primed for agricultural expansion.

To further enrich the analysis and establish parameters for discussing results, the study aimed to validate two Digital Elevation Models (DEMs): the RJ 25 project with a spatial resolution of 20 meters, and the Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 90 meters.

Enhancement of land-use capacity

With the relevant data at hand for optimizing agricultural production, determining areas of improvement within rural properties involves overlaying this data onto the pre-defined open areas designated for agricultural use. In this context, the distribution of suitability information within these areas is assessed, and the potential for enhancement is quantified

Results and Discussion

Comprehending the scope and distribution of the area of interest is a crucial facet for driving statistical analyses forward, and it assumes a significant role within geospatial manipulations. With the objective of enhancing rural property capacities, attention was directed towards land use and coverage details, particularly within pasture areas suitable for agricultural utilization. As of the first semester of 2021, the state of Rio de Janeiro featured registered rural properties spanning a vast expanse of 44.070,74 km². This comprehensive coverage encapsulates all sub-classifications attributed to a property, with a substantial 11.974,96 km² delineated as areas open for unrestricted usage – the very focus that intricately directed the analytical examination.

This measurement bears historical importance for the evolution of local economic and cultural landscapes, as the state's history is entwined with coffee cultivation in the Paraíba Valley and sugarcane production in the northern areas (Pereira de Melo & Adilson De Oliveira, 2017; Santos & Lima, 2015). The trajectory of local progress extended into the oil & gas sector, yet with the escalating need for food production and the assessment of local expansion capabilities (Marin et al., 2016), the possibility emerges to stimulate investment campaigns and agricultural exploration within the locality.

Based on the data overlay analysis, it was revealed that, within vector fronts, the open areas encompassed 37,02% of their territory with suitability for expansion according to the established environmental criteria. However, the operationalization of agricultural machinery necessitates safety conditions rooted in the undulation of the application terrain. As demonstrated by Silva et al. (2009) the secure operation of machinery adheres to a maximum gradient of 20%, preventing overturning and allowing the machinery to function at its maximum capability.

Addressing this necessity, the manipulation of DEMs provides a convenient approach to determine the terrain's slope within the study area. By overlaying the vector data onto the open study areas, it became possible to identify, through the representations derived from RJ25 and SRTM raster images, areas suitable for cultivation, accounting for 7,74% and 10,73%, respectively, as outlined in Table 1.

Dataset	Km ²	% of unrestricted usage areas		
Vector Data (Land-use and soil classes)	3.840,95	32,07 %		
RJ 25	926,46	7,74%		
SRTM	1.284,41	10,73%		

Table 8. Suitable areas among vector and raster Data.

Satellite imaging methodologies present varying applications based on the resolutions they encompass. Higher resolutions, such as those in the RJ25 dataset, deliver more detailed terrain descriptions, proving well-suited for focused analyses over smaller geographical areas (Amaral et al., 2009). On the other hand, the SRTM project operates with a coarser resolution of 90 meters, offering lower precision in comparison to the dataset under examination. However, SRTM data are extensively employed for extensive spatial analysis and environmental and hydrological studies (Chen et al., 2018; Melo et al., 2020), making them particularly fitting for statewide applications. Figure 1 portrays the distribution of viable areas resulting from the overlay with the SRTM project, offering a visual representation of the conducted analysis.





Figure 18. Distribution of suitable areas for enhancement in northern Rio de Janeiro.

Within the current framework, the geographical-physical analysis is given due consideration, delivering favourable results regarding the potential expansion of mechanized agriculture within underutilized areas of agricultural properties. However, in the crafting of public policies, this aspect assumes a pivotal role among the study factors, intricately woven into the economic, cultural, and ecological dimensions. These dimensions collectively validate the convergence of technological integration to elevate and refine productive processes (SILVA et al., 2006; Xavier Trindade & de Castro Nunes Pereira, 2019).

Conclusions

Efficient land use planning plays a pivotal role in optimizing agricultural production, aiming to minimize resource consumption while maximizing the value of the final product. Within this context, effective planning necessitates the selection of pertinent variables that lead to accurate outcomes. The integration of technology and agricultural machinery serves as an effective means of catalysing development and boosting productivity across diverse rural properties. The thoughtful design of applied methodologies determines the optimal deployment locations for such equipment. The presented study successfully identified soil and slope characteristics that provide the most favourable conditions for the proposed application, conducting a geospatial analysis-based comparison across varied imaging resolutions. This exploration unveiled an untapped expansion potential of 7.74% and 10.73%, respectively, within the unused areas of rural properties, as indicated by the RJ25 and SRTM projects.

However, the study represents just one facet of the multifaceted approach needed to drive actions that will directly influence the improvement of productive properties. Its focus on landscape and terrain must be accompanied and supported by studies encompassing cultural, economic, and ecological dimensions.

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Application of Drone with Multispectral Camera in Olive Grove to Assess Plant Health

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Abstract

Remote sensing can be an effective and useful monitoring tool for the vineyard, as data from sensors on board Unmanned Aerial Vehicles (UAV) can measure vegetative and reproductive growth and thus detect variability. Vegetation Indices (VIs) can be calculated through the images obtained from UAV, and compared with various agronomic characteristics of the vineyard. The objective of this study was to evaluate the multispectral response of the vineyard in three specific phenological phases and to analyze the spatial and temporal distribution of plant vigor. A multirotor UAV equipped with a camera featuring multispectral sensors was used to collect image data during the vineyard's growing season. Four vegetation indices (VIs): Normalized Difference Vegetation Index (NDVI), Normalized Difference Red Edge (NDRE), Green Normalized Difference Vegetation Index (GNDVI), Modified Soil Adjusted Vegetation Index (MSAVI), were calculated using the georeferenced orthomosaic UAV images. Computer vision techniques were used to segment these orthoimages to extract only vegetation canopy pixels. A high level of agronomic variability within the vineyard was detected. Pearson's coefficient showed a significant correlation between NDVI and NDRE indices and yield since early phenological stages (r=0.80 and 0.72). Shoot pruning weight (SPW) showed the highest values of correlation (r=0.84) with NDVI during the phenological stage of berries pea size. Simple linear regression techniques were evaluated using VIs as predictors of SPW, and accurate predictive results were obtained for NDVI and NDRE indices with lower RMSE values of 0.18 and 0.24, respectively. Assessing spatial variability and appreciating the level of vigor allows to improve vineyard management by increasing sustainability and production efficiency.

Keywords: precision oliviculture, remote sensing.

Introduction

In recent years, there has been an increase in olive growing and in the consumption of extra virgin olive oil (EVOO, [1]). It is cultivated almost entirely (over 98%) in countries of the Mediterranean area where traditional agronomic practices are used. However, a continuous change of landscape and cultivation techniques has been observed and requires appropriate agronomic choices for a successful crop. This situation, poses new challenges to ensure environmental and economic sustainability of olive farms [2]. These agronomic techniques are able to modify the vegetative and productive activity of the olive tree and require appropriate choices depending on the agro-climatic context (phytosani-tary management, irrigation, soil management, pruning, fertilization, etc...). Instead, the management of each single plant may depend on various conditions and thus requires differentiated management practices.

Since 1990's precision agriculture (PA) gave the farmer the possibility of changing crop management. Indeed, PA is a strategy of management which takes into account var-iability with the goal of increase crop efficiency and production quality and quantity. Var-iability can be expressed in several ways. As reported by Zhang et al., (2002) [3], variability affecting agricultural production can be classified into six groups: yield variability; field variability; soil variability; crop variability; variability related to abnormal factors; and management variability. Moreover, there are various sensors and platforms which can be used to investigate variability [4–6]. Senay et al., (1998) [5] distinguish three ways of measuring spatial variability in the field: continuously, discretely (e.g., point sampling of soil or plant properties), and remotely (e.g., through aerial photographs). Discrete sam-pling is generally characterized by a high precision of the investigated variable but cannot describe the complete variability and need precision geo-statistic techniques to spatialise the data [7–9]. Therefore, remote sensing represents the most important technique of ac-quisition data for olive growth in precision agriculture management [4,10]. This, can be performed using platforms at different distance from the object, which determines the area wideness [11,12]. Precisely, in the olive orchard the most important platform used is the Unmanned Aerial Vehicle (UAV, [4,6]) because it allows to determine huge areas in a low time of flight and can be equipped with different sensors [13,14].

In olive orchards traditionally managed, fertilizers and other inputs are applied at uniform rates without considering the field spatial variability [15]. This management may result in under-application or over-application of inputs with obvious economic and en-vironmental problems [16,17]. Furthermore, the abuse of the main agronomic source as fertilizers and water can compromise the quantity and the quality of the production [18,19]. Therefore, it is important to know the spatial variability of soil, crop and climate in order to apply the best site-specific management and to improve economic and environmental sustainability in olive orchard. Soil variability is probably able to determine a more

general state of fertility of the entire agro-ecosystem [7,20,21] while, the climate variability source is low modifiable. For this reason, it is better to investigate directly the crop charac-teristics.

The crop health status can be observed from several crop traits such as : nutritional [22,23], structural-biophysical [24,25], spectral [26], and productive [21,27]. The structur-al-biophysical status is strictly related to the vigour behaviour and can be measured in several ways such as TCSA (trunk cross section area) [9,26], LAI (Leaf Area Index) [24] or canopy volume [25].

The nutritional status is investigated using the analysis of leaves, as made by López-Granados et al., (2004) [22] who created a site-specific fertilization map for olive trees based on leaf nutrient spatial variability.

The knowledge of the biophysical characteristics of the plants is being very success-ful, in the last years, because it can be estimated using different sensors [28] such as Li-DAR [29], low cost RGB cameras [30], and other, with high correlation with the spatial health condition of the olive tree [31]. If the real conditions of the foliage volume were known precisely, it was possible to better regulate some treatments associated with it, such as phytosanitary treatments, obtaining considerable savings in economic and envi-ronmental terms [17,32]. The production of each plant is a good indicator of health status but can be determined only at the end of the year and can depend on other parameters [33].

Since the beginning of PA, the use of multi and hyperspectral information from the crop has increased because spectral information's are closely related to the health status of each tree. This information can be obtained through the use of Vegetation Index (VI),widely applied in the olive grove [4,34,35]. It is able to investigate with high precision a huge area and the main vegetative characteristics that are closely related with produc-tivity. Furthermore, by succeeding in modifying the vegetative characteristics, it is possible to achieve a vegetative-productive balance and maximum efficiency of the agro-ecosystem.

Recent advances in modelling and decision support systems (DSS) applied to agriculture promise to bring about important positive changes in olive orchard management. In order to be applied in olive grove, they require a high level of specific information providing a good understanding of the growing conditions of the plants [36,37]. In the literature, several studies have investigated the potential of the new technologies proposed for intelligent agriculture on the determination of certain crop parameters. Therefore the agricultural sector needs good indicators to accurately and reliably analyse multispectral plant information in order to be applied in precision agriculture using DSS [38–40].

Based on the above Tthe aim of this study was to investigate the ability of multispec-tral data acquired from a UAV platform to predict nutritional status, biometric character-istics, vegetative condition and production of olive orchard as tool to DSS.

Materials and Methods

Study area

The study area is located in Calatafimi Segesta (Trapani, Italy); it has a surface of 5860 m2 and a perimeter of 344 m with flat orography (Figure 1). According to the Kop-pen–Geiger's classification, the climate of the area is classified as Csa (Mediterranean hot summer climates; [41]). Climatic data of the year show a mean annual air temperature ranging from 18 to 22 °C and a mean annual precipitation of 550 mm (Sicilian Agromete-orological Information Service). The soil moisture regime is xeric, border with the aridic one, and the temperature regime is thermic.



Fig. 1. Geographical position of the study area in Sicily (Italy).



The study was carried out during the 2021 crop season in an olive orchard managed with ordinary practices in rainfall system. The olive grove, cv. Cerasuola, was in full productivity at the time of the experimentation. The plot layout has traditional training system with distance of 5 x 5 m; the total number of trees considered in the tests was 211 (Figure 2).



Figure2. Experimental olive grove.

Figure 3 shows the flowchart of the methods used for data acquisition and pro-cessing.



Figure 3. Overall flowchart of the experimental process

Field data collection

Plot perimeter and plants were georeferenced on DOY (day of years) 161 using the in-strument Stonex S7-G (S7-G, StoneX, New York USA) with differential RTK (Real Time Kinematic) correction as used in other studies to have a good accuracy and precision [42,43]. This instrument is able to receive L1 (1575.42 MHz) and L2 (1227.60 MHz) frequencies of the main constellation and it is also equipped with a slot for a SIM card and a GSM/GPRS/EDGE modem, in order to obtain real-time differential correction data from the RTK ground station network (CORS). On DOY 163 the TCSA at 0.50 m from the ground (trying to exclude any hyperplasic nodes typical of the olive tree) was measured for all plants [9]. On day 164, 50 trees were randomly selected from the field in which the height and diameter of the crown

were measured manually with a ruler.

Field samplings were carried out in order to investigate nutritional status using a regular 15m x 11 m grid on DOY 205 [22]. The sampling point was identified at the inter-section point (node) of the sampling grid, excluding the most external part of the field (Figure 3). A total number of 36 points was sampled. The sample was represented by an experimental unit of four adjacent olive trees. Each leaf sample consisted of four sub-samples of 25 healthy, fully expanded and mature leaves, collected from the central portion of the current season's unshaded branches at a height of 1.5 m above the ground surface, at the four cardinal points of each olive tree.



Figure 3: Sample grid and sample points used for nutritional and soil condition characterization.

After sampling, the leaves were dried at 70°C for 24 hours and milled to pass through a 0.25 mm mesh. Leaf samples were analyzed to determine the total nitrogen content (N) by the Kjeldahl method.

The olives were picked with a hand-held electric harvester model OLIVION P230 (Pellenc, France; Figure 4), when their maturity index was equal to 2.38, determined ac-cording to Furferi et al. (2010) [44]. Two operators had the task of laying and wrapping the nets under each plant. Finally, the production of each plant and that of the whole plot were evaluated quantifying the harvested olives using a proper load cell [45].



Figure 4. Field use of the Pellenc Olivion P230 shaker (a). Harvested olives (b).

2.3 Multispectral data from UAV and flight scheduling

Multispectral data were acquired through an aerial survey using a Phantom4 Multi-spectral (DJI, Shenzhen, China).

The Unmanned Aerial Vehicle (UAV) is equipped with four rotors on a rotating wing, one brightness sensor at the top. It is also capable of image position compensation as the relative positions of the CMOS sensor centers of the six cameras and the phase center of the on-board D-RTK antenna, are stored in the Exif in-formation of each image. The multi-frequency Global Navigation Satellite System (GNSS) positioning system can see and receive signals from the main constellations.

The multispectral camera has six 1/2.9" CMOS sensors, that is an RGB sensor for vis-ible light imaging and five monochrome sensors for multispectral imaging with a final resolution of 2.08 MP pixels. The monochromatic bands are Blue (B), Green (V), Red (R), Red-Edge (RE) and Near InfraRed (NIR), respectively with the following central wavelengths: 450 nm, 560 nm, 650 nm, 730 nm and 840 nm. The spectral resolution for R, G, B, RE bands is ± 16 nm and ± 26 nm for the NIR band. The lens has 62.7° FoV (Field of View), 5.74 mm focal length and f/2.2 aperture.

The flight was conducted in 2021 with automatic configuration using the waypoints and RTK mode for correcting geospatial data. The flight was performed at approximately 12:00 noon at a flight of 50 m, generating a ground surface distance (GSD) of 2.6 cm. Five GCPs (Ground Control Point) were placed before the flight. The GCPs were georeferenced using the Stonex S7-G instrument with an external dual-frequency antenna (L1/L2; Stonex geodetic antenna) in RTK mode and averaging about 60 coordinate points. Image acquisition was made at an average speed of 10 m s-1 in stop-and-go mode to minimize speed-related distortions. Both front overlap ratio and side overlap ratio were 70% while the gimbal pitch was set at 90° (downwards).

2.4 Image processing

The photogrammetric reconstruction was carried out using Agisoft Photoscan Pro-fessional version 1.7.3. The photogrammetric process employed is the classic scheme to reconstruct the orthomosaic multi-bands. Precisely, the different band image has been downloaded and uploaded in the software. The next steps were alignments, GCP upload, calibration in reflectance. Once the preparation was complete, the dens cloud, the Digital Elevation Model (DEM) and finally the orthomosaic multiband were constructed.

For geo-spatial data analysis and processing the open-source software QGIS ver. 3.2 [46] was used. The main geostatistical methods were used to create the various maps that allowed to compare and analyze the variability found in the olive orchard. Through a process of rasterization and vectorialization algorithm, it was possible to extract different information on the tree ([24]; Figure 5). The canopy area (CA) and crown volume (CV), were the bio-metric information while the spectral information was derived from the cal-culation of the main vegetation index (VI) used in the literature to determine vigour char-acteristics [4]. The VI used was the Normalized Difference Vegetation Index (NDVI; [34]) that was calculated using equation 1.

$$NDVI = \frac{\rho_{Nir} - \rho_{red}}{\rho_{Nir} + \rho_{red}} \tag{1}$$



Figure 5. (a) NDVI for canopy and false background color image. (b) Zoom of canopy extracted for plant and corresponding NDVI.

CA was extracted starting from the NDVI map among several OBIA steps. The first step was the image segmentation to differentiate the canopy from the background. It was performed using the K-means algorithm executed in a Saga tool of raster image analysis.

The DSM was extracted directly from the photogrammetric processing while the DTM was derived from some terrain point random selected and spatialized using a geo-statistical method (Figure 6). After calculating DTM and DSM, it was possible to determine the CV using the following equation (2) as defined in [24]:



$$CV = (DSM - DTM) - TrH$$
⁽²⁾

Where DSM is the Digital Surface Model; DTM is the Digital Terrain Model; TrHh is the trunk height (mean value of the 50 selected plants).



Figure 6: Data processing steps to obtain CV. (a) Digital Surface Model (DSM); (b) Digital Terrain Model; (c) Typical tree; (d) Crown volume calculated using the equation

2.5 Biometric data analysis

The aptitude of the orthomosaic and their DSMs to build the tree structures and to re-trieve their geometric features was evaluated. These parameters are namely projected area of the canopy (CA) and crown volume (CV); they were evaluated by comparing the UAV-estimated values and the on-ground values observed in the validation fields. In the case of the CA, the same methodology was applied in Torres-Sánchez et al., (2015) [25] in order to better quantify this variable. For this purpose, fifty olive trees were randomly se-lected in the field and their shape was outlined manually using the orthomosaic image to be used as an observed measure. The results of the GEOBIA (geographic object-based im-age analysis) analysis on the estimation of the CA and CV were compared to the observed measures to calculate the area of coincidence for each olive tree and calculate the overall accuracy. In the same olive trees selected for CA, the CV quantification and validation were applied. CV* was estimated starting from the manual measurement, assuming an ellipsoid form and applying a validated method (Eq3) for olive tree geometric measure-ments using the parameters measured on DOY 164 [25,47].

$$CV^* = \frac{1}{6} * \left(\frac{C_l * C_w}{2}\right)^2 * \frac{Th}{2} \tag{3}$$

Where Cl is the Canopy length (m); Cw is the Canopy width (m); Th is the tree canopy height (m). The effectiveness of the entire procedure to measure volume and area of the canopy of the fifty selected trees was evaluated



by calculating the root mean square error (RMSE) and correlation coefficient derived from the regression fit.

Results and Discussion

In our experiment we evaluated the nutritional, spectral, vegetative and production spatial variability in the olive grove. With regard to the crop nutritional status, it was investigated only TN, that showed a concentration below the threshold in all the samples as obtained by other authors [4,17,36]. Indeed, the total N concentration of plant leaves ranged from 0.4% to 1.46%, with a mean value of 0.92%. By geostatistical analyzing the maps, it was possible to obtain TN spatial variability.

Regarding the vigor characteristics, such as TCSA, a certain heterogeneity among the plants in the field was observed. The mean TCSA value of the whole plot was 297.3 cm2 \pm 109.6. These differences were reflected in growth and production activity as showed also in Noori and Panda (2016). Indeed, the TCSA values were statistically significant correlated with different variables expressing plant vigour such as canopy area extracted from the multispectral image (r =0.65***; Figure 6a). TCSA also statistically significant correlated with NDVI (r = 0.58***; Figure 6b) and productivity values (r =0.42***, data not show).



Figure 7. (a) Correlations between TCSA and CA; (b) correlations between TCSA and NDVI calculated as the average of all pixels within the CA of each tree.

NDVI,CA and CV have been calculated using the drone's multispectral image and GIS processing; therefore, they made it possible to quickly and easily investigate the variability of the field. NDVI, CA and CV on the ground had an average value of 0.71 ± 0.06 , 7.7 ± 2.09 m2 and 18.02 ± 2.2 m3, respectively. Crossing all vigour parameters such as CA, CV, and TCSA, the plants were clustered in three vigour groups (C1, C2, C3). These cluster groups represent the three-vigour classes: High (HV), Medium (MV) and Low Vigour (LV). K-means was the cluster algorithm used.





Figure 8 (a) Bar plot of CA and NDVI for the three groups of clusters; (b) Bar plot of CV and NDVI for the three groups of clusters.

The three vigour groups showed clear differences in terms of vigour. In both graphs (Figure) it can be seen that group C1 showed the lowest values while the highest values were shown by group C3. All three variables showed the same data trend for the three vigor groups. The CA showed values of $5.4 \text{ m}2 \pm 0.8$, $8.15 \text{ m}2 \pm 0.6$ and $9.6 \text{ m}2 \pm 0.65$ for the three-vigour level respectively. The NDVI showed values of 0.64 ± 0.02 , 0.72 ± 0.02 and 0.78 ± 0.02 for the three-vigour level respectively. Finally, the CV showed values of $15.6 \text{ m}3 \pm 0.84$, $18.5 \text{ m}3 \pm 0.73$ and $20.1 \text{ m}3 \pm 0.80$ for the three-vigour level respectively. From the statistical analysis, it appears that the NDVI of each individual tree was able to describe the variability of the field especially in terms of vigour characteristics. In fact, NDVI statistically significant correlated with the values of canopy area (r=0.87***, Figure 7a). Furthermore, the NDVI showed a good relationship with production activity (r = 0.63^{***} , Figure 7b).



Figure 8. (a) Correlation value between NDVI and Canopy area (m2); (b) NDVI and Production kg/plant).



Also CA had a good influence on the productivity of the olive grove. Indeed, it was observed that productivity depends on the canopy area of the single plants ($r = 0.75^{***}$, Figure 8). This result is supported by PCA analysis, where it was possible identify as the trees with high and low vigour were clustered with high and low production respectively (Figure 9). The average production and CA of all plants were used as a threshold to distinguish high and low production and canopy area.



Figure 9. (a) Correlation between CA and Production; (b) correlation between CV and Production.



Figure 10. Principal Component Analysis (PCA) of high and low CA and production.

The application of image reconstruction using SfM techniques allowed the generation of detailed DSM, DTM and orthomosaic, as shown in Figure 10. CV showed a good ability in reconstructing the geometry for each individual tree in the whole plot. Indeed, it showed a strong relation with the other vigour parameter and with the production capacity of the plants ($r = 0.74^{***}$).





Figure 11. 3D reconstruction of the whole study area and zoom of one tree.

Starting from the CA and CV calculated using the Qgis software, it was possible to carry out data validation using the ground truth with a good accuracy. In fact, the accuracy assessment between the observed and estimated values for CA resulted in RMSE equal to 0.54 and a statistically significant close linear relationship with R2 =0.98***.

CV showed an underestimation of the final volume when compared to field measurements. In this case, the coefficient of determination was $R2 = 0.67^{***}$ with RMSE equal to 9.5 m3 (Figure 11). Volume differences between the observed and estimated values do not denote real errors of the UAV-based measurements because the ground-based values were derived by applying the geometric equation that considers trees as full, ellipsoid shapes producing inaccurate estimates [25,48]. In contrast, the three-dimensional products derived from the 3D reconstruction, reproduce the irregular shape of the canopy, yielding better estimates of tree volume as showed in Figure 12.

Starting from the leaves sampling, it was possible determine the crop nitrogen status. The mean nitrogen concentration of the whole plot was 0.94 % depending of the tree and influenced only by the production activity (data not show), while the vegetative characteristic wasn't correlated with it. It was also possible to cross the different information with GIS program because yield depends on vegetative and nutritional status.



Figure 11. (a) Comparison between ground measured and UAV-estimated CV; (b) comparison between ground measured and UAV-estimated CA.





Figure 12. Comparison between geometric (red shape) and SFM reconstruction of the tree.

Using the three groups of cluster and plotting their score of nitrogen concentration and canopy area, it was observed that the whole plot showed clear heterogeneities. These clusters were statistically different p (< 0.001) in terms of productivity by ANOVA analysis (Figure 13). Moreover, the ANOVA test showed that CA has a greater effect than nitrogen concentration.



Figure 13. Cluster analysis of the three vigour groups (C1, C2, C3) according to total nitrogen content and CA and ANOVA test results for the production.

The technologies available today in precision farming are able to describe and determine the health status of the olive grove. Variability can be observed both in terms of soil and cultivation characteristics but the last ones are the most important to investigate the variability as showed in other studies [24,49]. Indeed, in our study the crop health status was determined using the vegetative, spectral and productive activity of individual trees. As confirmed by different studies, these parameters are strictly related and their knowledge can be used to opportunely manage the orchard [21,24,50]. As previously mentioned, the plant health was the most important factor in determining the production result. In the present work it was expressed from spectral, biometric and nutritional point of views. In general, the nutritional status of all the plants was deficient, as the whole plot had a foliar nitrogen concentration below the minimum threshold. Probably, the nutritional status was the main limiting factor for plant growth in the considered plot as found in another study [7]. The low NDVI values found [9,22] and the entire vegetative heterogeneity detected could be explained by the deficient nutritional status of the plants. Indeed, the nutritional condition for each plant was not correlated well with the vegetative parameters. However, this deficiency was one of the determining factors for plant production as obtained by PCA that supported the plant clustering into three groups (Fig. 13).

To express the vegetative variable, i.e. vigour, it was decided to use the TCSA, the canopy projection area and the canopy volume. Since the characteristics express a condition of vegetative vigour, all variables showed at least moderate correlations (Fig.6). TCSA is a condition formed over the years of cultivation and it cannot describe the annual condition of the plant, while the area of the canopy certainly expresses a precise condition at an exact moment. Probably, for this reason the canopy area was indeed more correlated with plant production and NDVI (Fig. 7). The crop spectral conditions were investigated by calculating NDVI that describes the general vegetative and nutritional conditions of each plant because the bands used for its calculation (NIR and red) are strongly related with them [51,52]. In this study, the NDVI showed low values, especially where conditions of low vigour and low nitrogen concentration in the leaves were found. As also show in other studies [24,53] the NDVI has a good relation with the vegetative status (Fig. 7). Moreover, when it correlates with the CA, it was able to discern the plants with high or low productivity with good precision (Fig 7a). When it was correlated with production, it was able to underline the plant with high vigour



(precisely with high canopy area; (Fig. 7b). NDVI showed better correlations with canopy area than the vigour parameters because the multispectral bands used in the calculation are sensitive to both effects: leaf efficiency (red band) and canopy structural conditions (NIR band) [51]. Since production was mainly linked to the availability of plant resources and therefore to CA, NDVI always proved to be a good indicator and predictor of production even in non-optimal nutritional conditions. These results emphasize that NDVI is more capable to determine the vegetative parameters than production. Therefore, by having precise multispectral and RGB images of the entire olive orchard, it is possible to use this information to obtain crop status data that can be used in development models or DSS for the optimization of agronomic management.

Crossing the spectral, biometric, productive and nutritional characteristics of each plant by cluster analysis very interesting results appear. Three statistically different clusters (C1, C2, C3) were identified by cluster analysis according to their vigour and nutrient characteristics (Fig 13). The production of the three clusters showed statistically significant differences. C1 was the most productive and vigorous, while C3 was the lowest. It shows that the productivity of the plants is positively related to the development of the canopy and secondarily to the nutritional conditions. High productivity was observed for plants with a very vigorous canopy and discrete foliar nitrogen concentrations. These results confirm that vegetative conditions were the main determinants of production, while nutritional status had no effect. These results are also supported by PCA (Fig. 13). Indeed, plants with high production and CA are classified as a more similar group than those with low production and CA. This effect can be explained by the greater availability of accumulated resources in the reserve organs of the more vigorous plants.

The UAV equipped with multispectral and RGB camera showed a good capacity to extract the vegetative information using spectral and biometric data. They can be able to predict the production and consequently to better manage variability with significant environmental, agronomic and economic benefits [17,20]. Geometric reconstruction showed interesting results. The high value of RMSE obtained between observed and estimated data were found in previous studies [13,25]. These volume differences were caused by ground measurements applying the geometric equation as explained in figure 12[25,48]. Indeed, similar magnitudes were observed between the two approaches; in fact, the largest and smallest trees on the ground remained the same in the geometric reconstruction. Therefore, if one assumes that data from 3D reconstruction are able to determine a better estimate of CV, it is possible to better balance and manage certain agronomic practices such as variable-rate treatments, resulting in significant product savings. Such savings consequently translate into greater environmental and economic sustainability. CV showed a strong relationship with CA and TCSA, pointing out that vigour conditions are interconnected. From the cluster analysis, the vigour conditions were able to differentiate the real health status of each tree expressed by its production. Getting accurate data on plant vigour is an important condition to obtain the best growth pattern of the olive tree and to better manage the orchard [31].

Conclusions

This study was able to assess how the main growth parameters measured via a high-resolution remote platform and multispectral and RGB sensors processed on various GIS platforms can express the real field conditions and influence site-specific management of the olive grove. It was possible to verify that the new technologies available in precision agriculture allow to obtain various information on the health status of olive trees. Precisely, the UAV platform equipped with multispectral and RGB cameras was able to determine, through the GIS analysis, the main vegetative characteristics such as TCSA, CA and CV. They can be modified with the different agronomic practices to improve crop efficiency. UAV technology has demonstrated an excellent ability to efficiently produce spectral and geometric data of hundreds of agricultural trees at field level in a timely and accurate manner, offering a viable alternative to hard and inefficient field work by investigating the entire spatial variability of the orchard within minutes. In addition, the GIS platforms used were able to spatialize the collected point samples data, such as the nutritional ones. All georeferenced information allows the creation of maps of orchard heterogeneity and the identification of incorrect growing conditions. This heterogeneity was expressed as spatial variability of different growth and production parameters. Knowing this variability is the key point for the creation of specific maps that allow the construction and use of accurate DSS systems for olive orchard management optimization. In this way, a site-specific management strategy can be applied to increase profitability by improving input utilization (fertilizers, pesticides, water, etc.) and field operations (pruning, spray application, irrigation, harvesting).

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Vineyard Monitoring with UAV to Extract Vegetation Indices

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Abstract

Remote sensing can be an effective and useful monitoring tool for the vineyard, as data from sensors on board Unmanned Aerial Vehicles (UAV) can measure vegetative and reproductive growth and thus detect variability. Vegetation Indices (VIs) can be calculated through the images obtained from UAV, and compared with various agronomic characteristics of the vineyard. The objective of this study was to evaluate the multispectral response of the vineyard in three specific phenological phases and to analyze the spatial and temporal distribution of plant vigor. A multirotor UAV equipped with a camera featuring multispectral sensors was used to collect image data during the vineyard's growing season. Four vegetation indices (VIs): Normalized Difference Vegetation Index (NDVI), Normalized Difference Red Edge (NDRE), Green Normalized Difference Vegetation Index (GNDVI), Modified Soil Adjusted Vegetation Index (MSAVI), were calculated using the georeferenced orthomosaic UAV images. Computer vision techniques were used to segment these orthoimages to extract only vegetation canopy pixels. A high level of agronomic variability within the vineyard was detected. Pearson's coefficient showed a significant correlation between NDVI and NDRE indices and yield since early phenological stages (r=0.80 and 0.72). Shoot pruning weight (SPW) showed the highest values of correlation (r=0.84) with NDVI during the phenological stage of berries pea size. Simple linear regression techniques were evaluated using VIs as predictors of SPW, and accurate predictive results were obtained for NDVI and NDRE indices with lower RMSE values of 0.18 and 0.24, respectively. Assessing spatial variability and appreciating the level of vigor allows to improve vineyard management by increasing sustainability and production efficiency.

Keywords: multispectral images, vigor, yield.

Introduction

Grape quality is influenced by several factors, such as genetic factors that distinguish cultivars and clones, or the effects of soil characteristics (Barbagallo et al., 2021), soil erosion (Novara et al., 2018), row orientation (Catania et al., 2019; Hunter et al., 2021; Pisciotta et al., 2019), nutrients, light, temperature and water availability (Hunter et al., 2014; Triolo et al., 2019), which occur as single factors or as an interaction (Mirás-Avalos et al., 2020; Poni et al., 2018). Together with the climatic conditions, these factors contribute to increase the spatial variability of vineyards, therefore information on spatial and temporal variation is essential to support farmers in decision making to enhance profitability. The estimation of the agronomic variability of each plot should be done from year to year and at different phenological stages of the vineyard (Bramley & Hamilton, 2004).

New technologies are available today for monitoring and managing the vineyard and controlling vegetative and productive growth. Using high-resolution remote and proximal sensors, spatial variability of vine vigour can be investigated, and chemical parameters determined from grapes (Kemps et al., 2010), at any time; this information can thus be used for the variable application of many agronomic practices according to the principles of Precision Viticulture (PV) (Matese et al., 2015).

Satellite systems and Unmanned Aerial Vehicles (UAVs) that capture images in the visible and near-infrared bands of the electromagnetic spectrum are widely used to generate vegetation maps (Roma & Catania, 2022). In particular, UAVs proved to be more effective tools in representing vineyard variability as they can easily discretise the canopy from the inter-row (Khaliq et al., 2019). They are equipped with spectral sensors; the combination of the different bands of the electromagnetic spectrum provides important information about the vegetative growth of crops (Pádua, Marques, Hruška, Adão, Bessa, et al., 2018).

Vegetation mapping is performed by calculating different Vegetation Indices (VIs) from specific wavelengths and is often used to estimate plant growth parameters. An equally important issue is the relationship between multispectral indices and vegetative vigour; it's known that there is a close relationship between Normalised Difference Vegetation Index (NDVI) and vigour (Costa Ferreira et al., 2007). A distance-based index commonly used in PV is Modified Soil-Adjusted Vegetation Index (MSAVI); it reduces the soil disturbance effect and produces more accurate vineyard vegetation assessment (Tassopoulos et al., 2021). The Normalised Red Edge Difference Index (NDRE) and the Green Normalised Difference Vegetation Index (GNDVI), are able to provide information on the health status of grapevine's through determining the variability of vegetation physiological parameters (Daglio et al., 2022; Tosin et al., 2022). The agronomic estimation of vine vigour is often carried out by assessing the Shoot Pruning Weight (SPW) (Rey-Caramés et al., 2016). SPW is related to the vegetative biomass in the growing season and, therefore, to vine vigour. Among the



vegetative growth parameters it is distinguished by its high sensitivity to variations in soil fertility and water availability (White, 2015). SPW is used to assess the relationship between vegetative and reproductive growth by calculating the Ravaz index (Taylor & Bates, 2012), which is an indicator of vine balance and grape quality (Smart & Robinson, 1991). The predictive study of SPW is a topic that has always attracted much interest; knowing in advance how the variability of this vigour parameter is distributed, allows to manage vines by balancing vegetative-productive development. It is reported in the literature that pruning weight correlates well with multispectral indices or RGB imagery (Caruso et al., 2017; García-Fernández et al., 2021; Rey-Caramés et al., 2015). Positive spatial autocorrelations were found through comparisons made between SPW and NDVI data of the vineyard canopy surveyed by UAV (Pastonchi et al., 2020).

The aim of this study is to determine vineyard spatio-temporal variability based in UAV high resolution multispectral images, in order to optimise vineyard management. In particular, vineyard multispectral orthoimages were used to detect some agronomic parameters, to assess the vegetative growth and to determine grape yield variability. Four vegetation indices and their relationship to vegetative growth and yield were examined, providing more detailed information to winegrowers for the management of crop operations. The spatial variability of SPW was also determined by assessing the most correlated multitemporal VI of the vineyard canopy.

Materials and Methods

Experimental site

The study was carried out during the 2021 growing season in a 15 years old vineyard, cultivar Catarratto. The experimental site was located within the Alcamo Protected Designation of Origin (PDO) area, western Sicily (Italy) at Tenuta Rapitalà farm (37°55'9.61"N; 13° 4'28.59"E). The vineyard is located at an altitude of 315 m above sea level and is drip irrigated. The plot has an extension of 8.2 ha with layout of planting 2.40 x 1.00 m (4,170 plants ha–1 37.92155°N 37.92155°N 37.92215°N 37.92215°N 37.92215°N 37.92245°N





Aerial platform and multispectral sensors used

The remote images were acquired with a UAV, a Da-Jiang Innovations (DJI) quadcopter model Phantom 4 (DJI, Shenzhen, China), classified as VTOL (Vertical Take-Off and Landing). The UAV can carry a maximum payload of 477 g for 20–30 minutes with a maximum flight range of 7 km. The flight autonomy of the UAV is approximately 30 minutes, guaranteed by a LiPo 4S battery with a capacity of 5870 mAh and a voltage of 15.2V. Three batteries were used to survey the entire plot. The Phantom 4 was used to acquire RGB and multispectral images; it was equipped with a camera composed of six 1/2.9" CMOS sensors, mounted on the UAV using a two-axis carbon fibre gimbal, one RGB sensor for visible light images, and five monochrome sensors for multispectral image acquisition. The gimbal mitigated airframe vibration (pitch and roll) caused by wind and allowed pointing vertically downwards for image collection. Multispectral sensors operate in the bands of blue (B): 450 nm, green (G): 560 nm, red (R): 650 nm, red-edge (RE): 730 nm, and near-infrared (NIR): 840 nm, with a resolution of 2.08 MP. Each sensor has a spectral sensitivity range of \pm 16 nm respect to its nominal wavelength, except the NIR sensor which has a spectral sensitivity range of \pm 26 nm (Tominaga et al., 2021). The features of the camera are focal length 5.74 mm, image size 1600 × 1300 pixels, angle of view (FOV) 62.7° and aperture f/2.2. Radiometric calibration is performed based on the irradiance measured in real-



time by the sensor located on the top of the UAV. In addition, a radiometric calibration was applied to the image blocks, using reference images from a calibrated reflectance panel (LABSPHERE INC., North Sutton, US).

Data acquisition

The flight sessions performed with the UAV were conducted with 70% forward overlap and 70% lateral overlap at \approx 70 m a.g.l height from the take-off point in a dual-grid configuration, obtaining an image pixel size (GSD) of approximately 3.7 cm for RGB and multispectral images. The field of view (FOV) was 51.50 × 41.25 m and the flight speed was 20 km h⁻¹. The camera takes photos automatically, at an interval of one second, and the image is stored in TIFF format.

Three flight sessions were carried out during the 2021 vegetative season in different vine phenological stages (Table 1). The first flight was performed at berries pea size, while the second at beginning of ripening. The last flight was made close to ripening, at full ripening. Surveys were conducted during these phenological stages based on the physiological vine behaviour corresponding to the ripening process. The flight operations were scheduled from 11:30 AM to 01:00 PM.

Table 1 – Remote sensing data acquisition during the 2021 growing season. Meteorological data logged by the station closest to the surveyed area (Sicilian Agrometeorological Information System; SIAS).

UAV flight missions							
Acquisition	Growth	DOY	Radiation	Wind Speed	Wind		
time	stage		(MJ/m ²)	(m/s)	direction		
18 June 2021	BBCH 75	169	26.40	1.62	N-O		
21 July 2021	BBCH 81	202	27.80	1.57	S-E		
28 August 2021	BBCH 89	239	25.84	1.68	S-O		

Data processing

The georeferenced multispectral images were mosaicked using Agisoft Metashape Professional Edition (Agisoft LLC St. Petersburg, Russia - https://www.agisoft.com/). A high-resolution orthophoto 3.7 cm pixel-1) in GeoTIFF format and a Digital Elevation Model (DEM) of the experimental vineyard were created. The first post-processing operation was to align the orthoimages. Automated procedures (batch processing) were then carried out to generate the dense points cloud and the generation of the multi-band orthomosaic. To assure the accuracy of the image, the ground control point (GCP) method was applied for geometric correction, fixing 14 points using a GPS receiver on the entire plot (Catania et al., 2020). Using the software QGIS version 3.22. it was possible to calculate the vegetation indices shown in Table 2.

Table 2	Vegetation	indices	and e	auations	used.
				9 4 4 4 1 0 1 10	

Vegetation Index	Equation	Author		
NDVI	$\frac{(NIR - RED)}{(NIR + RED)}$	Rouse et al. (1974)		
GNDVI	(NIR – GREEN) (NIR + GREEN)	Gitelson and Merzlyak (1998		

After computing the vegetation index maps, it was necessary to identify and segment the vineyard canopy from the soil and weeds by applying the unsupervised k-means segmentation algorithm as applied by (Cinat et al., 2019). Through a new k-means classification (k=3), three management areas with low (LV), medium (MV) and high (HV) vigour were identified.



Plant sampling and measurement

At full ripening, 71 vineyard blocks (VP) belonging to different areas of the vineyard (Fig.2), showing diverse vigour, were identified. Each block consisted of 6 vines. The Total Leaf Area per vine (TLA) was measured using the LI-3100C area meter (Li-COR Biosciences, Lincoln, NE, USA). During winter, shoot pruning weight (SPW) was determined using a dynamometer (Wunder, mod. 60, Milan, Italy).

Statistical and geostatistical analysis

The characteristics of the vegetation indices (count, mean, minimum, maximum, and standard deviation) from the UAV raster images were extracted using the Zonal statistical plugin in QGIS. Statistical data extracted from each vegetation index raster were processed using a shapefile with polygons corresponding to the sampling blocks VP1 and VP2, which included only vegetation pixels. The data obtained from the plant measurements were processed with a variance analysis model (ANOVA). The significance level (α) was set at 99% (p < 0.01). The null hypothesis (H0) in the comparison of the three groups is that all means are equal, whereas the alternative hypothesis (H1) is that not all means are equal. Tukey's multiple comparison tests were used to detect the different averages. The Simple Linear Regression Model (SLRM) was employed using the multispectral VIs that best correlated with the SPW sampling data. All the statistical procedures were performed using R software (R Core Team, 2020).

The spatial variability of multispectral indices and the vineyard vigour were conducted using QGIS. The procedure is illustrated in Ferro et al. (2023).



Fig. 2. Scheme of sampling used in the vineyard plot. Overview of the process for identifying the sampling blocks in the field performed using GCP information to obtain the contours of the sampling polygons.

Results and Discussion

Vegetation index data

Table 3 shows the average values and range of the vegetation indices. The values are distinct for the three flights performed during the growing season and indicated with the letter F, and thus flight F1 was performed at berries pea size stage, flight F2 at beginning of ripening, and F3 at full ripening. The mean values of NDVI and GNDVI, decreased gradually in the three phenological phases. This result can be explained by considering the spectral response of the vegetation in F2, in which the level of photosynthetic activity and efficiency is high, due to the activity of the chlorophyll pigments.



Table 3. Descriptive statistics of the vegetation indices obtained by UAV multispectral images at different growth
stages. The mean value of each index is obtained from 71 replicates \pm standard deviation (SD).

	F1		F	2	F3		
	mean ± SD	range	mean ± SD	range	mean ± SD	range	
NDVI	0.64 ± 0.03	0.60 - 0.68	0.57 ± 0.06	0.51 - 0.63	0.35 ± 0.05	0.31 ± 0.40	
GNDVI	0.46 ± 0.05	0.43 - 0.49	0.44 ± 0.03	0.40 - 0.48	0.42 ± 0.05	0.39 ± 0.46	

From the vigour maps generated, different vigour zones were identified by applying the k-means clustering algorithm. For each vegetation index considered, areas of low, medium and high vigour were identified from the first survey F1 (Fig. 3); the determinations made for the subsequent surveys (F2 and F3) confirmed this variability.



Fig. 3. Green normalised differential vegetation index map showing the high-vigour (HV), medium-vigour (MV) and low-vigour (LV) vegetation classes derived from a multispectral image remotely sensed by UAV during the F1 survey.

Fig. 4 (a) and (b) show row sections with different thickness and thus variability in the number of pixels; the differences identified in the rasters were observed in the vineyard, as illustrated in Fig. 4 (c) and (d).





Fig. 4. GNDVI map with zones of different vigour, (a) section of vineyard row with low vigour (LV), (b) section of vineyard row with high vigour HV). Canopy in LV vines (c), and HV vines (d).



The results of the vegetative-productive variability are shown in the boxplots in Fig.5.

Fig. 5. Box plots showing the vegetative parameters. (a) Leaf area (b) Shoot Pruning Weight. •Mean values; data were processed according to Tukey's test with 99% confidence level. Box plot marked with different letters are significantly different ($p \le 0.01$).

Correlation analysis between shoot pruning weight and UAV spectral indices

Table 4 shows the correlation data between vegetation indices and SPW. NDVI and GNDVI gave a good prediction for the weight of the pruning mass when evaluated in the phenological phases before veraison. These results indicate that sampling flights must be carried out during the first periods of vine development to have a more accurate estimation of the pruning mass weight. As berries approach ripeness and senescence processes of the chlorophyll, tissues are triggered, there is a risk of not making a real estimation of this agronomic parameter.

Table 4. Pearson correlation coefficients between pruning weight measured and the vegetation indices considered. With significance *p ≤ 0.05 , **p ≤ 0.01 , ***p ≤ 0.001 , n.s= not significant.

Shoot Pruning weight [kg/vine]							
	F1	F2	F3				
NDVI	0.844***	0.771***	0.521 ^{n.s}				
GNDVI	0.663**	0.696**	0.584*				

Based on the results of the relationships between SPW and multispectral data, it was decided to continue with the setting up of predictive models with the aim of verifying the validity of these correlations to extend these relationships and information on vegetative growth, to the entire vineyard. Obtaining this information will make it possible to optimise the pruning of the vineyard, adopting a balanced bud load according to the vegetative capacity of the vines. In agreement with the correlation values, NDVI from F1 shows the highest R2 value, while the other indices, although showing a valid linear regression, remain at lower values (data not shown). The SLRM were developed, which showed a good fit between VIs and SPW, for flight missions F1 and F2. Model error metrics were computed, which provide information on the prediction error of the agronomic variable. The best model was based on NDVI index referred to the F1 flight survey, which showed a good linear relationship with pruning weight (R2= 0.81; RMSE= 0.18; MAPE= 12.8 %).

The relationships between the forecast pruning weight and the observed value, for the four cases studied, are shown in Fig. 6 where the SLRM between the observed SPW and the predicted data using the NDVI at F1 as a predictor variable is presented, with correlation R2=0.69.



Fig. 6. Correlation between predicted and observed shoot pruning weight for monitored vines using SLRM based on a data set for model validation (p<0.001), developed as a function of NDVI values observed in F1 (R2=0.69);

Based on the semivariogram concept and models, kriging interpolation methods were evaluated for the spatial distribution of the predicted SPW data in the entire vineyard. Figure 7 shows the spatial distribution of vegetative vigour; this map was developed based on NDVI index data recorded in flight F1. The pruning weight values of the whole vineyard are concentrated around the average values of 0.6 kg.





Fig. 7. Maps obtained by interpolation of predicted pruning weight (kg). Set of points (training): 1,000 on all maps. SPW prediction maps calculated as a function of VIs based on NDVI (F1).

The results of the present study confirm the relationship between NDVI and pruning weight found by other authors (Baluja et al., 2012; Rey-Caramés et al., 2015). Taking into consideration the pruning weight data obtained with the predictive model based on NDVI (F1), vigour shows a distribution that is closely dependent on the spatial variability of the field and thus not random.

Conclusions

This study investigated the capability of a multi-spectral sensor mounted on a multirotor UAV to monitor vegetative indices derived from the spectral response of the vineyard, at different phenological stages of the crop cycle. According to the results obtained by the multispectral indices studied, it was possible to identify three different vigour levels in the vineyard. Through Pearson's correlation analysis it was found that a large proportion of the agronomic variables showed a stable correlation with the multispectral indices. SPW and vegetative vigour should be estimated before veraison, especially using NDVI.

Prediction maps can assist farmers in managing subareas of the vineyard with different vigour. SPW prediction maps can guide winegrowers in choosing the appropriate bud load for winter pruning. Finally, these results could be used to develop new pruning management techniques.

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Mapping of Coffee Ripeness Spatiotemporal Variability Using UAV Imagery

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Abstract

Timely and accurate monitoring of coffee ripeness is a key indicator for defining the moment of starting the harvest, especially in sloped areas where the harvest is carried out manually due to the absence of mechanization. This study aimed: (1) to predict the fruit ripeness using spectral variables; and (2) to quantify the spatiotemporal variability of the fruit ripeness. For that, an experiment with five arabica coffee fields was set up in the 2018-2019 and 2020-2021 seasons. During the coffee ripeness stage, five flights were conducted to acquire spectral information on the crop canopy using an unmanned aerial vehicle (UAV) equipped with a five-band (RGB, RedEdge, and NIR) multispectral camera. After that, 12 spectral variables composed of the five bands and seven vegetation indices were obtained. Prior to the flights, manual counts of the percentage of unripe fruits were performed using irregular sampling grids on each day for validation purposes. Then, the fruit ripeness was predicted with the random forest (RF) algorithm using as input the spectral variables. The algorithm performance, in terms of the coefficient of determination (R^2) and the root-meansquare error (RMSE), was 0.67 and 12.09%, respectively. Among the 12 variables used as predictors, the coffee ripeness index, red band, modified chlorophyll absorption in reflectance index 1, and the NIR band presented the highest importance (%) for building the prediction model. The importance of these variables ranged from 58.50 to 61.01%. Regarding the spatiotemporal variability maps of the fruit ripeness, the changes agreed with the expected reduction of the percentage of unripe fruits over time, as driven by the temporal evolution of the fruit ripeness. Finally, this study demonstrated that the methodology based on UAV imagery for mapping and monitoring the fruit ripeness at a fine scale can be used to replace or assist the time-consuming fieldwork.

Keywords: Digital agriculture, Coffee fruit ripeness, Drone, Machine learning.

Introduction

Coffee is recognized as the second most traded commodity globally whose selling price depends on the beverage quality, which in turn is influenced by the fruit ripeness degree at harvest (Silva et al., 2014). This is because ripen fruits provides a better quality beverage, while unripen and overripen fruits reduce its quality, as well as the color and size uniformity of the grains (Martinez et al., 2013; Silva et al., 2014). Due to these facts, the fruit ripeness monitoring became an important parameter for defining the moment of starting the harvest, especially for farmers that seeks to improve the coffee beverage quality. Thus, given the importance of the fruit ripeness degree at harvest for the production of higher quality coffee, mapping the fruit ripeness can be a useful tool for site-specific management of coffee plants with distinct qualities. In addition, timely and accurate monitoring of coffee ripeness is a key indicator for defining the moment of starting the harvest, especially in sloped areas where the harvest is carried out manually due to the absence or limited use of mechanization. At present, this process relies on visual inspection, which is time-consuming and labor-intensive, as well is limited to a few plants throughout the coffee field, which may not be representative. Therefore, there is a lack of alternative methodologies for faster measurements that can support harvest planning. Based on that, this study aimed: (1) to predict the fruit ripeness using spectral variables; and (2) to quantify the spatiotemporal variability of the fruit ripeness.

Materials and Methods

The study was carried out in the 2018-2019 and 2020-2021 seasons using five fields of arabica coffee (Coffea arabica L.) located in the Jatobá farm, southeastern Brazil (Figure 1). The relief in the area is mountainous (slope varies from 0 to 45%), and the climate is classified as "CWA", (humid subtropical with dry winter and hot summer) according to the Köppen-Geiger climate classification (Alvares et al., 2013; Nogueira Martins et al., 2021).





Figure 1. Location of the study area in Minas Gerais state, southeastern Brazil. Source: Adapted from Nogueira Martins

et al. (2021).

During the coffee ripeness stage, five flights (2 in 2018-2019, and 3 in the 2020-2021 seasons) were carried out to acquire spectral information on the crop canopy using an unmanned aerial vehicle (UAV) equipped with a five-band (R, G, B, RedEdge, and NIR) multispectral camera. The UAV flights were conducted between 11:00 and 13:00 h local time under clear-sky conditions at 60 meters above ground level at 9 m s-1 speed with 80% front overlap and 75% side overlap between images. After the flights, all images were processed using the AgisoftTM MetaShape software, version 1.5.3 (Agisoft LLC, St. Petersburg, Russia) following the procedures detailed in Nogueira Martins et al. (2021). The final orthomosaics were georeferenced in the QGIS software, version 3.2 (QGIS Development Team, 2016) using the information from the GCPs. Then, 12 spectral variables composed of the five bands and the following vegetation indices (VI's): Coffee Ripeness Index (CRI); Green-red Ratio Ripeness Index (GRRI); Modified Chlorophyll Absorption in Reflectance Index 1 (MCARI1); Excess of Red (EXR); Normalized Difference RedEdge Index (NDRE); Normalized Green-red Difference Index (NGRDI); and the Plant Senescence Reflectance Index (PSRI) were obtained (Table 1). These variables were obtained at the sampling point level, which was composed of three plants in the same cultivation row.

Vegetation index	Equation	Reference
CRI	$(R/R_{target})100$	Nogueira Martins et al. (2021)
GRRI	(G/R)	Johnson et al. (2004)
MCARI1	1.2[2.5(NIR - R) - 1.3(NIR - G)]	Haboudane et al. (2004)
EXR	1.4R - G	Meyer and Hindman (1998)
NDRE	(N - RE)/(N + RE)	Fitzgerald et al. (2006)
NGRDI	(G - R)/(G + R)	Zheng et al. (2018)
PSRI	(R - B)/N	Merzlyak et al. (1999)

R, Red; G, Green; B, Blue; RE, Rededge; N, Near-infrared; and RTarget, Average reflectance value of the red target in the red band.



After obtaining the spectral variables, polygonal masks were created for each sampling point using the QGIS software. Then, the average, minimum, maximum, and standard deviation (SD) values of the spectral variables pixels within the polygons were extracted using the zonal statistics tool. After the flights, manual counts of the percentage of unripe fruits (fruit ripeness) were performed using irregular sampling grids on each day for validation purposes. Then, the fruit ripeness was predicted with the random forest (RF) algorithm using as input the average, minimum, maximum, and SD values of the spectral variables. To develop and validate the RF models, the dataset was divided into training (n = 227, 70%) and testing (n = 96, 30%). After the predictions, the performance of the RF models was evaluated using the coefficient of determination (R2), and the root-mean-square error (RMSE) for the testing dataset. Lastly, the fruit ripeness spatiotemporal variability maps were arranged in a layout with different classes, whose area (%) was obtained to assess the temporal changes in the fruit ripeness.

Results and Discussion

The RF-based models demonstrated satisfactory performance in the fruit ripeness prediction only when using as input the average values of the spectral variables (R²: 0.67; RMSE: 12.09%). Oppositely, when using the minimum, maximum, and SD values of the bands and VI's, the R² and RMSE values were low and ranged from 0.18 to 0.41 and from 19.24 to 16.32%. Therefore, the maps were created using the average values of the spectral variables. Overall, the results reveal the potential of using remote sensing (RS) and machine learning for monitoring of coffee fruit ripeness. When compared to the literature, the RF model outperformed the linear regression approach previously used (R²: 0.57 and RMSE: 14.60%) (Nogueira Martins et al., 2021). Conversely, Herwitz et al. (2004) reported a higher correlation (R2: 0.81; RMSE not available) between the spectral variables and the fruit ripeness at the field level, which does not fully represent the variability of the fruit ripeness. Despite that, our results corroborates both studies, in which the use of RS-based methodologies in the coffee crop is still challenging due to the plant architecture (e.g., canopy volume, and crop yield) that influences the number of fruits displayed on the crop canopy.

Regarding the spectral variables that were used as predictors, the coffee ripeness index, red band, modified chlorophyll absorption in reflectance index 1, and the NIR band presented the highest importance (%) for building the prediction models. The total importance of these variables ranged from 58.50 to 61.01%. In relation to the spatiotemporal variability maps, the predicted fruit ripeness (% unripe fruits) ranged from 21.22 to 84.29% among the coffee fields (Figure 2). In addition, the spatiotemporal changes agreed with the expected reduction of the percentage of unripe fruits over time. The maps also presented a high spatial and temporal variability throughout the coffee fields.



Figure 2. Spatial variability maps of the fruit ripeness (% unripe fruits) obtained with the random forest models using as predictors the average values of the spectral variables. Source: author's data.

For field 1, when looking at the fruit ripeness classes, the area of plants within the two first classes (21.22 - 46.44%) of unripe fruits) increased from 40.99 to 53.26% from May 04th to May 24th, 2021 (Figure 3). On the other hand, the classes with the highest percentage of unripe fruits (59.06 – 84.29%) decreased from 30.14 to 17.60% within the same period (Figure 3). Overall, major changes occurred between the two first sampling dates due to the higher interval of days (Figures 2 and 3).



Figure 3. Temporal variation of the fruit ripeness from one of the evaluated coffee fields. Source: author's data

Conclusions

The RF-based model demonstrated satisfactory performance (R^2 : 0.67; RMSE: 12.09%) in the fruit ripeness prediction when using as input the average values of the spectral variables. Regarding the spatiotemporal variability of the fruit ripeness, the observed changes agreed with the expected reduction of the percentage of unripe fruits over time, specially between the two first sampling dates due to the higher interval of days. Lastly, this study enabled the detection and quantification of the spatiotemporal variability changes of fruit ripeness at a fine scale, showing that the time-consuming fieldwork can be replaced or assisted by this methodology.

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Performance of machine learning algorithms for forest species classification using WorldView-3 data in the Southern Alentejo region, Portugal

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Abstract

Recent advances in remote sensing technologies and the increased availability of high spatial resolution satellite data allow the acquisition of detailed spatial information. These data have been used for monitoring the Earth's surface, namely monitoring land use land cover, quantifying biomass and carbon, and evaluating the protection and conservation of forest areas. O WorldView-3 is a high spatial resolution satellite (0.50m) with 8 multispectral bands (visible and infrared) which allows obtaining detailed data from the Earth's surface.

This study aims to map the forest occupation by specie with two WoldView-3 images, and to evaluate the performance of machine learning classifiers (maximum likelihood, support vector machine and random forest) in two regions of Alentejo, south of Portugal. The main forest species are Quercus suber in one region and Quercus rotundifolia in another. The procedures performed were multiresolution image segmentation and object-oriented classification based on 4 bands (blue, green, red and near infrared). As auxiliary data, vegetation indices (NDVI and SAVI) and principal components were calculated.

In the object-oriented classification process, the three classifiers were tested. The support vector machine classifier was the one that presented the best accuracy (kappa and overall accuracy), for both images, allowing to obtain good results in the identification of forest species. In the image dominated by Quercus suber, the values of kappa and overall accuracy were 90% and 95%, and for the image where Quercus rotundifolia predominated, 90% and 96% respectively. The methodology applied to the high spatial resolution satellite data showed very good results in the identification and mapping of main forest species. Higher precision values stand out for the image where the Quercus rotundifolia predominates, where there is less spectral variation, namely fewer land use classes, thus reducing errors between classes that may be spectrally similar.

Keywords: maximum likelihood, support vector machine, random forest, multiresolution image segmentation, objectoriented classification, vegetation indices

Introduction

Recent advances in remote sensing technologies and the increased availability of high-resolution satellite data for Earth's surface enable the acquisition of detailed spatial information. High-resolution satellite images have been used for land surface monitoring, including land use/land cover monitoring, ecological processes analysis, biomass and carbon quantification, as well as assessment of forest protection and conservation efforts.

High resolution satellite images (e.g., WorldView-3) have been used to monitor land use/land cover (Galidaki et al., 2017), ecological processes (Ahmad et al., 2021; Galidaki et al., 2017), biomass (Gonçalves et al., 2019, 2017; Sousa et al., 2015; Galidaki et al., 2017) and carbon (Ahmad et al., 2021; Galidaki et al., 2017) quantification as well as their variability in space and time (Gonçalves et al., 2019, 2017). The classification of the satellite images and their accuracy are of the utmost importance (Meng & Xiao, 2011; Varin et al., 2020) several methods have been used in image classification ((Meng & Xiao, 2011; Varin et al., 2020; Vibhute et al., 2016) among which the multiresolution segmentation and object oriented classification ((Meng & Xiao, 2011). Moreover, several mathematical models have been used in object oriented classification, such as random forest (Varin et al., 2020), support vector machine (Varin et al., 2020) and maximum likelihood (Vibhute et al., 2016). The variability of the landscape in general, and of the forest areas in particular, make image classification a challenge. The diversity of the models reflects the need to accommodate the variability of the areas under analysis.

Apart from the selection of the models to classify the images, the selection of the explanatory variables plays also a key role in the accuracy of the classification (Varin et al., 2020), bands are frequently used, yet they do not enable to identify and delimit with accuracy some land uses (Varin et al., 2020). Vegetation indices, combining two or more bands enable a better differentiation and delimitation of different land uses (Varin et al., 2020). Moreover, they enable the isolation of tree canopies from other land use types because the enhance their differences (Fonseca & Fernandes,



2004; Marcussi et al., 2010; Che et al., 2019).

Two vegetation indices area frequently used Normalized Difference Vegetation Index (NDVI) and Soil-Adjusted Vegetation Index (SAVI). The NDVI is a widely used vegetation index for vegetation identification and discrimination between species. It is employed because vegetation exhibits high reflectance in the near-infrared region and, conversely, absorbs a significant amount of light in the red region (Rouse et al., 1973). SAVI is a vegetation index also very used for vegetation studies, it helps mitigate the effects of soil interference and accounts for areas with less dense vegetation (Huete, 1988). Both NDVI and SAVI play a crucial role in discerning and characterizing vegetation types, particularly in the context of forest species, enhancing the accuracy of classification outcomes. In image classification, there is redundant information due to the high correlation between bands. Principal Component Analysis (PCA) allows reduction of information eliminating the strong correlation between bands and generate new variables, known as principal components (Thenkabail, 2016).

In object-based image classification, the image segmentation process, where the minimum unit is the object, aims to group pixels considering their spectral, spatial and dimension characteristics (Ma et al., 2017) that represent different objects on the surface. Three adjustment parameters were considered: spectral and spatial detail, and the minimum segment size. These parameters allow for the grouping of adjacent pixels and identification of segments based in each input dataset. Spectral detail allows for object segmentation based on color characteristics. A small spectral detail value results in fewer segments, each covering a larger area. Spatial detail enables object segmentation based on object proximity. Lower values allow for finer segmentation between closely grouped objects. The minimum segment size parameter specifies the minimum size, in pixels, for a group of contiguous pixels. All segments with a pixel count less than the specified minimum are merged with the nearest neighboring segment for a better fit. While there isn't a specific interval for this parameter, smaller values result in less homogeneous segments (Visalli et al., 2021). The adjustment of these parameters is tailored to the specific study area's characteristics and the desired level of segmentation accuracy.

The objective of this study is mapping the tree canopies for the dominant forest species using two WorldView-3 images. Additionally, the study aims to evaluate the performance of machine learning classifiers such as Maximum Likelihood (MLH), Support Vector Machine (SVM), and Random Forest (RF) for cartographic production of forest species in two regions of Alentejo, southern Portugal. In the northern region of Alentejo (39° 5' 15.16"N; 8° 1' 13.35"W), cork oak (Quercus suber) dominates, while in the southern region (38° 3' 5.71"N; 7°38' 43.54"W), holm oak (Quercus rotundifolia) is dominant.

Material and Methods

2.1. Study Area

The study areas correspond to two satellite images of 25 km² each, located in the Alentejo region (Figure 1), southern Portugal. The region is characterized by a Mediterranean climate, where summers are hot and dry, and winters are cold and humid, with greater temperature ranges and intensity in land. The terrain is marked by plains, with an average elevation of approximately 200 m. Image a) is predominantly composed of cork oak (Quercus suber) and image b) of holm oak (Quercus rotundifolia).



Figure 19. Study area location (a) dominance of cork oak; b) dominance of holm oak.

2.2. Remote sensing data



The two images from the WorldView-3 satellite used in this study were acquired in: a) September 21, 2020, and b) June 14, 2020. Both images have four bands corresponding to wavelengths in the electromagnetic spectrum's blue (B) (491.9 nm), green (G) (541.1 nm), red (R) (660.1 nm), and near-infrared (NIR) (824.0 nm) regions, and a spatial resolution of 0.50 m, which result from the fusion process with the panchromatic band.

Multiresolution segmentation and object oriented classification were used to attain the forest cover maps. The explanatory variables were the four bands, two vegetation indices (NDVI and SAVI) and principal components of the for bands (Figure 2). Multiresolution segmentation was tested with four data sets of explanatory variables: i) near-infrared band, NDVI e second principal component (NIR, NDVI, CP2); ii) near infrared band, first and second principal component (NIR, CP1, CP2); iii) NDVI, SAVI and second principal component (NDVI, SAVI, CP2); iv) red and NIR bands e and NDVI (R, NIR, NDVI). Three parameters were considered in multispectral segmentation spectral detail, spatial detail and minimum segment distance.

2.3. Methodology

In the Figure 2 is presented a flowchart with the main steps of the methodology, from the original bands until the resulted LULC forest maps.



Figure 20. Methodology flowchart

For the spectral and spatial detail parameters (both of which can vary between 1 and 20), a higher value was considered for the former to allow for spectral differentiation of various land use/land cover classes. For the latter, a medium value was chosen to obtain objects of small dimensions, such as isolated canopies, or larger objects when contiguous canopies are present. In the segmentation process, the values that best suited the isolation of tree canopies, considering spectral and spatial detail, and the minimum segment size were determined as follows: for the cork oak-dominated image, the values were 19, 10, and 100 respectively; for the holm oak-dominated image, the values were 18, 15, and 100 respectively. In sparse forest areas, it was possible to obtain objects corresponding to individual tree crowns. Whereas in dense forest areas where the crowns of the individual trees touch each other, isolating individual crowns was not possible, instead segmentation resulted in clusters of crowns.

With the segmented image, the next step was the object-based image classification process. Three machine learning algorithms were tested: Maximum Likelihood (MLH), Support Vector Machine (SVM), and Random Forest (RF). Initially, classes are assigned to the identified objects, acting as training data for the classifiers tested. In the cork oak-dominated image, nine classes were considered (cork oak, holm oak, stone pine, eucalyptus, water, soil, urban area, agriculture, and shadow). In the holm oak-dominated image, seven classes were considered (holm oak, eucalyptus, water, soil, urban area, agriculture, and shadow). The data set for the classification included as explanatory variables the four original bands, two vegetation indices (NDVI and SAVI), the first and second principal components (PC1 and PC2) and the objects that resulted from the multiresolution segmentation. For RF were used 500 decision trees and 20 knots, which according to several authors (Breiman, 2001; Ienco et al., 2019; Karasiak et al., 2017; Pageot et al., 2020) are suitable to reach good accuracies. For SVM, the maximum number of samples was used to define each class was 0, all samples are used in the training of the classifier.

To assess the accuracy of the four land use/land cover maps resulting from the object-based image classification, a random sampling of 50 points was done for each class (8 LULC classes), for a total of 450 points for image a) and 350 for image b). Each point was assigned a LULC class based on visual analysis with the help of true-color and false-color composite imagery and base map provided in ARCGIS and Google Earth. This information was compared with the



classification results from an accuracy assessment using a confusion matrix, Kappa coefficient (Eq. 1), and overall accuracy (Eq. 2). The confusion matrix (Congalton et al., 1983, p. 1673; Stehman, 1997, p.1221) displays the number of pixels correctly classified against the number of pixels predicted for each class during classification, thus assessing the degree of agreement with reality. The information in the rows represents user accuracy (omission errors), while the columns represent producer accuracy (commission errors). A commission error occurs when pixels are included in an incorrect class, while an omission error occurs when pixels are excluded from the class to which they belong (Fonseca & Fernandes, 2004).

The confusion matrix enables the calculation of the Kappa coefficient (Kappa) and overall accuracy (OA).

$$Kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} x_{+i})} \times 100$$
 Eq. 1

$$OA = \sum_{i=1}^{k} \frac{N_{ii}}{N}$$
 Eq. 2

For the processes calculation of the vegetation indices, principal component analysis, multiresolution segmentation, and object-based image classification, Geographic Information System (GIS) tools were employed using the ARCGIS software version 10.8.

Results and Discussion

In the multiresolution segmentation, the input data set that yielded the best result was the one of red and nearinfrared bands, and NDVI, with a Kappa coefficient of 67% and an overall accuracy of 79%. According to Landis & Koch (1977), Kappa coefficients ranging between 41-60% correspond to good classifications and from 61-80% very good. In this study variable combinations including NIR, CP1, CP2, and NIR, NDVI, CP2 are good, while those including NDVI, SAVI, CP2, and R, NIR, NDVI are very good (Table 1). The accuracy improved with the inclusion of vegetation indices (NDVI and SAVI). However, the most significant contribution to accuracy came from the original red and near-infrared bands in combination with NDVI. It was also observed that the principal components did not contribute significantly to increase accuracy

	· · · · · ·	Classification				
N	Variables	Spectral	Spatial	Segment	Kanna	Overall
IN	v allables	detail detail size		size	Кирри	accuracy
1	NIR, CP1, CP2				54%	69%
2	NIR, NDVI, CP2	10	10	100	58%	73%
3	NDVI, SAVI, CP2	19	10	100	64%	77%
4	R, NIR, NDVI				67%	79%

Table 9. Multiresolution segmentation accuracy.

The multiresolution segmentation was used to object-based image classification, with SVM attaining the best accuracy when compared with RF and MLH in both images. The accuracy was higher for image b) composed mainly of holm oak then for image a) with predominance of cork oak, due to the its smaller variability in land cover.

A similar study by Sousa et al. (2010) using high-resolution imagery from the Quickbird satellite, with three LULC classes had high accuracy (91%). This discrepancy can be attributed to the greater complexity of our study area, characterized by high spectral variation due to the presence of multiple LULC classes and spatial variation due to object size. As in this study, errors along the tree canopy edges were observed, possible due to the irregular characteristics of each forest species' canopies, stemming from their shapes, textures, and lighting conditions.

These results are in agreement with those found by Volke & Abarca-Del-Rio (2020), which demonstrated that the Support Vector Machine algorithm is efficient for this classification method, even when using LANDSAT and ASTER satellite imagery, achieving an accuracy of 97% for LULC mapping. The segmented images, with defined objects corresponding to isolated or aggregated tree canopies, can be observed in the figures 3, illustrating the two forest species areas in question in this study.



argorannis.							
		Segmenta	tion			Class	ification
Image	Variables	Spectra 1 detail	Spatial detail	Segment size	Classifiers	kappa	Overall accuracy
					MLH	84%	92%
a)		19	10	100	SVM	90%	95%
	D NID NDVI				RF	89%	94%
	\mathbf{K} , $\mathbf{M}\mathbf{K}$, $\mathbf{M}\mathbf{D}\mathbf{V}\mathbf{I}$				MLH	66%	85%
b)		18	15	100	SVM	90%	96%
ŕ					RF	90%	95%

Table 10. Kappa coefficient and overall accuracy for both images and for the three machine learning algorithms.



Figure 3. Forest classification, a) quercus suber dominance and b) quercus rotundifolia dominance.

Conclusions

In this study, it was identified and delineated the tree crowns of forest species present in the image through segmentation and object-based image classification tools in the ARCGIS v10.8 software. The segmentation process, of high-resolution images, allows for detailed adjustments to surface objects.

Object-based image classification using WorldView-3 satellite imagery produced good results in identifying forest species crowns. The Support Vector Machine classifier, with the original bands and vegetation indices, in particular NDVI, led to land use/land cover maps with an overall accuracy of 95% and 96% and Kappa coefficients of 90%. The reflectance values for each class obtained by selecting objects to train the classifier discriminated very well between most of the classes identified. The image's acquisition date, corresponding to the dry season, enhanced a greater contrast between forest species and other land use classes, reducing the confusion with shrub vegetation and soil. However, some errors still occurred due to spectral similarity between certain forest species (e.g., cork oak vs. holm oak), crown characteristics, and shadow presence near canopies.

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Multispectral and hyperspectral sensors application to evaluate canopy variability in olive tree plants

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Abstract

Remote and proximal sensing platforms are revolutionizing precision olive farming by opening up new possibilities for development in the industry. Proximal sensing platforms operate close to the vegetation, while remote sensing platforms, such as Unmanned Aerial Vehicles (UAVs), operate from a greater distance but offer the advantage of rapid data collection for plot analysis. This study aimed to compare multispectral and hyperspectral data obtained using both remote and proximal sensing platforms. Multispectral data were collected using a DJI multispectral camera mounted on a UAV Phantom 4. Hyperspectral data acquisitions were conducted using a FieldSpec® HandHeld 2^{TM} Spectroradiometer (HHS) on canopy portions exposed to the South, East, West, and North directions. Geographic Information System software was employed to process the multispectral images and extract spectral information for each cardinal direction's exposure. Three Vegetation Indices, namely NDVI, NDRE, and MSAVI, were utilized for analysis. The multispectral data effectively captured the variability within the entire plot, allowing for differentiation of each plant's health status. On the other hand, hyperspectral data provided a more precise description of vegetation health conditions and appeared to be correlated with the cardinal direction of exposure. The correlation coefficients (r) between multispectral and hyperspectral data were 0.63^{**} for MSAVI, 0.69^{**} for NDVI, and 0.74^{**} for NDRE, indicating strong relationships between the two platforms. Interestingly, the South and West exposures exhibited the highest correlations between both platforms.

Introduction

Since the early 2000s, precision agriculture, known as Precision Farming (PF), has revolutionized crop management, tailoring practices like irrigation and tillage to field variability. This relies on various technologies, including spectral cameras, categorized as multispectral and hyperspectral.

Multispectral cameras capture a limited number of spectral bands, while hyperspectral cameras offer a wider range with finer detail. Spectral data are crucial for assessing crop health, processed in various ways. Hyperspectral data are increasingly popular, notably for calculating Vegetation Indices (VI) like NDVI, NDRE, and MSAVI, commonly used in olive farming for insights into biomass, Leaf Area Index (LAI), and more.

Multispectral data dominate olive orchards, used for tasks like fertilization, biophysical analysis, irrigation management, pruning, and yield prediction. In contrast, hyperspectral data from remote platforms determine biometrics, LAI, nutritional status (N and K), water, yield, and fruit quality.

Comparing multispectral and hyperspectral data in agriculture is limited but often favours hyperspectral versatility in crop productivity, classification, biomass estimation, and nitrogen content assessment.

Multispectral cameras are linked to remote platforms like UAVs, while hyperspectral sensors are used proximally due to their noise sensitivity. However, hyperspectral cameras can also be used remotely, though few studies compare data from different viewpoints.

The study aimed to assess olive canopy conditions using remote (UAV) multispectral and proximal hyperspectral sensors, employing three Vegetation Indices, to determine if they capture similar data.

Materials and Methods

Study area

The field test took place in Calatafimi-Segesta, Trapani, Italy, at coordinates Lat 37°51'48.21"N; Long 12°57'15.17"E (WGS84) (**Figure 8**), characterized by a Csa climate (Mediterranean hot summer climates). Climatic data from 1985 to 2020 revealed an average annual air temperature of 16.1 to 18.6°C and annual precipitation of 440 to 495 mm (Sicilian Agrometeorological Information Service). The soil moisture regime is xeric, bordering on aridic, and the temperature regime is thermic. The experiment was carried out in 2021 within an olive orchard following local standard management practices, without irrigation





Figure 21. Experimental site location; Maps Data: Google ©2021, QGIS.

Instrumentation used and setup

Multispectral data were gathered using a DJI Phantom4 Multispectral drone, known for its high precision and integrated multispectral imaging system. The camera consists of six 1/2.9" CMOS sensors: one for RGB visible light imaging and five monochrome sensors for multispectral imaging. These sensors cover bands including Blue (B), Green (V), Red (R), Red-Edge (RE), and Near Infrared (NIR) at specific central wavelengths.

The camera's lens has a 62.7° field of view, a 5.74 mm focal length, and an aperture of f/2.2. This setup achieves a final image resolution of up to 1600×1300 pixels.

The UAV is a quadcopter equipped with four rotors and is capable of autonomous flight along predetermined routes. It includes a solar irradiance sensor for pre-calibration and utilizes EXIF information for geolocation (**Figure 8**). For precise positioning, it employs a multi-frequency Global Navigation Satellite System (GNSS) that receives signals from multiple satellite constellations, achieving high accuracy through Real Time Kinematic (RTK) correction.



Figure 2. UAV survey and planning mission.

A remote UAV equipped with a multispectral camera was used to capture multispectral data. The flight mission was accurately planned using DJI GS Pro software, setting parameters for altitude, speed, and camera settings. To minimize unwanted elements like shadows and weeds, the flight was scheduled at noon on day 217, when the sun was at its zenith.

Before the flight, five Ground Control Points (GCPs) were strategically positioned in the field and accurately georeferenced using the S7-G GNSS receiver by Stonex, a receiver GNSS multi-band able decoding signal from GPS, GLONASS, Galileo, and Bei Dou, with improved accuracy via RTK differential correction data. GCP coordinates were collected in RTK mode, averaging 60 measurements. With GCPs in place, the UAV took flight under clear skies and low wind conditions, following a predetermined route and waypoints.



The UAV operated at an altitude of 50 meters above ground level, leveraging RTK differential corrections to achieve a ground sample surface (GSD) of 2.6 cm. Image acquisition occurred at an average speed of 10 m·s-1 in a stop-and-go mode to minimize forward speed-related distortions. To ensure detailed and undistorted images, a 70% front and side overlap was maintained between images, and the gimbal pitch was set at 90°, facing downward.

Hyperspectral data were collected using a FieldSpec® HandHeld 2[™] Spectroradiometer (HHS), a handheld device. The HHS operates in the spectral range from 325 to 1075 nm, providing accurate readings with a spectral resolution of less than 3 nm and 16-bit radiometric resolution (Figure 3). It captures spectra within a 25° field of view, ensuring high signal-to-noise ratios in less than one second. Notable features of the HHS include a low light dispersion grating, integrated shutter, DriftLock dark current compensation, and second-order filtering. It also includes practical features such as a colour LCD, computing capabilities, ample internal data storage, a laser pointer, and compatibility with GNSS receivers for georeferencing.



Figure 3. Hyperspectral sensor during the acquisition data placed at about one meter from the canopy.

Hyperspectral data were collected from 24 randomly selected plants on the same day as the UAV flight. Measurements were taken starting at 01:00 pm in four directions: South, West, North, and East. For each direction, three measurements were taken, and radiometric reflectance calibration was carried out using a calibrated Spectral white reference.

The acquisitions were performed at a distance of about one meter from the canopy in the four lateral sections of the plants directly in the field. This ensured that the hyperspectral data focused solely on the canopy without interference from the soil in all four directions.

The collected data were processed using the instrument's proprietary software (HH2 Sync and ViewSpec Pro). Each acquisition produced a .asd file, which could be further processed in the proprietary software and saved in various formats.

Results and Discussion

The hyperspectral data revealed distinct reflectance patterns in 24 selected plants and their cardinal-exposed sections. These plants displayed typical agricultural characteristics, with higher reflectance in the near-infrared (NIR) regions compared to the visible spectrum. Reflectance peaks were evident around 555 nm (green) and 770 nm (NIR), while a dip occurred around 690 nm. Notably, reflectance varied based on cardinal exposure directions, with the South showing the highest values and the North the lowest.

Three vegetation indices (NDVI, NDRE, MSAVI) were calculated from the hyperspectral data, and significant differences were observed among cardinal exposures. MSAVI had the highest average value, followed by NDVI and NDRE.

Regression analysis demonstrated strong relationships between these indices, with high R^2 values, indicating their interdependence. The most significant correlation was found between MSAVI and NDVI.

In summary, hyperspectral data provided insights into plant reflectance patterns and the relationships among vegetation indices, highlighting the impact of cardinal exposure directions on these characteristics.

Utilizing the responses of the three distinct vegetation indices, ANOVA was employed to compare the data obtained by the two sensors, multispectral and hyperspectral, as illustrated in Figure 4. The influence of exposure was statistically significant and more pronounced in the hyperspectral data than in the multispectral data. Notably, West and South exposures produced the most consistent results in multispectral imagery, displaying minimal data scatter across all indices.

Intriguingly, exposure had a negligible impact on the multispectral data, contrasting with the hyperspectral data.

Specifically, in the South and West exposures, both NDVI and MSAVI values were statistically higher compared to those obtained from multispectral images (p-value <0.05). Conversely, in the North and East exposures, values consistently remained lower, but the presence of high data dispersion precluded any significant distinctions.



Wavelength [nm]

Figure 4. Hyperspectral signature averaged over different canopy exposures.

The strongest correlations between the indices derived from the two datasets were observed in the southern and western exposures for all three indices. For instance, NDVI in the West exposure exhibited a correlation of $r = 0.69^{**}$ between multispectral and hyperspectral data, while the MSAVI correlation reached its peak at $r = 0.63^{**}$ in the same exposure. NDRE also displayed a robust correlation of $r = 0.74^{**}$ in the South exposure when comparing multispectral and hyperspectral data (Table 1).





Figure 5. (a) Correlation between MSAVI values UAV multispectral based and the mean MSAVI value from hyperspectral proximal data. (b) Correlation between NDVI values UAV multispectral based and the mean NDVI value from hyperspectral proximal data. (c) Correlation between NDRE values UAV multispectral based and the mean NDRE value from hyperspectral proximal data.

Multispectral images effectively captured the spectral condition of each plant, showing good linearity in the extrapolated data (Figure 6). No statistically significant differences were observed for the same indices among various exposures for all three indices.

Table 1	11. NDVI,	NDRE :	and MS	AVI f	from hy	yperspe	ctral da	ita. Va	lues ar	e mean	\pm st.de	v. of	the 24	selecte	ed plants.
D	oifferent let	tters in t	he colui	mn ine	dicate s	statistic	ally sig	nifica	nt diffe	rences	at a sig	nifica	ince le	evel of t	5%.

Exposure	NDVI	NDRE	MSAVI
S	0.65 ± 0.05 a	0.17 ± 0.02 a	0.79 ± 0.04 a
W	0.64 ± 0.05 a	0.17 ± 0.02 a	0.78 ± 0.04 a
Ν	$0.50\pm0.15\ b$	$0.14\pm0.04\ b$	$0.64\pm0.20\ b$
Е	$0.51\pm0.14\ b$	$0.15 \pm 0.03 \text{ ab}$	$0.66\pm0.13~b$
Average	0.57 ± 0.13	0.17 ± 0.03	0.72 ± 0.14

The comparison between multispectral and hyperspectral data revealed that different VIs assign different values to the same level of crop stress. In general, MSAVI provided higher values, followed by NDVI and then NDRE, both in multispectral and hyperspectral data.

Data from the hyperspectral sensor, providing a side view of the object, correlated well with aerial multispectral images from the drone, with attention to exposure. Hyperspectral information is more accurate but also more susceptible to errors than multispectral information. This effect is attributed to the variation in data and the lower correlation value between hyperspectral data in the four exposures. The exposures with the best correlation among the VIs calculated from the two datasets were South and West.



Figure 6. Comparison of spectral response of hyperspectral and multispectral data

Conclusions

The data of multispectral images captured by drones can be effectively compared with hyperspectral data obtained from closer proximity systems, especially when using the right wavelengths and acquiring data from the South and West exposures of olive trees. The data from the remote platform showed strong correlation and precise mapping of the entire plot, enabling accurate investigations.

However, the potential to gather spectral information from crops, advancements in proximal sensing platforms like UAV, and ongoing technological improvements are making hyperspectral sensors increasingly appealing for precision farming.

This study demonstrated that hyperspectral data acquired from a closer viewpoint through proximal platforms can provide more accurate descriptions of crop spectral conditions, despite challenges related to limited coverage and



variable data quality influenced by factors like exposure and brightness. The study also highlighted the potential benefits of combining hyperspectral and multispectral data. Nevertheless, aspects such as timing and data management for the two different platforms require further evaluation for future applications.

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