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Principles of Sustainable Agriculture: Defining Standardized Reference Points

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Abstract: No question remains regarding our need to change toward sustainable agriculture. When ranking the industries that have more prevalent environmental impacts, agriculture holds a considerable share of responsibility. However, as sustainability is an ambiguous concept surrounded by controversy and debate, rather than attempt to describe its meaning through a single universal definition, we instead stressed the need to delineate a set of fundamental principles. With the goal of putting the sustainable-agriculture concept into practice, an inductive qualitative content analysis was employed based on multivariate methods on hundreds of different definitions, theories, notions and sustainability indicators gathered through a deep-structured literature review. Through this novel approach, we were able to identify four fundamental principles for sustainable agriculture (integrated management, dynamic balance, regenerative design, and social development), and concluded that in order to shift our current agricultural systems into more efficient and sustainable ones, we need to start making better use of natural and human resources. This work provides guidelines for reference that can be used by anyone whenever they make a decision regarding sustainable agriculture or apply a methodology to assess a particular behavior, process or situation.

Keywords: discourse analysis; integrated systems; IRAMUTEQ software; sustainability definition; sustainable production; textual data processing

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1. Introduction

Intensive conventional agriculture contributes to climate change, water pollution, loss of biodiversity, or natural-resource depletion, as well as being directly affected by it. Even though such concerns are broadly acknowledged, we continue to uphold excessive and unsustainable production or consumption habits that are responsible for exceeding our planet's boundaries or reaching irreversible tipping points. The world we know today is therefore doomed if food production continues business as usual [1].

It is also assumed that sustainability may help us to build resilient societies by means of knowing how to adapt, evolve or transform in the face of climate change's severe impacts, or any other disturbing event [2]. Due to our population growth rate, we must simultaneously focus on feeding humanity while not depleting natural resources [3–5].

There is a clear reluctance regarding our transition toward sustainability on a global level. The main reasons include the gap in our knowledge around sustainability, such as the lack of standardization and transparency, and the disagreement among interested parties regarding its meaning and ways to approach it [3]. The concept's inherently ambiguous nature and the absence of a widely accepted single definition is one major cause for this argument, and it also contributes to the emancipation of inadequate sustainability-related research studies and parallel assessment methodologies [6–9]. Sustainability assessments are often characterized as having biased design, erroneous interpretations, flawed conclusions, and serious incompatibility issues due to the difficulties of data comparison [10–12].

Regardless of being on the top tier of the scientific and governmental agenda, the disparity of what it means still deeply affects how sustainability has been applied in practice by farmers, stakeholders, or even in the policymaking process [13]. Numerous efforts have been devoted trying to delineate a single description. However, the larger dilemma seems to be when we have to weigh up, trade off, or agree over sustainability targets, as it obliges us to assess or choose between highly variable values or beliefs [3].

As an alternative solution for the incessant debate and search for a universal definition, this work stresses the need to define principles for sustainable agriculture as standardized reference points [14,15]. Thus, in order to translate the eclectic vision of sustainable agriculture into a list of fundamental principles, we systematically analyzed a representative collection of thoughts, ideas, indicators, and theories promoted by peers, specialists, NGOs, or governmental organizations involved in sustainable farming.

Aiming to reform the way we think and in order to approach such a nonabsoluteness problem with new systems of learning, we have addressed this issue from an integrated and multidisciplinary point of view by combining basic lexicography with multivariate analysis. Through a high-level literature review followed by a breakdown of doctrines from various relevant documents, we aspired to identify areas of complementarity and concern between emerging meanings of sustainable agriculture.

The purpose of this study is therefore to use robust, viable qualitative analysis to identify fundamental principles that are capable of guiding our transition toward sustainability in a practical and functional way. Using this approach not only allowed us to illustrate fundamental principles of sustainable agriculture, but also to establish impartial criteria that can be widely accepted as trustworthy, and to encourage reflection on how to produce sustainably, what is being sustained, for whose benefit and at whose cost.

This work is thus a formal and empirical attempt to indirectly tackle the big questions of defining and normalizing sustainability through reference points. Outcomes are seen as a valuable addition to the literature on sustainability by proposing an integrated and novel perspective to deal with the inherent complexity and debate around the concept of sustainability, while it can also be used as a compass to which anyone can refer to whenever making a decision regarding sustainable production.

2. Evolution of the Concept of Sustainability

Although the first considerations for the potential issue of population growth and its alarming reflection on the economy and well-being were initially drawn by Malthus [16], the concept only became widespread after the 1980s with the Brundtland Commission report [17]. Since then, there have been other praised attempts to define sustainability, reflecting different values, priorities, and goals over time [18].

However, this ambiguous concept of sustainability is today mostly perceived in a triple bottom line (TBL) perspective, in which people, planet, and profit are seen as imperative components. This theory coined by Elkington [19] was translated into three fundamental pillars—environment, economy, and social, despite the fact that other dimensions can also be considered based on different aspects [18]. Nevertheless, the focus on environmental concerns still prevails, neglecting all the other categories, which thus remain underrepresented, such as the social, economic, institutional, political, and ethical [4,13,20].

The bottom line is that any attempt to construe a precise, absolute, and all-encompassing definition of the concept is doomed to failure due to its complex and ambiguous nature [9,21]. In fact, the variety of emerging meanings have mostly motivated incessant debates around the usefulness of the sustainability concept and the lack of practical applicability, as concrete examples of its usability are still difficult to find [13]. Consequently, many ad hoc modeling approaches and a wide variety of inadequate tools and sustainability indicators have been developed [3,22].

In the following subsections, we examine in more detail the conceptual and practical issues when using sustainability as a norm for guiding change in agriculture—either through a system-property perspective, a philosophical approach, or a measurable criterion, as these broad interpretations of sustainability in agriculture have been emerging among literature within different underlying foundations.

2.1. Sustainable Agriculture: Two Schools of Thought

The literature reveals two main substantive interpretations of sustainable agriculture. On one hand, sustainability is interpreted as an approach or a philosophy motivated by an awareness of the negative impacts of agricultural activities, while on the other, sustainability is perceived as a set of strategies that should be applied to enhance resilience, building upon the system [23,24].

When seen as a philosophy, the concept of sustainability itself is interpreted as an ideological or management approach to agriculture, with the underlying goal of motivating the adoption of alternative approaches [24]. Despite its ability to motivate change and the adoption of sustainable practices on a lower hierarchical level, the lack of generally approved alternatives or even the often-distorted view of circular perspectives, may have held back its higher purpose toward sustainable food production [23]. This line of interpretation is therefore frequently questioned due to our lack of knowledge on key related concepts, a biased view either of circularity or prescribed sustainable practices and approaches as alternatives for conventional agriculture [24,25].

Interpreting sustainable agriculture as a goal-prescribing concept and a set of values also brought about the rise of the so-called alternative agricultures—despite the incessant debate on whether some can indeed be qualified as sustainable or not [26,27]. These can include agroecology, organic, biodynamic, regenerative, permaculture, environmentally-sensitive, community-based, wise-use, low-input, ecological, farm-fresh, extensive, and integrated production [5]. Alternative production is often associated with a set of defined and knowledge-demanding technologies, interventions, practices, or policies, mostly resource-conserving and used to improve the use of natural capital [26]. Overall, their strategy tends to mimic nature and approach a regenerative and circular perspective, implying the reduction or elimination of the use of processed chemicals, such as fertilizers and pesticides [23,26].

Nevertheless, there is one common discussion regarding the low productivity and efficiency of such sustainable agriculture systems, and the query continues to hang over whether this shift can be done while seeking to maintain and enhance food production for future generations [28]. In fact, it is often implied that most alternative approaches will not respond to climate-change challenges or assure food security due to their being essentially extensive and demanding more land to reach the same amount of outputs. It is with this remark that a sustainable intensification approach is usually defended [26].

In summary, it may not be easy to distinguish between alternative approaches as several integrate the same strategies, practices, or technologies. However, all these are generally suggested by ideological interpretations of sustainability, and tend to be based on recognized impacts, types of problems emphasized, and considerations of what could constitute an improvement of the systems' performance [3].

Against this notion, the other interpretation of sustainable agriculture, the system-property perspective, defends that when considering the dynamic nature of the concept itself, as well our ever-changing modern world, it is seen as critical for sustainable agriculture not to prescribe a concretely defined set of technologies, as these may restrict options for farmers [25,29]. It is therefore assumed that it is not the practices that should be sustainable, but rather our process of innovation and adaptation itself. Moreover, as the interpretations of sustainability are context-specific, ways and means to produce food sustainably should not be imposed models or methods, but instead a process to continuously learn and improve [21].

Another concern raised regarding the context-specific nature of sustainability is the fact that this ideological approach cannot be entirely useful for guiding change on a universal basis, as certain practices or technologies may not be appropriate in regions where circumstances or issues are different [25]. Thus, this attempt to link management strategies to sustainability directly fails as regards the inherent necessity to match certain technologies to specific environments [23]. In other words, one size does not fit all, and for that matter this ideological approach may encounter serious downsides when trying to reach higher hierarchical levels of the sustainability picture, such as national or global levels. In addition, due to the temporal nature of sustainability and the innate progression of our modern times, the need to be constantly evaluating performance and impacts in order to improve approaches is not facilitated if sustainability is being interpreted as a philosophy or a set of management strategies [5,30].

The system-describing concept, by interpreting sustainability either as an ability to fulfill a diverse set of goals or as an ability to continue over time, is for that matter seen as a useful alternative to guide farmers toward change [23,24]. Furthermore, when interpreting sustainability as a system property developed to respond to challenges and threats, at its core this perspective can be related to contemporary concerns and to the possibility of using sustainability as a criterion for guiding agriculture to respond to rapid changes, as it supports resiliency building and performance assessment [23,30]. This perspective is therefore inherently grounded in resilience and durability goals, and is described as being developed from the need to overcome threats, stresses, and the capacity to adapt to change [25].

However, despite being logically more consistent than the former, it falls down on practical conceptualizations. To overcome this and to be seen as a useful criterion for guiding the agrarian sector toward sustainability, it must be system-oriented, quantitative, predictive, and diagnostic [23]. However, those traits are hard to accomplish. In fact, such need for diagnosis is a major limiting factor when trying to interpret sustainability as the ability to fulfill a set of goals [23,30,31].

2.2. Sustainable Agriculture: A Set of Indicators and Attributes

Above all, attempts to make this concept more operational—even if interpreted as a philosophy or as a system property—tend to rely more and more on measurements and evaluations of sustainability [3,31]. However, as its interpretation is always dependent on the perspectives of the analysts holding the measurement results and the context in which the evaluation is being operated, one single precise assessment methodology capable of measuring sustainability seems to be another impossibility [3,28]. An option to overcome this issue is to look to the situation as a whole and try to normalize the concept by establishing a set of standardized reference points. Only afterward, and for each particular case happening in a certain context, should specific principle-based parameters and criteria be selected to properly measure sustainability credentials [32]. Thus, we first must recognize the importance of sustainability in agricultural systems, and only then develop methods and ways to empirically measure sustainability of well-defined farming systems [18,33].

To surpass this bickering, several nonsustainability indicators have also been suggested to be used instead of common sustainability indicators. The logic is that these remove the prior need to define what is sustainable production, facilitating the assessment and monitoring process. Nonsustainability indicators for agriculture include: land degradation, changed botanical composition of forests and pastures, prolonged negative trends in yields, lower per capita availability of agricultural products, increasing use of submarginal lands, high intensity of input use, and reduced biodiversity, among others [3,34].

Nevertheless, to date, indicator-based tools continue to be the most commonly used methods when evaluating the sustainability of a specific practice. Despite being generally structured on four hierarchical levels: (i) dimensions; (ii) themes; (iii) subthemes; and (iv) indicators, the diversity of terminology used in the literature to define the various levels inevitably complicates the debate on sustainability even more [3,4,35].

Indicators, for example, are often described as measurable variables used to evaluate the sustainability in any theme or subtheme [36]. Yet, a plethora of other different terms are also used in literature—being sometimes identified as a variable, a parameter, a statistical measure, a proxy, a value, a meter or measuring instrument, a fraction, an index, a piece of information, a single quantity, an empirical model, or a sign, among others [3,37,38]. On the contrary, even though themes and subthemes can be used to translate sustainability goals, when conceptualizing sustainability indicators, Velten et al. [9] assumed that sustainable agriculture is a set of ideal objectives or goals that must be achieved. In this context, principles were described as strategies that should or should not be applied in different areas or fields of action. Notwithstanding, principles can either be seen as universal rules or laws, while values and goals are subjective and may change over time or between different realities. Values are for that reason based on our current circumstances, demands, or needs. These are important to express individual beliefs or opinions, and if used strategically may contribute to accomplishing objectives. Thus, principles can ultimately drive both values and goals, and as such they can overcome any hierarchy level [14,28].

It was considering this background that we decided to look for ways to gather objective certainties gifted with the ability to transcend individuals or cultural differences, while also unchangeable over time. It must be stressed how the time factor was one key element to ponder, as sustainability is also a means to assure that we will not compromise the ability of future generations to meet their own needs. We must not forget that we did not inherit anything from our ancestors, but rather we borrow it from our children [17].

3. Materials and Methods

Following the previous premises, this section presents the methodology used for data collection, preparation, and analysis.

Our first step was based on the construction of a database with different interpretations and definitions of what it means to produce food sustainably. In order to identify and collect the main theories, thoughts, and descriptions regarding the definition of sustainability, we reviewed key issues on the concept of sustainability—sustainable development and sustainable agriculture, along with food security. For data collection, we searched peer-reviewed scientific journal volumes and issues published in all years up to and including 2020 regarding sustainable agriculture, together with official reports, doctrines, and guidelines in various relevant documents issued by public, private, and academic partners.

Regarding peer-reviewed issues, we looked for academic publications in English, French, and Portuguese related to the topic, through major online citation databases—Science Direct/Scopus, Web of Science, and Google Scholar. As for official guidelines and reports from public and private entities, we carried out our search mostly on each institution's website, including organizations known to be related to agriculture or sustainability such as: WCED, OECD, FAO, USDA, WBCSD, UNEP, IOBC, IFOAM, and IUCN; big hitters in the food industry such as: Nestlé and Unilever; or even NGOs with certification programs such as: Fairtrade International, the Rainforest Alliance, and ISO, among others.

After the search, we narrowed down all the publication material into a directory. Relevant information that gave at least a minimal definition or explanation of the meaning of sustainability in agriculture (or nonsustainability), associated terminologies, indicators, or any guidance toward sustainable decision-making was gathered and identified according to major categories referred to in the literature: (i) dimensions; (ii) themes and subthemes; (iii) indicators; (iv) goals; (v) attributes; and (vi) definitions. Finally, we tackled and prepared for analysis 100 different definitions, 55 goals, 41 attributes, and hundreds of indicators, themes, or sustainability dimensions from a total of 179 references.

With this database catalogue, we proceeded toward the delineation of the text corpora so it could thereafter be systematically and empirically analyzed using IRAMUTEQ software. In order to employ an inductive qualitative-content analysis, all the data collected had to be firstly transcribed for the preparation of the corpus, so as to be inserted in the software. The purpose was to generate a robust database with a holistic perspective of the meaning of sustainable agriculture so we could determine key classes and the connection between them by identifying analytical possibilities and new interpretative pathways.

Hence, the organization of the data for analysis (corpus text) was carried out according to the requirements and possibilities of IRAMUTEQ. All the material was transcribed into a single file, separating sets of text by a command line. As mentioned, each set (or variable) was chosen according to major categories identified in the literature and often used when cataloging sustainability-assessment methodologies. Thus, variable 1 corresponded to the "dimensions" category and was coded as *Susagri_01. We proceeded likewise to all the other 5 variables, correspondingly: themes, and subthemes (*Susagri_02); indicators (*Susagri_03); goals (*Susagri_04); attributes (*Susagri_05); and definitions (*Susagri_06). Nonsustainability characterizations were also included and transcribed on the same basis.

The subjects were mostly sustainability specialists, researchers, agricultural and food organizations, major agribusiness companies, and institutional bodies involved in this discussion ($n = 179$). Our transcribed corpus for analysis comprised a total lexicon set of 15,526 words, with 2370 distinct and 1029 of single occurrence. The global analysis of the corpus in IRAMUTEQ was made up of 459 text segments (TSs), which are the context units created automatically by the software [39].

Five different textual analyses from simple to multivariate were then executed on the corpus using IRAMUTEQ; namely: (i) classical textual statistics to identify frequency of words, single words (hapax coefficient), grammatical classes, and root-based words (stemming); (ii) search for group specifications and factorial correspondence analysis (FCA); (iii) cluster analysis through Reinert's method using descending hierarchical classification (DHC); (iv) analyses of similarity; and finally (v) a word cloud. All the analyses in the IRAMUTEQ software were performed in the English language.

Only after the preparation and coding of the initial corpus into TSs were the three main steps taken toward the delineation of sustainable agriculture principles: (i) first, we started to perform descending hierarchical classification by data processing and the consequent FCA; (ii) then, we interpretated the classes generated based on their factorial representation and major active vocabulary between clusters with greater chi-square (χ^2) values and statistically significance ($p < 0.0001$); and (iii) we considered FCA results of forms (words) and variables (categories), results from similarities analysis on frequent vocabulary, and the whole context of high-scored TSs (either by cluster or by variable), and finally established a set of key principles.

IRAMUTEQ software was considered appropriate for this study purpose, as it enables the organization and the categorization of the data inserted into thematic categories by using descending hierarchical classification (DHC). It also shows the emerged thematic classes and confirmed connections between them in a way that can add quality to the presentation of supported outcomes [39,40]. In addition, as IRAMUTEQ is a software program developed in the Python language with functionalities provided by the statistical software R, it offers accuracy and rigor to qualitative textual data analysis [39].

The fundamental principles of sustainable agriculture were therefore identified based on a deep-structured reflection on confirmed clusters of different meanings for sustainability, complemented with major and contemporary concerns that must imperatively be addressed when idealizing a sustainable system. Through this approach and using a credible, in-depth, qualitative data analysis, it was possible to identify, interpret, and translate major cluster classes into universal principles of sustainable agriculture.

4. Results and Discussion

4.1. Multivariate Analysis

For the descending hierarchical classification analysis (DHC), corpus processing was performed in 15 s with 72.33% of the total corpus used by the software (332 of the 459 TSs). In IRAMUTEQ, due to the programming employed, the context of the words is always weighed, and a minimum of 70% is considered an efficient index use of TSs [41]. The corpus we analyzed presented 1734 active forms and 214 supplementary, with an average of 33 words per TS.

A dendrogram was then generated with four classes. As shown in Figure 1, two ramifications are evident. Ramification 1 (R1) has two clusters: (i) cluster 4 with 71 TSs (21.4%), and cluster 1 with 83 TSs (25%). On the other hand, ramification 2 (R2) leads to cluster 2 with 57 TSs (17.2%), and cluster 3 with 121 TSs (36.5%).

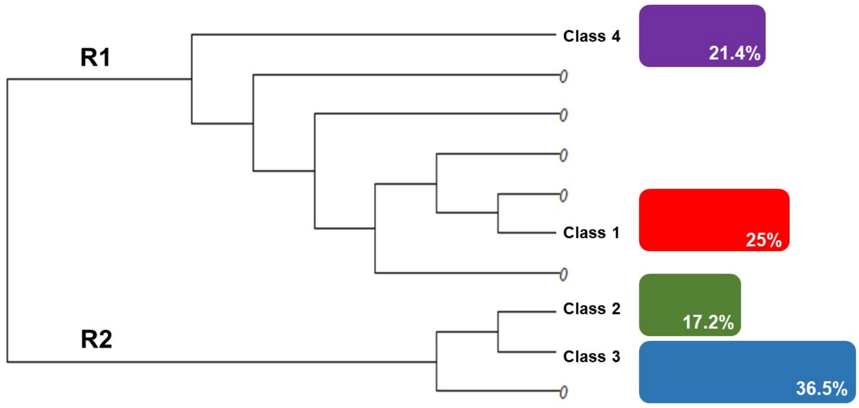


Figure 1. Global descending hierarchical classification of class constructs.

From these results, it was possible to draw up interpretations of the formations of each cluster, as well as to understand the similarities and differences between them. Using the dendrogram of the global DHC, it can be perceived that the stabilization of the classes occurs after two macro ramifications.

In R2, for example, clusters 2 and 3 demonstrate higher affinity with each other, with 53.7% of the total in the corpus. In addition to a strong distance from the other two classes, three subdivisions on internal levels also occurred in R1 between clusters 1 and 4. Cluster 4 therefore has fewer relationships between the words in the context of the classes, as it is farther away from the DHC switching, in particular with cluster 3. Clusters 2 and 3, on the other hand, are the closest ones. The closer the classes are, the greater the contextual affinity and the likelihood of future relationships in the construction of the reference standards for sustainable agriculture (or principles). Furthermore, we can observe that despite the fact that 10 distant areas of discourse emerged from this analysis, only these four showed sufficient strength to exist as a class.

Finally, we proceeded to factorial correspondence analysis (FCA). The correspondence analysis is achieved as a result of the analysis of descending hierarchical classification (DHC), and both are interpreted together allow discourses to be linked into variables [42].

In Figure 2, we present the different grouping of words or vocabulary that constitute each of the classes proposed in the DHC in a Cartesian plan. For better comprehension, in the same figure we join both FCAs of the data pertaining to classes and the centered position of each class. In this Cartesian plane, the approximations and distances between the classes also can be identified according to the positioning in the quadrants, allowing us to interpret the results as follows: (i) the relationship of clusters 2 and 3 is confirmed by their approximation on the left quadrant over the horizontal axis, demonstrating homogeneity in the representations between these two classes and distance to others; (ii) both cluster 1 and cluster 4 stayed in the right quadrants, despite class 4 is visibly more isolated in the bottom-right quadrant (Q4).

Following this initial analytical step, and in order to understand the intensity and importance of each word in the context, we considered TSs of each variable and class for a more qualitative interpretation. Entering into a detailed interpretation of each class composition, the following can be highlighted: (i) clusters 2 and 3 share the representation of both themes and indicators collected when defining nonsustainability and sustainability, respectively—revealing that despite opposite terminology, the means toward a desired sustainable end can be similar at its core. In regard to cluster 1, it mostly gathered representations of given definitions and established dimensions of sustainable agriculture, proving an inherent link between previous attempts to define and categorize sustainability into fundamental pillars. Finally, cluster 4, despite gathering mostly representations of sustainable agriculture attributes, goals and themes, when considering most frequent forms, has a clear connection within governance and institutional scope with empathy toward international standards and sustainable-development goals (SDGs).

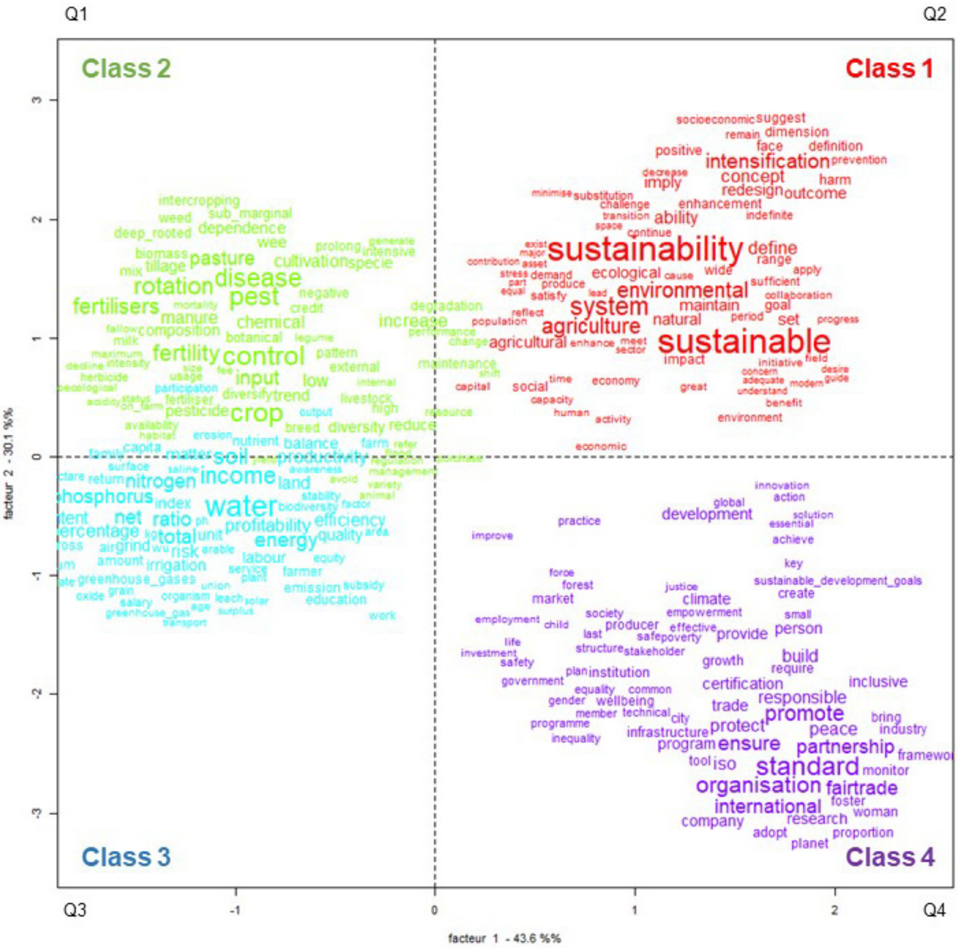
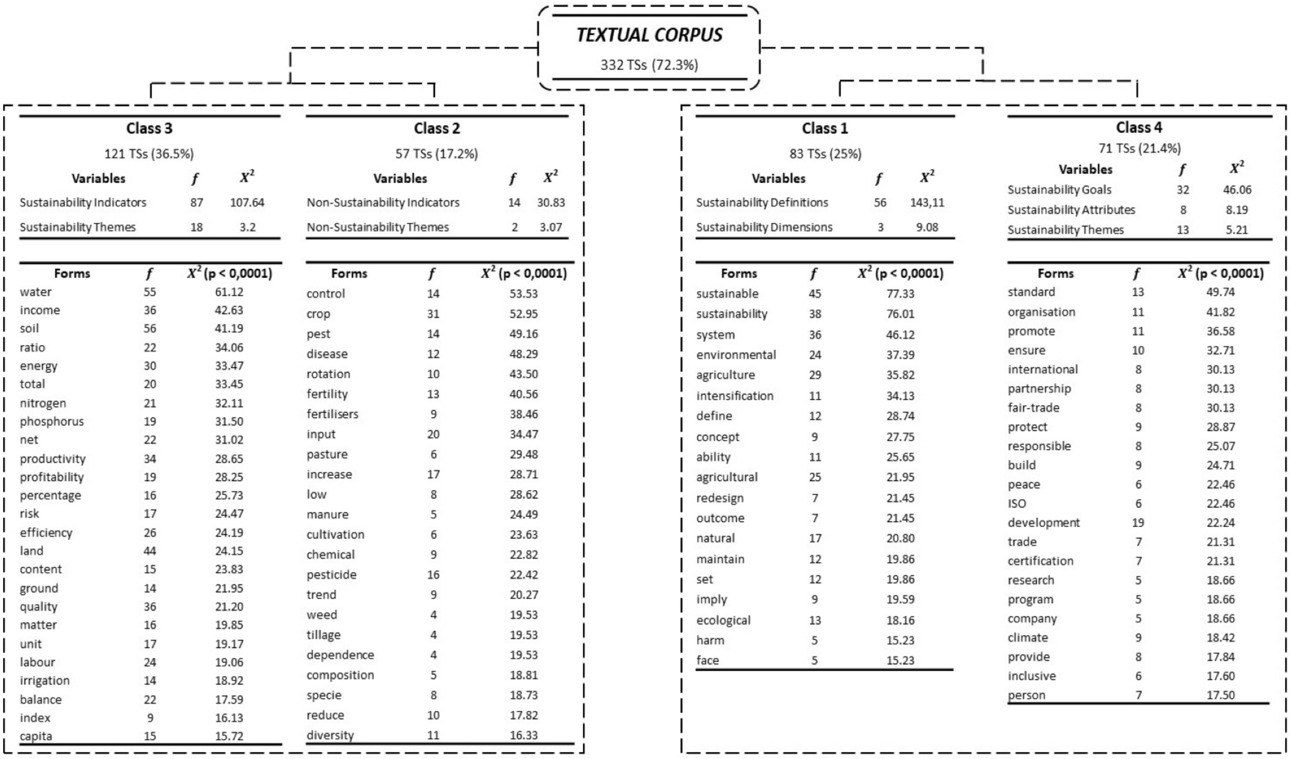


Figure 2. Factorial representation of four clusters in a Cartesian plan.

We then analyzed the associative strength between words (forms) and their respective class. The program uses the chi-square test (χ^2) for creating a dictionary of words, as a lower chi-square value represents a lesser relationship between the variables [42]. Figure 3 shows the stronger forms where the chi-square test was greater than 3.84, and $p < 0.0001$. This figure was inspired by a type of dendogram (phylogram), and the visualization of the main words with similar vocabulary between each class is complemented with their frequency (TSs) per class and chi-square results.

Specificities and correspondence factor analysis were also used in TSs with variables, allowing the analysis of forms according to each category (definitions, attributes, goals, dimensions, themes, and indicators).

In Figure 4, we can visualize the distribution of the vocabulary according to the two main axes (hypergeometrical law), and where each variable is stronger. This illustration also enabled us to interpret which main factors can best explain the variability of discourse and variables. It can therefore be endorsed that all the debate around the definition of sustainable agriculture can be branched into two dimensions: from more theoretical conceptualizations (definitions, attributes, and goals) to methodological concerns (themes and indicators) regarding dimension 1 (vertical axis); to the point of view and nature of the vocabulary used to describe sustainability notions (through a sustainability or nonsustainability angle) for dimension 2 (horizontal axis).



Class 3 — 121 TSs (36.5%)

Variables	f	X^2
Sustainability Indicators	87	107.64
Sustainability Themes	18	3.2

Forms	f	X^2 (p < 0,0001)
water	55	61.12
income	36	42.63
soil	56	41.19
ratio	22	34.06
energy	30	33.47
total	20	33.45
nitrogen	21	32.11
phosphorus	19	31.50
net	22	31.02
productivity	34	28.65
profitability	19	28.25
percentage	16	25.73
risk	17	24.47
efficiency	26	24.19
land	44	24.15
content	15	23.83
ground	14	21.95
quality	36	21.20
matter	16	19.85
unit	17	19.17
labour	24	19.06
irrigation	14	18.92
balance	22	17.59
index	9	16.13
capita	15	15.72

Class 2 — 57 TSs (17.2%)

Variables	f	X^2
Non-Sustainability Indicators	14	30.83
Non-Sustainability Themes	2	3.07

Forms	f	X^2 (p < 0,0001)
control	14	53.53
crop	31	52.95
pest	14	49.16
disease	12	48.29
rotation	10	43.50
fertility	13	40.56
fertilisers	9	38.46
input	20	34.47
pasture	6	29.48
increase	17	28.71
low	8	28.62
manure	5	24.49
cultivation	6	23.63
chemical	9	22.82
pesticide	16	22.42
trend	9	20.27
weed	4	19.53
tillage	4	19.53
dependence	4	19.53
composition	5	18.81
specie	8	18.73
reduce	10	17.82
diversity	11	16.33

Class 1 — 83 TSs (25%)

Variables	f	X^2
Sustainability Definitions	56	143,11
Sustainability Dimensions	3	9.08

Forms	f	X^2 (p < 0,0001)
sustainable	45	77.33
sustainability	38	76.01
system	36	46.12
environmental	24	37.39
agriculture	29	35.82
intensification	11	34.13
define	12	28.74
concept	9	27.75
ability	11	25.65
agricultural	25	21.95
redesign	7	21.45
outcome	7	21.45
natural	17	20.80
maintain	12	19.86
set	12	19.86
imply	9	19.59
ecological	13	18.16
harm	5	15.23
face	5	15.23

Class 4 — 71 TSs (21.4%)

Variables	f	X^2
Sustainability Goals	32	46.06
Sustainability Attributes	8	8.19
Sustainability Themes	13	5.21

Forms	f	X^2 (p < 0,0001)
standard	13	49.74
organisation	11	41.82
promote	11	36.58
ensure	10	32.71
international	8	30.13
partnership	8	30.13
fair-trade	8	30.13
protect	9	28.87
responsible	8	25.07
build	9	24.71
peace	6	22.46
ISO	6	22.46
development	19	22.24
trade	7	21.31
certification	7	21.31
research	5	18.66
program	5	18.66
company	5	18.66
climate	9	18.42
provide	8	17.84
inclusive	6	17.60
person	7	17.50

Figure 3. Dendogram with the percentage of TSs in each class, and words with greater chi-square (χ^2) and $p < 0.0001$.

Thus, with this particular analysis, and against previous assumptions, the distinction between nonsustainability and sustainability variables (dimension 2) is clear, despite most of the vocabulary appearing concentrated in the center.

Finally, and looking to contextualize the construction of all four classes as much as possible, highly scored TSs were also considered. When coding and processing the corpus text into TSs, IRAMUTEQ automatically attributes scores for each unit of direction. The higher the value of this score, the greater the density of the TS within the class [39].

Table A1 (see Appendix A) shows high-score TSs and forms. The stronger extracts were captured as an example from each of the four classes and gathered for reflection. In addition, and to better contextualize each statement into the full background, entire discourses were also caught from the original corpus and displayed together with corresponding TS. The selection criteria for statements and TSs to be presented was according to their importance and score, and until the information saturation point was reached. Among all the text segments, the peak score value was 453.49.

Based on the analyses and scrutiny of high-scored TSs together with previous interpretations of forms and variables, all four classes generated from the IRAMUTEQ software were designated accordingly as: (i) sustainable intensification systems design (class 1); (ii) sustainable management practices (class 2); (iii) performance and impact assessment (class 3); and (iv) fair trade and workers' rights (class 4).

From the observation of each class's factorial representation, it is now understandable why class 2, "sustainable management practices", and class 3, "performance and impact assessment", are closer and more interconnected with each other. This result enhances the relationship and necessity to assess and measure in order to better manage a certain system [31]. Beyond that, the societal weight and comprehensiveness of class 4, "fair trade and workers' rights", justifies why this cluster was more isolated from the others—in particular when social concerns emerged among specialized literature later on and in some cases are still underrepresented [4,13,20]. In regard to class 1, "sustainable intensification systems design", its focus on a holistic approach to redesign production systems validates its central position between cluster 2 and cluster 4 (Figure 1).

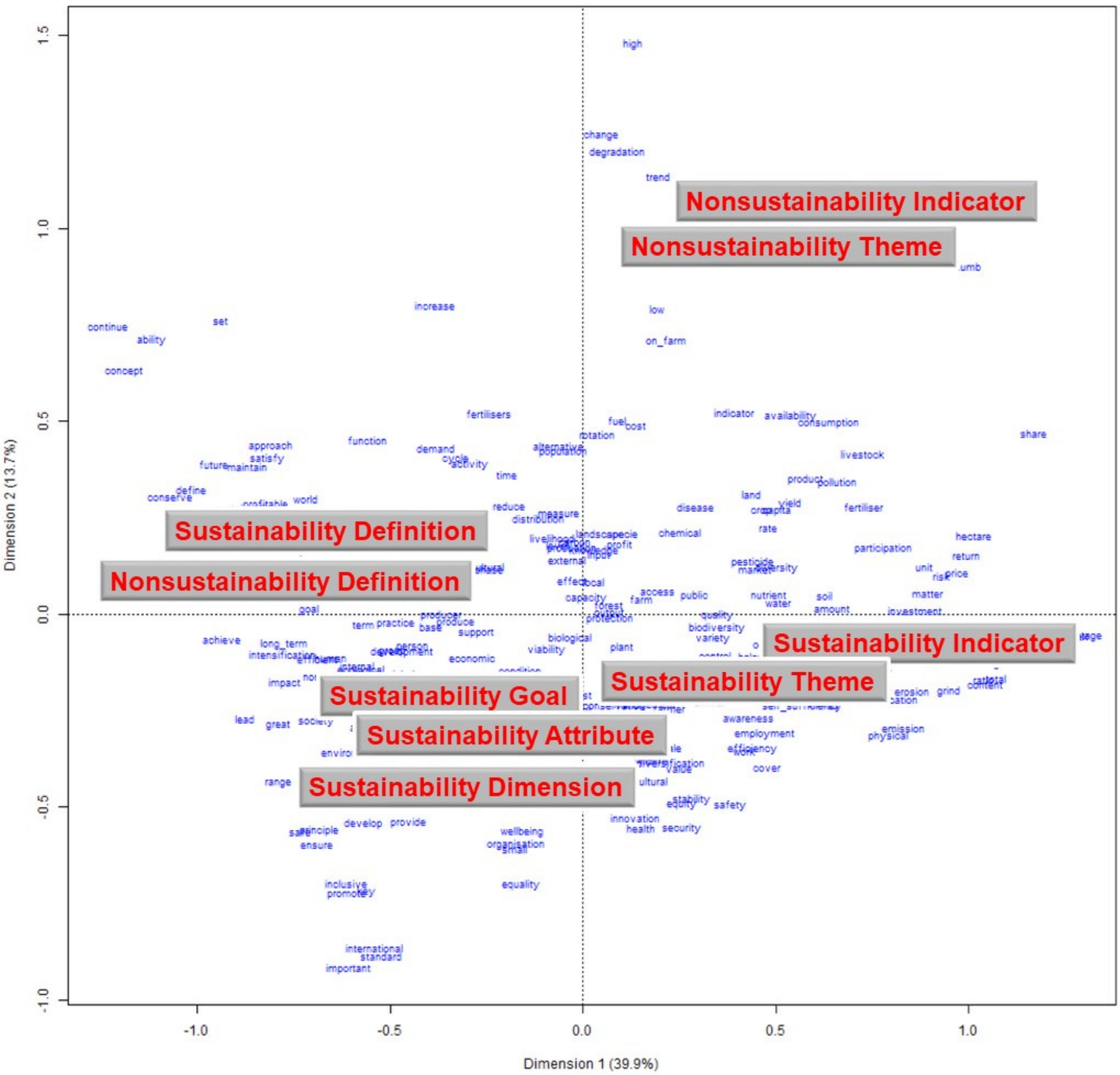


Figure 4. Distribution of the vocabulary according to FCA of forms and variables.

4.2. Universal Principles for Sustainable Agriculture

To close this analysis and reflect upon results from the scrutiny of notions, theories, and indicators proposed by 179 references, it becomes clear how sustainability has a number of different definitions and inherent concepts regarding its meaning. By coding and analyzing different text segments on sustainable-agriculture connotation through several multivariate analyses using IRAMUTEQ software, four main classes of meanings were exposed. These also gave place to corresponding universal principles by recognizing different interpretative pathways and the connection between them.

Thus, with the delineation and interpretation of all four classes, along with the contemplation of major vocabulary, associated variables, and original citations rated into context, we established four fundamental principles for sustainable agriculture: integrated management, dynamic balance, regenerative design, and social development.

It should be understood, though, that each principle is interconnected with the others, and all are interdependent. Despite the many different contexts in which the analyzed notions were assessed, these common principles end up unifying all the approaches that must be taken regarding our need to shift toward sustainable agriculture. In order to produce food sustainably, all the following established principles must therefore be considered and treated as a whole.

4.2.1. Integrated Management

The first principle is integrated management, which has its origin in the contemplation of cluster 2. Embracing natural-based pest control and plant-protection solutions as stronger concepts of the class, it is our understanding that sustainable agriculture should be based on agro-ecology principles where an integrated and regenerative approach is necessary, and therefore enforced. Natural-based solutions (NbS) are cost-effective solutions inspired and supported by nature. These naturally provide simultaneously environmental, social, and economic benefits, and help to build resilience. Such solutions are known to benefit biodiversity and support the delivery of a range of ecosystem services [43].

Acknowledging that all food cultures are agro-ecosystems—or part of an ecosystem—any managing process or decision-making should be ecologically focused and allow advantage to be taken of all possible natural-based interactions or synergies within the farm and its surrounding context [44]. This principle aims to enhance the possibility to optimize the use of internal farm resources as biodiversity, and to reduce the need for external inputs with serious direct impacts on the environment and people. It also dictates the need to acknowledge complementary and alternatives for pest management that rely on the regulating capacity of biodiversity and ecosystem services [27].

Natural capital valorization is the keyword of this principle, and it implies that natural capital must be integrated with human capital in order to achieve sustainability. We should integrate human knowledge and ecosystem services in any decision-making within our production system, and thus farmers must understand the best alternative agricultural practices considering their present situation and context, in a certain time and place. To produce efficiently and sustainably, the entire system must therefore be comprehended in order to know the conditions under which agricultural inputs are either complementing or contradicting biological processes [27,45].

Like all other principles, this too is dynamic and relentless. The continuous inception of new knowledge, new technologies and new methods that must be taken into account over time is implicit. In addition, considering that integrated systems often involve complex combinations between associated management techniques [27], greater skills and knowledge of farmers or decision-makers are imperative. Thus, the integrated management principle is about making the best use of nature's goods and services. It is the attempt to integrate as many natural processes as possible into the management of food-production processes to make use of human capital productive and to share knowledge and skills between farmers to improve their self-reliance. Integrated management means putting natural capital and human capital together to solve either common agricultural or environmental problems.

4.2.2. Dynamic Balance

This goal of improving performance and reducing impacts is also intertwined with the second principle, the incessant search for dynamic balance. Its close link with the previous one advances that this principle emerged from class 3, "performance and impact assessment", which was the closest to class 2. Major vocabulary was mostly represented by ecological and economic indicators, and therefore around off-farm inputs and their direct impacts on natural resources such as soil and water, or farm outputs and their weight on our productivity and income.

However, we must seek for balance in any situation, and thus we must continuously assess and evaluate in order to be able to adjust and optimize. Sustainability is not fossilization of something; rather, it is enhanced capacity to adapt in the face of unexpected changes and emerging uncertainties [27]. As the overall goal is the long-term stability of the economy and environment, this principle implies that this is more achievable throughout the process of continuous assessment/adaptation/assessment cycle. Continuation and equilibrium are therefore the keywords of this principle.

Notwithstanding, besides monitoring and assessing in order to improve or adapt, the dynamic-balance principle also advocates the requisite to rebalance our needs and actions, as an integrative approach is necessary but not sufficient. We need to continuously look for equilibrium among and around our systems. Changes must occur from every corner—through the entire supply chain to consumption choices and daily lifestyle [5].

Moreover, at any time-decision there will be inevitably some form of trade-off between and within the choices of different options. Beyond the urge to address and eliminate any major imbalances, in cases where decisions will inevitably result in a negative impact, the norm of the mitigation hierarchy should be applied to assure equilibrium. Mitigation hierarchy involves reducing the impact through some form of mitigation measure every time it is not possible to avoid the negative impact in the first instance [46]. Ideally, with this approach any consequent negative impact will be offset to zero.

More companies and organizations are setting net-zero and net-positive impacts for environmental issues—such as carbon, biodiversity, and water and food waste, or even for socioeconomic issues such as zero accidents, deaths, and injuries in the workplace. Governments are also leaning toward this idea of net-impact approaches, in particular when addressing issues related to climate change and natural-resource depletion [36]. As a response to that requirement, planetary boundaries are today being used globally to set net-zero or net-positive targets [1].

Planetary thresholds are known as tipping points—or environmentally and socially acceptable limits—that must be considered when carrying out a sustainability assessment. Once again, knowledge transfer is extremely necessary to educate boards, shareholders, investors, policymakers, and other stakeholders to engage them for this purpose [1].

A second idea is to appeal for accountability of our own acts through ecological tax reform (ETR). This policy reform includes the Pigouvian tax proposed by Arthur Pigou in 1920, with increased energy taxes, carbon taxes, or even the "polluter pays principle", in which it is argued that governments should require polluting entities to bear the costs of their pollution [14,26]. In other words, the proponent of an activity must bear the burden of proving that this action will not cause significant harm [9]. This notion that major players must bear greater responsibility in light of the pressures they exert on the environment was reaffirmed to some extent by the Paris agreement, in which it was stipulated that developed countries should provide financial resources toward climate finance [1].

Thus, the dynamic-balance principle dictates that we must continuously evaluate in order to minimize impacts and maximize benefits in decision-making. In situations where we cannot avoid negative impacts on environmental or socioeconomic issues, we must at least be able to set net-zero (and ideally net-positive) targets and apply the full mitigation hierarchy. However, for the success of these incentives, policy design and public support also play a crucial role.

4.2.3. Regenerative Design

The third principle is regenerative design. This principle is linked to the concept of the circular economy and regenerative economy, and it was underpinned by class 1, "sustainable intensification systems design". High-score vocabulary from class 1 advocated sustainable intensification as contributing to sustainable, resilient, profitable, and robust farming systems. The redesign of systems was often proposed as necessary to maximize co-production of both favorable agricultural and environmental outcomes [5].

Efficiency is easily linked to circularity on this basis, as contemporary intensive agricultural systems tend to be wasteful and harmful, contributing to natural capital depletion and also leading to external higher costs on-farm and across system boundaries [5]. To redesign agricultural systems, it is necessary then to replace less-efficient system components with sustainable alternatives.

Redesign can be centered on the composition and structure of agro-ecosystems—from the substitution of new crop varieties or livestock breeds better adapted to the context in cause, to the replacement of some inputs by biological control agents, or enhancing process diversification to add value and transform waste into reusable byproducts. Thus, redesign harnesses agro-ecological processes toward higher efficiency, and develops components that deliver beneficial services for the production of crops and livestock [5].

Another strong concept reinforced in class 1 was biomimicry, which is the process of learning and redesigning our products, processes, and policies using nature's wisdom [47]. Thus, circularity, sustainability, and regenerative design are all connected, as all mean to translate nature's strategies into design with the hope of achieving a unique system that is more efficient and effective in a particular context.

The duality seems to emerge when we think of efficiency as greater productivity to improve profitability. In these terms, nature is considered as just a resource for economic growth. However, as efficiency must go hand in hand with regenerative (or circularity) in order to be sustainable, the economy and ecology should as well. Rather, nature has been reduced to a mere resource that serves our modern economy, which cherishes endless production and consumption [48]. Production and consumption are necessary, but here too they must be restrained and within planetary boundaries.

To promote sustainable intensification, we must then be aware of how efficiently we are using natural resources in order to produce enough for our own well-being, and at the same time reduce waste and not harm the environment. We must think circularly, and learn from nature's wisdom. It is here, in this attempt to produce sustainably and efficiently, that biomimicry is most expressive. A linear approach can no longer be maintained or supported by any means, as improved resource-use efficiency through regenerative design, beyond reducing pressure on natural resources, can also help to increase profitability for the lower demand on inputs and added value to outputs [36].

Furthermore, as the degradation of agro-ecosystems directly affects the entire chain, in particular the income of the poor, sustainable agriculture is needed not only to conserve, protect, and enhance natural resources, but also to upgrade human and social capital. Protecting and restoring the ecosystems that naturally support our species is therefore crucial [36]. Thus, sustainable intensification based on regenerative design harnesses the potential benefits of ecosystem services or circularity, allowing for increments in productivity through a balanced use of resources and inputs. Regenerative design advocates the need to design systems through the lens of sustainable intensification, regenerative philosophy, and circular economy. Only then we will be able to assure food security while preserving natural resources over time. Circular efficiency is then the keyword of this principle.

4.2.4. Social Development

As it becomes clear that better agricultural and food systems should be redesigned to reduce food waste, increase productivity, and promote the balanced use of natural resources, there is an inherent need to increase community engagement and reduce inequity, regardless of the forms of production [27]. Contained within the common definition of sustainable development, the fourth and last principle established here for sustainable agriculture concerns ethics and human rights. The social-development principle is identified here as another fundamental commandment to produce sustainably, as agricultural development that fails to benefit those whose livelihoods depend on it is by definition unsustainable [36]. In addition, as intergenerational equity is the long-term scale of sustainability, we not only need to respect and assure future generations' needs, but also allow present generations to thrive. A sustainable agricultural system is therefore an extension where people not only have secure and equitable access to the natural resources they need to produce food for their consumption and to assure fair income, but also a platform where any human being can fulfill their potential in dignity and equality in a healthy environment [49,50].

This principle had its origin in class 4, "fair trade and workers' rights", where conditions for farmers and producers to build thriving farms and food businesses, both socially and economically fair, were strongly scored and accentuated. Initiatives that enhance social, economic, and environmental development; facilitate long-term trading partnerships; and enable greater producer control over the trading process are among the most frequent concepts found upon analysis. However, policy reforms are also needed here to assure the development of social capital and for equal participation in agricultural development [36]. Policy change is once again necessary to enhance farmers' capacity-building—including entrepreneurial and managerial capacity—to increase their participation in policymaking, to integrate and involve agricultural research, to build trustful social infrastructures and novel partnerships with better flows of information, and to equally distribute benefits, particularly among all genders [27].

5. Conclusions

Using IRAMUTEQ software, we employed an inductive qualitative content analysis based on multivariate methods on 100 different definitions, 55 goals, 41 attributes, and hundreds of indicators, themes, or sustainability dimensions. By systematically analyzing this representative collection of observations, interpretations, performance-assessment methodologies, and main guidelines promoted by peers, specialists, major agribusiness corporations, NGOs, or governmental organizations involved in sustainability and food production all over the world (n = 179), we were able to highlight four main meanings of what sustainable agriculture is about. Interpretation of the results led to the categorization of obtained clusters: (i) sustainable intensification systems design (cluster 1); (ii) sustainable management practices (cluster 2); (iii) performance and impact assessment (cluster 3); and (iv) fair trade and workers' rights (cluster 4).

Upon reflection, and considering the previous literature review on different schools of thought on the definition of sustainability, complemented with contemporary matters regarding our shift toward global sustainable development, we translated these classes of meanings into four universal principles of sustainable agriculture: integrated management, dynamic balance, regenerative design, and social development. All principles are intertwined and interdependent, and must be considered or treated as a whole.

Thus, chartered on key concepts as natural-based solutions for agricultural challenges, use of ecosystem services and synergies, human knowledge and new technologies, stability and equilibrium over time, mitigation hierarchy, net-zero and net-positive targets, planetary boundaries, circular and regenerative economies, biomimicry, community engagement, and fair trade, these four principles were advanced as fundamental guidelines to promote change toward sustainable agriculture.

Through this novel approach, we were able to put the sustainability concept into practice and translate the eclectic vision of sustainable agriculture into a list of keywords and reference points. It was concluded that to produce food sustainably, we must make better use of available natural and human resources, and this can be achieved by integrating both ecosystem services and human capital, reducing and balancing the use of external inputs, redesigning efficient systems using a regenerative approach, and enhancing social capacities. Inevitably, setting targets to at least stay within planetary boundaries, and to promote policy changes apropos public support, are other common mandatory grounds necessary to support our transition toward sustainability [1].

Finally, the impossibility of ever attaining a single, universally accepted definition of sustainable agriculture should be considered. This is due to the complex nature of the concept [9,21], along with the typical bias faced when using different sustainability-assessment tools owing to our inability to comprehend and aggregate different dimensions of sustainability [3,23,28]. However, it can be stated that this work tackled novel means in a formal and empirical way to better understand and normalize sustainability globally.

Our results are also in keeping with the idea that humanity can neither guarantee an economy nor social well-being without assuring environmental health first [51]. Despite the incessant focus on environmental concerns leading toward limited evaluations, it is also argued that all fundamental pillars should be considered equal when weighing its impact on sustainable development. Even when perceiving sustainability through prominent models, such as the acclaimed TBL perspective, it seems that this too tends to misguide us toward erroneous and flawed interpretations due to a common separation and disconnection between those three fundamental pillars [51]. Thus, we defend the necessity to dismiss models in line with limited views of sustainability; we refer in particular to those where built capital tends to stand over natural resources and ecosystems, and that our established principles not only safeguard hierarchical interdependency principium among sustainability components, but also prevent the tendency to stipulate trade-offs between them [51].

Nominated principles are therefore intended not only to complement existing frameworks and sustainability assessments, but can be used as standardized reference points capable of guiding anyone on how to make operational decisions in a truthful and consistent way.

Nevertheless, although a vast collection of ideas and disagreements in the debate on sustainable agriculture were gathered for this study, and despite our objectives being successfully achieved, it should be acknowledged the full extent of definitions and fields of disciplines over this discussion that may well have not been included. Moreover, considering language and cultural barriers, there is a high likelihood that relevant information from less-developed countries was missed. Such cultural differences may have other perspectives considered crucial to truly scale our conclusions on a global level. Thus, the authors of this work acknowledge the limitations associated with research of this nature regarding the generalization of findings. Further international and multicultural collaboration is therefore encouraged to overcome this issue.

In order to validate our integrated interpretation of the idea of sustainable agriculture into standardized reference points, further research should also be conducted in which established fundamental principles are applied in a constructive manner and in different contexts. Following Meul et al.'s [33] statement on how to develop an assessment methodology to evaluate sustainability, we suggest designing an assessment tool for a particular production system based on all four principles, and after defining sustainability objectives and targets considering context specificities, to test it in the field (in-farm) for end-users' validation.

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Appendix A

Table A1. Excerpts and text segments from the representations of corpus text.

Class 1	Text Segment	Reference
*Susagri_04 Score: 337.37	"The sustainable intensification of agricultural systems offers synergistic opportunities for the co-production of agricultural and natural capital outcomes. A previous study proposed three non-linear stages in transitions towards sustainability: efficiency, substitution and redesign . . . Efficiency and substitution are steps towards sustainable intensification, but system redesign is essential to deliver optimum outcomes as ecological and economic conditions change."	[5]
*Susagri_06 Score: 329.59	" . . . sustainable agriculture attempts to mimic the key characteristics of a natural ecosystem . . . "	Hauptli et al. (1990)
	"Environmental values associated with sustainability include mimicry of nature and an 'ecocentric' ethic."	[23]
	"Mimicry of nature [is when] . . . sustainable agriculture attempts to mimic the key characteristics of a natural ecosystem."	Hauptli et al. (1990)
	"The ecocentric position [is for] valuing ecosystems or species without regard to their impact on human welfare."	Douglass (1984)
	"We define agricultural sustainability as the ability to maintain productivity, whether of a field or farm or nation, in the face of stress or shock. A stress may be increasing salinity, erosion, or debt . . . A frequent, sometimes continuous, relatively small, predictable force having a large cumulative effect. . . . A shock is a force that was relatively large and unpredictable."	Conway & Barbier (1990)
*Susagri_04 Score: 327.05	"Efficiency and substitution are steps towards sustainable intensification, but system redesign is essential to deliver optimum outcomes as ecological and economic conditions change. This desire for agricultural systems to produce sufficient and nutritious food without environmental harm . . . And going further to produce positive contributions to natural, social and human capital, has been reflected in calls for a wide range of different types of more sustainable agriculture. SI aims to avoid the cultivation of more land, and thus avoid the loss of unfarmed habitats, but also aims to increase overall system performance without net environmental cost."	[5]
*Susagri_06 Score: 314.41	"Sustainability is an ideology. Sustainable agriculture is a philosophy and system of farming. It has its roots in a set of values that reflect a state of empowerment, of awareness of ecological and social realities, and of one's ability to take effective action."	MacRae et al. (1990)
*Susagri_06 Score: 304.52	"Sustainable intensification is defined as an agricultural process or system where valued outcomes are maintained or increased while at least maintaining and progressing to substantial enhancement of environmental outcomes. It incorporates the principles of doing this without the cultivation of more land (and thus loss of non-farmed habitats), in which increases in overall system performance incur no net environmental cost."	[5]

Table A1. *Cont.*

Class 2	Text Segment	Reference
*Susagri_04 Score: 344.28	"Self-sufficiency through preferred use of on-farm or locally available 'internal' resources to purchased 'external' resources:" • Reduced use or elimination of soluble or synthetic fertilisers • Reduced use or elimination of chemical pesticides, substituting integrated pest management practices • Increased or improved use of crop rotations for diversification, soil fertility and pest control • Increased or improved use of manures and other organic materials as soil amendments • Increased diversity of crop (and animal) species • Maintenance of crop or residue cover on the soil • Reduced stocking rates for animals	[23]
*Susagri_03 Score: 337.09	• Productivity: yields, quality of products, cost/benefit ratio, economic return to labour • Stability: combination of resilience and reliability, nutrient balance, erosion levels, biophysical characteristics of soils such as compaction and percentage of organic matter, yield trends, number of species grown, income per species, incidence of pests, diseases and weeds, and variation of input and output prices such as coefficients of variation of input/output • Adaptability: adoption of new alternatives and/or farmers' permanence in a system, capacity-building activities, proportion of area with an adopted technology • Equity: initial investment costs and share of benefits by different farmers' groups • Self-reliance: participation in the design, implementation and evaluation of alternatives, degree of participation in decision-making, cost of external inputs, use of external resources	López-Ridaura et al. (2002)
	• Seed sourcing • Soil fertility • Pest and disease control • Weed control • Crop management	[38]
*Susagri_04 Score: 303.57	"Quantities of chemical fertilisers and pesticides used per unit of cropped land implies that the rates of fertiliser and pesticide application should be based on soil fertility status and the level of occurrence of pests and diseases. Overuse of these inputs may lead to leaching of fertiliser and pesticides into soil and groundwater, to increased nitrate content of soil, groundwater, and crops, and to diverse human health problems."	[18]
*Susagri_04 Score: 289.47	"Reduce chemical inputs relative to typical farms, and included rotations, legumes, tillage and cover crops for management of fertility, erosion and weeds."	Dobbs et al. (1991)
*Nonsusagri_03 Score: 285.03	Indicators of non-sustainability directly visible: • Resource base: Increased landslides and other forms of land degradation; fragmentation of land; changed botanical composition of forests and pastures; reduced water flows for irrigation • Production flows: Prolonged negative trends in yield; increasing production inputs per production unit; lower per-capita availability of agricultural products • Resource management practices: Less fallow, crop rotation, intercropping and diversified management practices; increasing use of sub-marginal lands; increased use of legal measures to control land use; high intensity of input use	Jodha (1990)

Table A1. *Cont.*

Class 3	Text Segment	Reference
*Susagri_03 Score: 453.49	Ecological indicators of sustainable agriculture: • Nutrient balance • Efficiency of fertiliser use • Efficiency of Irrigation Water use • Soil erosion • Saline content • Soil quality	Nambiar et al. (2001)
	Economic indicators of sustainable agriculture: • Crop productivity • Net farm income • Cost/benefit ratio of production • Per-capita food grain production	[18]
*Susagri_03 Score: 399.31	Ecological indicators of sustainable agriculture: [Olive grove] • Varieties • Biological diversity • Pesticide risk • Percentage of land planted with crops • Percentage of non-arable land • Eroded soil • Organic matter content, Nitrogen, and energy balance • Herbicide use • Irrigation water use	Gomez-Limón & Riesgo (2010)
	Economic indicators of sustainable agriculture: • Farm income • Net margin • Indebtedness • Gross margin • Liquidity • Profitability	Hřebíček et al. (2013)
*Susagri_03 Score: 345.33	Economic indicators of sustainable agriculture: • Crop productivity, per-capita food production, net farm return and benefit–cost ratio Social indicators of sustainable agriculture: • Food self-sufficiency and adequacy and effectiveness of the extension services Ecological indicators of sustainable agriculture: • Depth to Ground water table, water-use efficiency, soil quality (pH, organic matter content, Nitrogen, Phosphorus and potassium), nitrogen oxide in Ground water and chive plants	Zhen et al. (2005)

Table A1. *Cont.*

Class 4	Text Segment	Reference
*Susagri_04 Score: 269.39	Fairtrade aims to ensure fairer terms of trade between farmers and buyers, protect workers' rights, and provide the framework for producers to build thriving farms and organisations. The key objectives of the Fairtrade Standards are to: • Ensure that producers receive prices that cover their average costs of sustainable production • Provide an additional Fairtrade Premium which can be invested in projects that enhance social, economic and environmental development • Enable pre-financing for producers who require it • Facilitate long-term trading partnerships and enable greater producer control over the trading process • Set clear core and development criteria to ensure that the conditions of production and trade of all Fairtrade certified products are both socially and economically fair as well as environmentally responsible	FLO (2020)

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