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Sustainable Agriculture as a Social Imperative: A Comprehensive Analysis of its Impact and Strategic Approaches to Enhancing Planetary Health

La agricultura sostenible como imperativo social: Un análisis exhaustivo de su impacto y enfoques estratégicos para mejorar la salud planetaria

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Abstract: This study scrutinized the paramount role of social responsibility in promoting sustainable agriculture, emphasizing the importance of this interrelationship for the planet 's future. In a context in which rapid demographic growth presents one of the most significant challenges to sustainable food production, agroecology emerges as an indispensable factor that is closely linked with social progress. An in-depth exploration of the complex structure of modern food systems highlights the pressing need for integrated and holistic strategies to address these challenges. Building on this argument, strategic and coherent decision making is proposed as a critical component of our globalized society. Against this backdrop, we observed a vigorous resurgence of interest in organic and biodynamic agriculture, indicating a shift toward more environmentally harmonious and long-term sustainable practices. In conclusion, the discourse delves into a discussion of the concept of responsible agricultural intensification, viewing it through the lens of regenerative agriculture. This brief reflection underlines its predominant importance in shaping a future in which sustainable agriculture is not just an ideal but a firmly established reality.

Keywords: Agroecology; Climate Change; Governance; Social Welfare; Sustainable Development.

Resumen: *Este estudio examina el papel primordial de la responsabilidad social en la promoción de una agricultura sostenible, haciendo hincapié en la importancia de esta interrelación para el futuro del planeta. En un contexto en el que el rápido crecimiento demográfico presenta uno de los retos más significativos para la producción sostenible de alimentos, la agroecología emerge como un factor indispensable estrechamente vinculado al progreso social. Una exploración en profundidad de la compleja estructura de los sistemas alimentarios modernos pone de relieve la acuciante necesidad de estrategias integradas y holísticas para hacer frente a estos desafíos. Partiendo de este argumento, se propone una toma de decisiones estratégica y coherente como componente crítico de nuestra sociedad globalizada. En este contexto, observamos un vigoroso resurgimiento del interés por la agricultura orgánica y biodinámica, lo que indica un cambio hacia prácticas más armoniosas con el ambiente y sostenibles a largo plazo. Para concluir, el discurso se adentra en un debate sobre el concepto de intensificación agrícola responsable, viéndolo a través del prisma de la agricultura regenerativa. Esta breve reflexión subraya su importancia predominante en la configuración de un futuro en el que la agricultura sostenible no sea solo un ideal, sino una realidad firmemente establecida.*

Palabras clave: *Agroecología; bienestar social; desarrollo sostenible; resiliencia; soberanía alimentaria.*

1. Introducción

1.1. Aim of study

This manuscript explores the vital role that sustainable agriculture plays in addressing pressing global issues, such as climate change, biodiversity loss, and food security. It delves into the intricate relationship between agroecology, climate-smart agriculture (CSA) (strategic approach that seeks to improve resilience to climate change, reduce greenhouse gas emissions and increase agricultural productivity in a sustainable manner) (Sharifi & Simangan, 2023), and regenerative farming, proposing a comprehensive approach to agricultural practices that not only ensures food production but also integrates social, economic, and environmental dimensions. The ultimate goal is to promote sustainable development in food systems while safeguarding the health of the planet.

In particular, the study examines how population growth influences food security and agricultural sustainability, underscoring the importance of innovative strategies to meet the rising global demand for food. Through an exploration of agroecological practices, the manuscript highlights their potential to enhance social well-being, foster resilience to climate change, and promote biodiversity, especially in rural areas where food sovereignty is a critical concern.

The document also evaluates climate-smart agriculture as a promising solution for reducing greenhouse gas emissions while simultaneously increasing resilience to climate fluctuations and boosting productivity. By focusing on regenerative agriculture, it assesses how this approach contributes to ecosystem restoration, improves soil health, and aids in climate change mitigation, all while navigating the complex balance between the need for agricultural intensification and environmental conservation.

Moreover, this work identifies the challenges and opportunities inherent in transitioning towards sustainable agricultural systems. It also emphasizes the socio-economic, cultural, and policy-related factors that either facilitate or impede the widespread adoption of environmentally conscious farming practices. Through this exploration, the study presents a vision of a more sustainable future for agriculture, where both productivity and planetary health are safeguarded for future generations.

1.2. Population growth; Mother of all planetary ills

The viability of our planet has become a pressing issue, as the global population continues its upward trajectory. The necessity to feed a steadily growing population presents a logistical hurdle and ushers in critical ethical and environmental considerations (Altieri and Nicholls, 2017). Thus, it is essential to examine how population expansion influences the sustainability of food production. Given the current population growth rate, demand for food is expected to increase at an unprecedented rate; This finding suggests the need for more than just an increase in food production, which necessitates sustainable strategies for long-term outcomes.

It is pivotal to scrutinize how food is produced, the resources used in the process, and the overall environmental impact (Briggs & Hill, 2020). With population growth, sustainability of food production has become a vital challenge. This requires adopting agricultural and livestock practices that are not only production-efficient, but also environmentally friendly and resource-minimizing (Gliessman, 2014).

Considering the substantial population growth, there is an urgent need to meet global food demand. The escalating need to feed an expanding population is a daunting challenge that could precipitate both economic and humanitarian crises if not adequately addressed; hence, the promotion of a more efficient global agricultural system must offset future uncertainties on a planetary scale. According to the latest UN projections, the world population is expected to reach 8.5 billion by 2030, potentially soaring to an astounding 10.4 billion within the next three decades (Röös *et al*., 2021; Briggs & Hill, 2020; FAO, 2018; Gliessman, 2014).

A sustainable approach to food production necessitates a comprehensive consideration of numerous factors, including biodiversity preservation, soil and water conservation, minimization of chemical fertilizer and pesticide use, and effective agricultural waste management. This strategy calls for the implementation of innovative policies and practices that strike a balance between human necessities and ecosystem preservation (Campbell *et al*., 2017).

While population growth presents significant challenges to food production sustainability, these challenges can also serve as catalysts for innovation and transformation within food systems. Transitioning toward more sustainable and efficient agricultural practices, paired with policies advocating equitable food distribution, is a pivotal step in ensuring sustainable food production as our population grows (Godfray *et al*., 2010). To address these challenges, all stakeholders —farmers, consumers, scientists, policymakers, and businesses— must actively participate in steering food systems toward a sustainable future.

As the population experiences exponential growth, a herculean effort is needed to ensure the environmentally conscious expansion of agricultural output. Among other objectives, this endeavor should strive to reduce food waste and secure adequate food access for battling hunger and malnutrition (Springmann *et al*., 2020). Consequently, the global agricultural system must evolve toward a more efficient waste management model. Given the magnitude of this task, it demands innovative production techniques and a shift in our mindset and approach to food security (global challenge interlinked with equity, social justice and the ability of food systems to cope with climate change) (Hobbs *et al*., 2008).

This was reflected in the Sustainable Development Goals of the United Nations General Assembly in 2015 as part of the 2030 Agenda (Altieri and Nicholls, 2017). Considering the above, an unavoidable question arises: Which sustainable development goals do we want to achieve? (**Figure 1**). Without proactive action, dystopian images of people scavenging for food to survive —often portrayed in apocalyptic-themed movies— could become a widespread reality rather than mere fiction. This potentially catastrophic scenario, which is already a harsh reality for some, spurs scientists and stakeholders to thoroughly examine the barriers to implementing sustainable vegetable crops and devise innovative strategies to overcome them (Wezel *et al*., 2009).

In this context, the goal of addressing these issues is to maximize the use of available resources and technologies to enhance agricultural productivity in an ecologically friendly and resilient manner; this is to meet the global food demand, a task that seems straightforward at first glance but is extraordinarily complex in practice (Chowdhury *et al*., 2020; Godfray *et al*., 2010). Each aspect previously mentioned represents pieces of a colossal puzzle that aims not only at mass food production, but also to create agricultural systems that balance productivity with environmental respect.

The shift to more sustainable and environment-friendly practices is imperative and cannot be postponed. The sad images of famine and desolation that we portray are not inevitable but potential realities if we fail to act with due diligence and responsibility; this constitutes a call to action for researchers, policymakers, farmers, and citizens alike: the future of our global food system, and ultimately, the survival of our species, hangs in balance (Godfray and Garnett, 2014).

Wrapping this investigation, the conversation transitions to explore the idea of accountable farming enhancement, examining it from the perspective of regenerative agriculture. This concise consideration emphasizes its crucial role in sculpting a future where agriculture sustainability is more than just a lofty goal, but a solidly grounded reality.

Figure 1
Sustainable development goals

Source: Author's own elaboration based on Leach *et al*. (2022) and O'Neill *et al* (2022).

2. Systematic review methodology

This systematic review utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, as described by Regona *et al*. (2022). The PRISMA protocol is a well-established and respected methodology that aims to improve the clarity, uniformity, and thoroughness of systematic reviews. This approach involves multiple steps, such as establishing study selection criteria, creating a comprehensive search strategy, choosing relevant studies, collecting data and conducting data analysis and synthesis.

By following the PRISMA protocol, this work maintains a high standard of methodological rigor, thereby enhancing the credibility and accuracy of its results. Additionally, this method helps identify emerging patterns, trends, and knowledge gaps in the current literature, ultimately contributing to a more thorough understanding of the research subject. The review process included searching for pertinent publications in Scopus and Web of Science (WoS), which are considered the two primary bibliographic databases for scholarly work containing the literature relevant to this study.

3. Agroecology as a starting point for the theoretical framework

3.1. Social well-being through environmentally responsible agricultural practices

Agroecology (an integrative approach that combines ecological principles with agricultural management, promoting sustainability, biodiversity and food sovereignty) (Abbas *et al*., 2021) has emerged as a fundamental facet of social well-being and sustainability. Agroecology integrates ecological principles into the design and management of sustainable agricultural systems (James *et al*., 2023). Such an approach surpasses simple considerations of agricultural yield and economic efficiency, reaching the environmental, social, and cultural realms.

Socially, agroecology catalyzes collective well-being by championing food sovereignty and nurturing agricultural systems that are resilient to climatic fluctuations. This empowers farmers with control over their land and seeds, thereby diminishing their dependence on external resources. This transition bolsters food and nutritional security, particularly in rural communities, by ensuring access to diverse nutritionally rich foods. Agroecology emphasizes the role of local and traditional knowledge in agricultural ecosystem management. It promotes an exchange of wisdom and skills between farmers and communities, fortifying system resilience, solidifying community bonds, fostering social cohesion, and contributing to individual dignity and autonomy (James *et al*., 2023; Campbell *et al*., 2014).

Therefore, agroecology can be conceptualized as an integrated system of plant and animal production practices tailored to local conditions, designed for long-term sustainability, and aimed at meeting human food and fiber needs, enhancing ecosystem quality, and the natural resource base that underpins the agricultural economy while encouraging rational resource usage (Worstell & Green, 2017). Another significant facet is the contribution of agroecology to climate-change mitigation.

Traditional agricultural systems are a major source of greenhouse gas emissions; in contrast, agroecological systems promote biodiversity, amplify carbon sequestration in the soil, and minimize reliance on synthetic fertilizers and pesticides, all of which contribute to greenhouse gas emissions (Bezner-Kerr *et al*., 2021; Lynch & Cain, 2020). From an economic perspective, agroecology benefits local communities. While yields may be lower than those in intensive farming systems, input costs are also reduced, and farmers gain more economic autonomy.

Moreover, crop diversification often results in heightened economic resilience by shielding farmers from market fluctuation. Therefore, agroecology plays a significant role in biodiversity conservation (preservation of biological diversity as a central element for agricultural sustainability and ecosystem resilience) (D'Annolfo *et al*., 2017). On the other hand, agroecological systems which are more biodiverse than conventional systems, can contribute significantly to the conservation of plant and animal species, many of which are crucial for food and agriculture (Tittonell, 2014; Francis et al., 2003).

Regardless of one 's stance on agroecology, the concept of food systems has become an increasingly important focal point in research and public policy. This heightened interest stems from escalating concerns about nutrition, food security, environmental issues, trade, and public health (Van Zanten *et al*., 2021). Feeding an entire planet, in anthropological terms, entails more than merely producing sufficient food.

It is also crucial to consider diet quality, the environmental impact of food production and distribution, and the socioeconomic implications of these elements. In our increasingly globalized and urbanized world, it is essential to structure governance, stakeholders, and drivers of production systems (John *et al*., 2021; Sumberg & Giller, 2022). While an agroecological approach seeks to efficiently integrate natural biological cycles and controls, ensure farm economic viability, and improve the quality of life of farmers and society at large, the perception of what constitutes agricultural sustainability is not uniform, sparking ongoing debate (Tscharntke *et al*., 2012).

Agroecology is often examined from an anthropocentric perspective, but two other dominant perspectives exist: ecocentric and technocentric. The ecocentric approach shifts the focus from human development sprawl to organic and biodynamic farming techniques, aiming to transform consumption patterns and the allocation and use of natural goods (Gliessman, 2014).

This perspective has significant implications in the fields of environmental ethics and conservation, where the value of species and ecosystems is measured not only by their utility to humans, but also by their intrinsic worth. This outlook prioritizes protecting biodiversity and the environment beyond direct human benefits (Ong & Liao, 2020). Conversely, technocentric agroecological methods primarily rely on cutting-edge technology and science for sustainable and eco-friendly agricultural production.

Both viewpoints highlight the importance of agroecology as a route toward sustainability and resilience in food production; consequently, as we grapple with the challenges of climate change, biodiversity loss, and food insecurity, it is imperative to adopt approaches that harmonize environmental protection with efficiency and equity in food production. Thus, agroecology provides both a vision and a set of practices that can guide us toward these objectives, and its importance will likely continue to rise in the future (Campbell *et al*., 2017).

4. Complex food systems; simple comprehensive strategies

The inherent complexity of contemporary food systems is undeniable, comprising a sequence of interconnected processes spanning from the dawn of agriculture and evolution to processing and distribution, final consumption, and eventual disposal. The importance of sustainable development of such systems is unquestionable, where critical issues such as food security, global health, climate change, biodiversity preservation, and social justice converge (Salam *et al*., 2021). Transitioning toward a sustainable food system is a process filled with interdependent variables ranging from governance and culture to public policies (Altieri and Nicholls, 2017). Decisions can yield unforeseeable outcomes, possibly resulting in unexpected consequences.

In this context, it is vital to analyze resilient strategies, such as agroecology and sustainable intensification (agricultural intensification approach that seeks to maximize productivity without compromising environmental integrity or social equity) (Ong *et al*., 2020), that adapt to varying contexts and seek enduring impacts on agricultural management. The transition toward these practices demands a more precise redefinition of food systems, understanding them as complex, evolving entities replete with both linear and nonlinear interactions (Chowdhury *et al*., 2020).

The shift toward sustainable agriculture necessitates a holistic approach that encompasses all the dimensions of food systems. Strategies should not only pursue productivity and efficiency targets but also address environmental, social, and economic sustainability. Environmentally, sustainable agriculture should endeavor to minimize its environmental impact, implying reduced reliance on agrochemicals and fossil fuels, promotion of crop and species diversity, and adoption of farming techniques that foster healthy soil, water, and biodiversity.

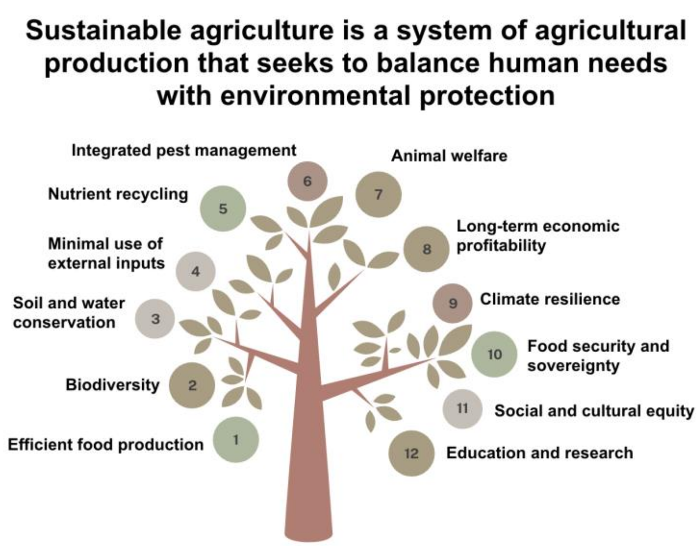
Additionally, mitigating and adapting to climate change is pivotal, as agriculture is both a victim and a significant contributor to this global phenomenon (Adesina *et al*., 2023). Socially, sustainable agriculture should focus on empowering farmers, enhancing working conditions, and advocating equity and inclusion (Godfray and Garnet, 2014). This involves ensuring fair trade, providing access to education and training, and respecting the rights and knowledge of indigenous and local communities. Economically, sustainability must guarantee fair and stable income for farmers and rural communities, achievable through policies supporting local and regional agriculture, measures encouraging the diversification of agricultural income, and tools protecting farmers from market fluctuations and extreme weather events (Ayers & Dodman, 2022).

This holistic perspective emphasizes the multifaceted nature of food systems, emerging from the interaction between interdependent components. Hence, factors such as information, communication, governance, cultural dynamics, and government policy transformations interact with one another and influence food supply dynamics, generating uncertainty and potentially triggering unintended or undesirable consequences because the long-term effects of decisions and actions are not always predictable (Wezel *et al*., 2009).

Recognizing and considering the possibility of these unintended consequences when assessing their impacts is essential; thus, it is crucial to identify and analyze well-established methods that are specifically applied to foster healthier agriculture, most of which emphasize ecological balance. In this sense, at least 12 key factors are involved in sustainable agriculture (**Figure 2**) (FAO, 2018). Given the considerations mentioned above, most agrocultural approaches have clear principles and environmental, economic, and social objectives (Gupta *et al*., 2023). They have evolved, and in some instances, have held prominent positions on the political agenda since their inception. These agricultural strategies are generally adapted to various production methods and conditions, or consider the entire agricultural system in their design.

They often involve professional participation and, in some cases, have an associated market such as organic farming. While their scopes may differ (more global, such as agroecology or sustainable intensification, and more focused, such as permaculture or high nature value farming), they all represent options for farmers that will significantly impact their crop management in the long term.

Figure 2
Key factors involved in sustainable agriculture



Source: Author's own elaboration based on Pelling & O'Brien (2024).

To address these challenges, an integrated strategy connecting all levels of the food system (from farmers and consumers to policymakers and scientists) is required. This strategy could include promoting agroecology and organic farming, adopting sustainable and healthy diets, encouraging local and fair value chains, and ensuring active participation of all food system actors in the decision-making process (Van Zanten *et al*., 2021).

5. Climate-Smart Agriculture as an effective strategy for sustainability

Climate-Smart Agriculture epitomizes a pioneering paradigm, incrementally fortifying its position as a potent stratagem to grapple with the manifold challenges introduced by climatic flux within the sphere of agricultural production. With the objective of transmuting and recalibrating agricultural modalities, CSA's objective orbits around buttressing developmental progression and securing food sustainability in the context of dynamic scenarios engendered by climatic alterations (Campbell *et al*., 2014).

The strategic fabric of CSA is woven around three quintessential struts: bolstering resilience and adaptation to climate change, moderating greenhouse-gas emissions, and fostering agricultural productivity in an ecologically balanced manner. The adaptation and resilience facets of CSA encourage practices that empower agricultural production ecosystems to acclimate to evolving climatic dynamics. This comprehensive perspective can encapsulate procedures such as agricultural biodiversity through crop diversification, integration of climate-resilient seed variants, advanced methodologies for water and soil conservation, and architecting anticipatory mechanisms to forewarn potential climatic threats (**Figure 3**) (Smith *et al*., 2007; Sharifi & Simangan, 2023).

Concurrently, CSA acknowledges the substantial contribution of agriculture to the escalation of greenhouse gas emissions (GGE) triggered by factors such as synthetic fertilizer utilization, methane emissions from livestock, and deforestation driven by agricultural proliferation. To overcome this predicament, CSA endorses the adoption of practices that minimize these emissions, including proficient nutrient stewardship, manure administration, agroforestry, and methods of soil and water preservation (Smith & Burch, 2023).

The third cornerstone of this trinity, the sustainable enhancement of agricultural productivity, aspires to intensify the effectiveness of food production operations to cater to the swelling global demand without jeopardizing subsequent generations' ability to fulfill their sustenance requirements; this objective can be realized by optimizing agricultural inputs, integrating precision technologies, refining postharvest preservation practices, and facilitating inclusive, sustainable supply chains (Smith *et al*., 2021). Thus, CSA is perceived as a paradigm revolution in agricultural management. By embedding climate change considerations into the planning and deployment of agricultural endeavors, we can contribute substantially to food security and sustainable development while simultaneously minimizing our imprint on the climate (Mukherjee & Arora, 2023).

Figure 3
Actions that prevent global warming

Source: Author’s own elaboration based on McKinley *et al*. (2023).

However, CSA does not represent a prescribed set of practices; rather, it manifests as a holistic approach that necessitates contextual adaptation according to localized climatic, cultural, socio-economic, and environmental conditions. Consequently, its effective implementation mandates a robust research and innovation backbone supplemented by the proactive engagement of farmers and other stakeholders in the food ecosystem (Lynch & Cain, 2020).

Furthermore, this methodology interweaves climate change considerations into the planning and realization of sustainable agricultural practices, thus facilitating more informed decision-making processes. This tactical framework offers a roadmap for communities at risk of elevating agricultural output and income levels, while simultaneously initiating practices that mitigate atmospheric emissions.

CSA, emerging as a response to the adaptation and mitigation challenges facing humanity, is articulated around four main axes: enhancing agricultural productivity to stimulate economic growth, food security, and development; improving adaptive capacity at different levels, from an individual farm to the nation as a whole; and reducing GGE, including the carbon footprint (Springmann *et al*., 2020). The CSA concept has been refined through the contributions and interactions of the multiple stakeholders involved in its development and implementation.

This strategy seeks to provide globally applicable principles for the management of agriculture in a changing climate, which would serve as a basis for political support and recommendations from multilateral actors, such as the United Nations' FAO. It is crucial to note that climate change presents an additional threat to agriculture, particularly in developing countries. Many current agricultural practices have harmful impacts on the environment and are responsible for a substantial proportion of the anthropogenic GGE (Campbell *et al*., 2017).

It is essential to note that CSA does not prescribe a set of specific practices but rather provides an approach that must be tailored according to local climatic, cultural, societal, economic, and environmental conditions. This necessitates robust research and innovation, along with the active involvement of farmers and other stakeholders in the food system. CSA signifies a paradigm shift in the management of agricultural systems. Incorporating considerations of climate change into the planning and implementation of agricultural activities can contribute to food security and sustainable development while mitigating the impact of climate change. Although this is an ambitious approach, it is increasingly necessary worldwide to face unprecedented environmental challenges (Smith *et al*., 2021; Lynch & Cain, 2020).

6. Agricultural production models that boost planetary health

The escalating concern for health, the environment, and social justice is catalyzing a shift in the way we produce and consume food. Organic and biodynamic agricultural surfaces within this intricate milieu are exemplars of production models that underpin sustainability, soil vitality, biodiversity conservation, and equitable distribution of social benefits. While they rest on different foundations, both share a vision of harmonizing with nature to produce healthy and nutritious food.

Organic farming is an agricultural management system that shuns synthetic chemicals, such as fertilizers and pesticides, and promotes biodiversity, soil biological activity, and natural cycles. It is rooted in the belief that agriculture should be a holistic and self-sufficient system, and regards the soil as a living entity that must be nourished and conserved (Zhen *et al*., 2024).

From a commercial perspective, organic products have witnessed substantial growth, fueled by increasing demand for healthier and sustainable food. Agriculture and animal husbandry are time-honored practices pivotal to many developed and developing economies. Modern agricultural methods have a significant environmental impact by altering elements such as biogeochemical cycles, soil erosion, carbon sequestration, and other ecological processes (Godfray & Garnett, 2014; Chowdhury *et al*., 2020).

Organic farming represents an intriguing intersection in which tradition converges with innovation. It pays homage to the tried-and-tested knowledge that has been cultivated over generations while concurrently welcoming new, inventive methods, thus crafting a harmonious blend of the old and the new. It amplifies the agroecosystem 's resilience against climate change impacts, which translates into robustness capable of withstanding temperature fluctuations and droughts and preventing soil erosion. It also encourages environmentally respectful management combined with conservation and restoration activities. Notably, the costs associated with organic farming are lower than those associated with conventional agriculture, and these practices aid farmers and communities in adapting to climate change impacts by meeting many prerequisites for successful mitigation strategies (Campbell *et al*., 2017).

Emerging as a potent means of minimizing environmental footprints within sustainable development, organic agriculture operates on the tenet that organic inputs in agricultural practices can mitigate harmful effects on the ecosystem, while preserving its natural cycles during recovery. Furthermore, organic farming can improve food quality (Hobbs *et al*., 2008). This type of agriculture avoids the use of chemical fertilizers, pesticides, synthetic plant growth regulators, and feed additives in livestock farming.

Marrying organic farming using emerging technologies is crucial for overcoming the limitations and challenges of these processes. Innovative approaches and methods are shaping trends toward sustainable environments and improving productivity and quality of life for many farmers, all with a deep respect for nature (Francis *et al*., 2003). This process primarily relies on crop rotation, use of mineral additives, and biological nutrient systems to ensure optimal plant protection.

Organic farming represents a meticulously crafted production methodology, the primary objective of which is to safeguard soil vitality, ecosystem integrity, and human well-being. This agricultural modality is steadfast in its reliance on inherent ecological mechanisms, biodiversity sustenance, and localized cyclical patterns while meticulously evading the incorporation of potentially harmful inputs (Smith *et al*., 2021; FAO, 2018; Campbell *et al*., 2017).

By contrast, biodynamic agriculture is a type of organic farming that incorporates both spiritual and astrological concepts. Developed in the 1920s by the Austrian philosopher Rudolf Steiner, it is based on the notion that a farm should be viewed as a holistic, self-sustaining organism. Biodynamic farmers use an array of herbal and mineral preparations to enhance soil health (considered key in agroecological and regenerative practices, with emphasis on soil management as a living organism essential for sustainable production) (Smith *et al*., 2021) and promote plant and animal diversity.

These methods potentially offer sustainable solutions to the current food production challenges. By minimizing the environmental impact, promoting soil and ecosystem health, and producing high-quality food, these systems can contribute to a healthier and more sustainable future. Intriguingly, biodynamic farmers follow the movements of the sun and moon to determine the best time to plant and harvest plants, flowers, and fruits with the aim of maximizing their superior properties. Given the significant role that mysticism plays in biodynamic agriculture, practitioners of this discipline are particularly attuned to the subtle and unseen forces at play in nature, perpetually seeking the interconnectivity of all elements, both beneath and above the Earth's surface (James *et al*., 2023).

However, the implementation of these production methods is challenging. These encompass the need for additional research to enhance our understanding and optimization of these systems, the necessity for policies that bolster sustainable agriculture, and the urgency to increase public awareness of the benefits of organic and biodynamic foods. Despite these challenges, the escalating demand for healthy and sustainable foods suggests a promising future for organic and biodynamic agriculture. As an increasing number of people become cognizant of the repercussions of food production on human health and the environment, we can expect a surge in the adoption of these sustainable farming methods (James *et al*., 2023; Foley *et al*., 2011).

As previously mentioned, biodynamic agriculture offers a comprehensive and spiritual perspective on agriculture. This approach extends beyond ecological principles and integrates aspects of astrology, homeopathy, and spirituality into farm management. In this context, the farm is expected to be a comprehensive organism in which all components —crops, animals, and soils— are interconnected and should be managed as an integrated entity. Although biodynamic agriculture currently represents only a small fraction of the agricultural market, it is gaining appreciation for diligent and nature-friendly production methods.

Both organic and biodynamic agriculture advocate practices that improve soil health, such as crop rotation, composting, mulching, and diversification of crops and species. By conserving and enhancing soil health, these farming techniques promote long-term productivity, climate resilience, and biodiversity conservation (Van Zanten *et al*., 2021; FAO, 2018; Altieri & Nicholls, 2017).

Through soil enhancement and crop revitalization, biodynamic practices encourage superior plant growth and contribute to planet healing. Thus, biodynamic agriculture can be seen as the oldest tradition of environmental farming and the most sustainable processing method, adaptable across various climatic zones and under different conditions. Socially, both organic and biodynamic agriculture can contribute to equity and social justice by promoting fair trade, respect for labor rights, community participation, and the recognition and use of traditional knowledge and practices. These aspects are pivotal for ensuring the social sustainability of food production systems (Briggs & Hill, 2020).

7. Understanding the concept of regenerative agriculture as a process of responsible agricultural intensification

The term responsible agricultural intensification (responsible intensification of agriculture that increases productivity without compromising the environment, balancing economic, social and ecological dimensions) (James *et al*., 2023) denotes a strategy aimed at amplifying agricultural productivity while minimizing environmental impacts and fostering social equity. With escalating pressures on natural resources and climate change, this strategy is crucial for maintaining food security and sustainability of food production systems. Within this framework, regenerative agriculture (practice that not only restores degraded ecosystems, but also improves soil health, biodiversity and the water cycle, mitigating climate change) is a promising approach (Chowdhury e*t al*., 2020).

This concept encompasses a collection of farming practices that preserve and enhance the natural systems. Instead of focusing solely on productivity, regenerative agriculture perceives a farm as an ecosystem that bolsters soil health, biodiversity, water cycling, and carbon storage. In doing so, they can rejuvenate degraded ecosystems, mitigate climate change, and provide a sustainable foundation for food production.

Regenerative agriculture practices include crop rotation, species diversification, holistic grazing management, composting, agroforestry, and mulching. These practices can augment soil organic matter, improve water retention, enhance biodiversity, and reduce greenhouse gas emissions. In addition, they can amplify the resilience of farming systems to climatic fluctuations and enhance food quality and safety (Campbell *et al*., 2014).

Delving into the concept of agricultural intensification, duality emerges between productive efficiency and long-term ecological impact. This approach underscores the need to balance economic, social, and environmental considerations toward intensification, thus promoting fair and beneficial transition policies toward socially responsible practices. Although this term can seem ambiguous, its interpretation largely hinges on the context in which it is used. In its simplest sense, this implies increasing the output per input unit and optimizing the usage of existing resources (Adesina *et al*., 2023).

However, an increase in efficiency in one dimension may not align with an increase in the others. For instance, intensive fertilizer usage may enhance soil productivity in the short term but could lead to adverse effects that result in soil degradation and subsequent productivity loss in the long term. Therefore, considering these trade-offs is critical when seeking to intensify agricultural production (Wezel *et al*., 2009).

Consequently, sustainable intensification embodies a rigorous quest to arbitrate among competing demands and unravel integrated solutions that are efficiently optimized across multiple dimensions. This frequently demands the endorsement of comprehensive methodologies that echo the tenets of biodynamic agriculture and illuminate the intricacies of the interconnectedness of various facets within the entire agricultural system (Sumberg & Giller, 2022). One must remember that this avant-garde approach must encompass the three pillars of sustainability, environmental integrity, social equity, and economic prosperity, intimating that any feasible solution must conform to the standards of ecological responsibility, economic soundness, and social justice (Gupta *et al*., 2023).

With these prerequisites etched in our minds, we observe the significant metamorphosis of agricultural policies throughout the annals of time, transitioning from an era focused on the maximization of productivity during the Green Revolution to a contemporaneous, enlightened approach that places equal emphasis on both environmental preservation and societal welfare; each trajectory possesses a distinct set of merits and impediments (Campbell *et al*., 2014; Foley *et al*., 2011).

These policies can radically revolutionize future agricultural landscapes, fostering the adoption of intensive cultivation techniques and nurturing systems designed to yield various benefits. Such systems are characterized by robust food production that simultaneously places a premium on the conservation of biodiversity and reduces the living standards of the farming community (Adesina *et al*., 2023).

As we probe deeper into the techniques elucidated thus far, we have traced the evolutionary trajectory of conventional methodologies, such as crop rotation and combination. These established techniques are ingeniously fused with a myriad of spatially optimizing strategies that find their genesis in permaculture, thus painting a vivid tableau of the interplay between tradition and innovation in the quest for sustainable agricultural practices (James *et al*. 2023).

Upon closer inspection, these methods represent a shift toward a healthier form of agriculture, one that not only targets mass food production, but also emphasizes the protection and enhancement of the environment. However, despite their numerous potential benefits, they present challenges, including the need for specific skills and knowledge, possible short-term yield reduction during the transition to these practices, and a lack of adequate policies and support programs. However, it is important to remember that soil restoration and the recovery and transition of ecosystems to their natural states ultimately rely on each contribution (Springmann *et al*., 2020).

Despite their tremendous benefits, the implementation of regenerative agriculture poses several challenges. On the one hand, this may necessitate a shift in established farming practices and an increase in knowledge and skills among farmers. However, it may involve short-term economic and production risks, although it can enhance farm profitability and resilience in the long-term. Therefore, political and financial support for the transition to regenerative agriculture is crucial. Socially, regenerative agriculture can foster equity and social justice by advocating for greater farmer autonomy, respect for labor rights, and the inclusion of farmers in decision-making processes (Altieri & Nicholls, 2017).

It can also promote a connection to the land and acknowledge the significance of natural systems for survival and well-being. Thus, intensification through regenerative agriculture is a promising strategy to enhance sustainable agricultural productivity. By understanding and collaborating with natural systems, we can produce healthy and nutritious food while rejuvenating ecosystems and fostering equity and social justice (James *et al*., 2023; Springmann *et al*., 2020).

8. Challenges and opportunities in shaping a sustainable agricultural future

This kind of research, focused on sustainable agriculture, agroecology, and responsible intensification, offers numerous benefits, although it also faces significant challenges. Among the "pros", the capacity of this research to generate holistic solutions to global problems such as climate change, biodiversity loss, and food insecurity stands out.
By integrating approaches like regenerative and agroecological farming, it promotes agricultural practices that not only enhance productivity but also restore soil health, conserve natural resources, and strengthen ecosystem resilience. Socially, these practices foster equity, ensure social justice in rural communities, and grant greater autonomy to farmers by reducing their reliance on external inputs (Pelling & O'Brien, 2024; Adesina *et al*., 2023).

Furthermore, research in sustainable agriculture contributes to the development of food systems that are more equitable and environmentally friendly, creating a direct link between food production and biodiversity conservation. This is particularly important in the context of demographic growth and the depletion of natural resources, where innovation is required to maintain the balance between productivity and sustainability (John *et al*., 2021).

However, it also presents "cons" and significant obstacles, for instance; the transition to sustainable agricultural models may face resistance due to the inertia of conventional systems, where the intensive use of chemical inputs and short-term yield maximization remain dominant. Shifting to agroecological or regenerative practices may require considerable initial investment in terms of time, resources, and training, which could discourage some producers, especially those with financial limitations. Additionally, potential reductions in initial yields during the transition to more sustainable systems can create economic uncertainty, affecting both farmers and supply chains (Bezner-Kerr *et al*., 2021).

Among the most important challenges, is the need for adequate public policies that support farmers in adopting sustainable practices. On the other hand, the lack of governmental incentives or specific subsidies that promote the transition to more sustainable models is a recurrent challenge. Moreover, the necessary knowledge to implement these practices is not always available, highlighting the need for educational and training programs focused on agroecology and the regeneration of agricultural ecosystems (Francis *et al*., 2003). Another key challenge is the cultural shift required in how food and agriculture are valued, where price is not the sole criterion but also the social and environmental benefits (Salam *et al*., 2021).

Looking to the future, the outlook is hopeful, though full of challenges. Growing awareness of the impacts of climate change, environmental degradation, and food crises is driving increased interest in sustainable practices. Technological innovations, combined with traditional and local knowledge, have the potential to transform food systems in ways that are more resilient and environmentally respectful (Mukherjee & Arora, 2023). However, it will be crucial for future research to continue integrating interdisciplinary approaches, promoting collaboration among scientists, farmers, policymakers, and communities. In this way, progress can be made toward a truly sustainable agricultural system, where food production is compatible with the preservation of the planet and the well-being of future generations.

9. Conclusiones and final thoughts

This document emphasizes the critical role of social responsibility in sustainable agriculture and asserts its pivotal role in protecting planetary health (link between the health of the planet and agriculture, emphasizing how sustainable practices can improve global resilience in the face of environmental challenges) (O'Neill *et al*., 2022) and human prosperity. In a world increasingly conscious of environmental and social challenges, the discourse urgently advocates the adoption of agricultural practices that interweave sustainability and social responsibility. As agriculture forms one of the bedrock of society, its impact on planetary health is substantial. Therefore, it is paramount to address this issue with sustainability and acute social awareness.

In view of the above, this work presents a profound exploration of the integration of agroecology, climate-smart agriculture, and regenerative agriculture into the global food system. The document's originality lies in its ability to synthesize these frameworks within the context of growing environmental and social challenges, demonstrating how modern agricultural systems must evolve to meet future demands. By advocating a blend of tradition and innovation, the manuscript explores a vision where farming practices not only enhance productivity but also restore ecological balance, foster social equity, and improve biodiversity.

One of the key contributions of this literature review is its in-depth analysis of responsible agricultural intensification, positioning regenerative practices at the forefront of solutions for climate change mitigation and ecosystem restoration, articulating a critical shift in mindset from seeing agriculture as merely a means of food production, to viewing it as a comprehensive system that supports planetary health. The proposed strategies acknowledge the complexity of global food systems and the interconnected nature of social, economic, and environmental dimensions, emphasizing how sustainability must be holistically approached.

Central to this discussion is the concept of regenerative agriculture, which not only preserves but also enriches natural systems. Unlike conventional methodologies that primarily focus on productivity, the RA perceives farmland as a complex ecosystem and aims to promote soil health, biodiversity, water cycles, and carbon capture. It accomplishes not only the revival of deteriorating ecosystems, but also the mitigation of climate change and the establishment of a sustainable platform for food production.

Concurrently, climate-smart agriculture has emerged as an innovative strategy for reorienting and transforming agricultural systems to address the impacts of climate change on food production (Leach *et al*., 2022). As highlighted in the manuscript, this approach relies on three key pillars: adaptability and resilience to climate fluctuations, mitigation of greenhouse gas emissions, and the sustainable enhancement of agricultural productivity.

Crucially, climate-smart agriculture does not prescribe a rigid set of practices but advocates a flexible approach that must be contextualized according to local climate, cultural, societal, economic, and environmental conditions. Agroecology has emerged as a comprehensive approach aimed at meeting a diverse range of human needs, fortifying environmental protection, and the efficient and sustainable use of natural resources.

It presupposes agriculture as an integrated, self-sufficient system and regards soil as a living entity that necessitates nourishment and protection. Economically, it can benefit local communities, as despite potentially lower yields compared to intensive farming systems, input costs are also reduced, fostering greater economic autonomy among farmers.

It is essential to acknowledge that the transition to sustainable and socially responsible agricultural practices does not solely rest with farmers, but is a shared responsibility involving the entire society. Consumers, policymakers, educational institutions, and corporations play vital roles in instigating sustainable food systems. The shift toward more sustainable and socially conscious agriculture must be inclusive, taking local conditions into account, and encouraging the active participation of all stakeholders.

This involves implementing supportive policies, educating and training farmers, and raising consumer awareness of the importance of sustainable food production. Innovation and research are pivotal in developing technologies and practices that enhance the efficiency and sustainability of farming practices, including the optimization of agricultural inputs, adoption of precision technologies, and improvements in postharvest handling practices.

Otherwise, sustainable agriculture extends beyond food production and is linked to social justice, equity, and community welfare (D'Annolfo *et al*., 2017). In this sense, agriculture must be conceived not only as a means of production, but also as an instrument to achieve a wider objective: constructing a more just, equitable, and sustainable world for present and future generations. In a world facing unprecedented environmental challenges, the adoption of sustainable and socially responsible agricultural practices is not merely an option; it is an unequivocal imperative for planetary resilience and the well-being of all species that share our planet.

Finally looking to the future, this manuscript offers a roadmap for transforming agricultural policy and practice. Its emphasis on agroecology, climate-smart agriculture, and regenerative methods will likely resonate with policymakers, researchers, and practitioners seeking sustainable pathways to address food security, environmental resilience, and social justice. Likewise, the forward-looking perspective of this work holds the potential to influence future agricultural developments by encouraging innovation, enhancing global food systems, and promoting a more equitable and sustainable world.

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