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Overcoming Barriers of Sustainable Agrifood Supply Chain Through Conservation Agriculture and Multi-Capital Sustainability

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Abstract*—Most important phases of a sustainable Agrifood supply chain are agriculture, transformation, and transport. Conservation agriculture has garnered significant attention in recent agricultural research, prompting a surge in peer-reviewed publications and global interest. Likewise, multi-capital sustainability is relevant technique to design sustainable Agrifood supply chain. Hence, those techniques can have significant role to overcome barriers to implement sustainable Agrifood supply chain particularly in the agriculture phase. In this vein, stakeholders are increasingly dedicating time and resources to support farmers in adopting conservation agriculture, with a focus on refining its efficacy. However, concerns persist regarding the sustainability of agriculture practices. This study addresses the challenges hindering the practical application of sustainable agriculture, known as the implementation gap, with a specific emphasis on conservation agriculture. The primary objective is to identify barriers impeding the practical implementation of sustainable agriculture. Through a comprehensive literature review, we explore barriers to implementing conservation agriculture techniques and multi-capital sustainability. Our analysis reveals widespread adoption of conservation agriculture across various regions globally. Key obstacles to its implementation include limited access to information, financial constraints, insufficient technical knowledge, adaptability issues, restricted market access, influence from demonstrations and peers, considerations of farm size and type, environmental conditions, risk perception, social and cultural factors, infrastructure limitations, and constrained access to resources.

Keywords*—Sustainable Agrifood Supply chain, conservation agriculture, multi-capital sustainability, implementation gap, barriers, comprehensive literature review,

I. Introduction

To implement a sustainable Agrifood supply chain all along the Agrifood product life cycle, Managers have to improve the sustainability index in the main phases having high impact on environment, society and economy. One of these phases is agriculture. Fig. 1 shows most important phases of a sustainable Agrifood supply chain and the relationship between decision/policy maker and those phases.

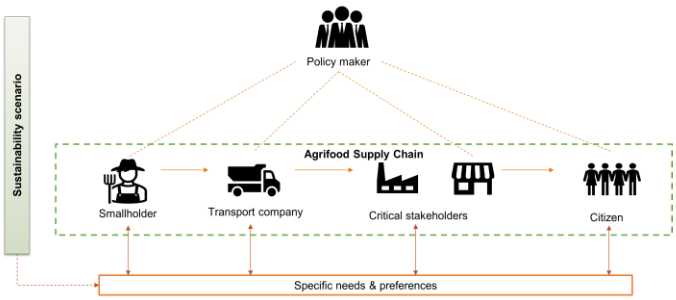

Fig. 1. *Sustanable Agrifood supply chain elements*

The future of agriculture hinges on farmers' proactive adoption of innovative technologies and practices aimed at mitigating climate change. Stakeholders are progressively channeling attention and resources into assisting farmers in embracing Conservation Agriculture (CA) and cultivating new knowledge to enhance their performance [1].

Current global development trends are inherently linked to globalization, giving rise to inequalities, risks, and global un-sustainability. Achieving the objectives of intricate global sustainability cannot solely rely on policies and technologies

[2]. Instead, a profound cultural shift is imperative to attain sustainability [3]. Conservation Agriculture (CA) emerges as an agricultural method focused on resource conservation and sustainability. Its purpose is to increase production and attain high yields while concurrently enhancing the natural resource foundation, achieved by adhering to three interconnected principles. Additionally, the implementation of other effective practices such as plant nutrition and pest management is crucial [4]. Furthermore, over the last three decades, there is an increasingly evident impact of global climate change on agriculture [5].

The transition from traditional extensive agriculture, characterized by high-yielding varieties, inorganic fertilizers, extensive irrigation, intensive pest management, and mechanization, to intensive farming practices is influenced by the need for heightened productivity and efficiency in agriculture [6,7]. This shift is essential in adapting to contemporary demands and challenges in the agricultural sector. However, the consequences of this transition are noteworthy. Global agriculture is grappling with the adverse effects of rising temperatures and changing weather patterns, which have direct implications for crop yields and farming viability. Furthermore, agriculture itself plays a substantial role in environmental concerns, contributing approximately 30% of greenhouse gas emissions [7].

The pivotal transformation of agriculture for the future lies in the adoption of novel technologies and practices, prominently the promotion of CA, as farmers actively engage in climate change mitigation efforts. Stakeholders are progressively directing their attention and resources towards facilitating farmers in the adoption of CA, aiming not only to enhance their performance but also to contribute significantly to the transition towards a more sustainable and resource-efficient agricultural future [3]. This shift in focus, from a mere pursuit of profit to a comprehensive approach prioritizing enhanced performance and quality, represents a positive development. It signifies a broader acknowledgment of the imperative need for agricultural systems that are not only sustainable but also resilient, capable of adapting to the ever-evolving environmental challenges. This marks a substantial step towards fostering agricultural practices that are not only economically viable but also environmentally and socially responsible, aligning with the broader goals of sustainable development.

By placing a strong emphasis on performance and quality, stakeholders are not only recognizing the immediate gains but also underscoring the critical importance of long-term viability. This nuanced approach is rooted in the growing understanding of the intrinsic link between sustainable practices and the overall health of agricultural ecosystems. It signifies a paradigm shift towards acknowledging that a delicate balance between profitability and environmental responsibility is indispensable for the enduring success of agriculture. Thus, in response to the pressing challenges posed by climate change and environmental concerns, farmers are being strongly encouraged to transition from conventional to eco-friendly practices. This transition involves embracing a spectrum of sustainable methods, including organic farming, agro-ecology, and CA. The overarching goal is to curtail the negative impact of farming on ecosystems and proactively promote agricultural practices that are in harmony with environmental sustainability. This holistic shift not only contributes to the resilience of agricultural systems but also aligns with the broader vision of responsible and sustainable farming practices.

Transitioning to these practices not only benefits the environment but also offers long-term advantages for farmers. It improves soil fertility, reduces reliance on external inputs, and enhances resilience to climate-related issues. Encouraging this shift aligns with the broader goal of balancing global food needs with environmental preservation for future generations [7]. Table I highlights the fundamental differences between conventional and conservation agriculture systems in terms of their practices and approaches. Conservation agriculture focuses on more sustainable and environmentally friendly farming techniques compared to conventional agriculture.

TABLE I. KEY CONTRASTS BETWEEN CONVENTIONAL AND CONSERVATION AGRICULTURAL SYSTEM [4]

Feature	Conventional Agriculture	Conservation Agriculture
Approach towards nature	Dominates nature	Least interference with natural processes
Tillage practices	Excessive mechanical tillage and soil erosion	No-till or drastically reduced tillage. (biological tillage)
Erosion control	High wind and soil erosion	Low wind and soil erosion
Crop residue management	Residue burning or removal (bare surface)	Surface retention of residues (permanently covered)
Water infiltration	Low infiltration rate of water	High infiltration rate of water
Organic matter incorporation	Use of ex-situ FYM/composts	Use of in-situ organics/composts
Cover crop practices	Green manuring (incorporated)	Brown manuring/cover crops (surface retention)
Weed management	Kills established weeds but also stimulates more weed seeds to germinate	Weeds are a problem in the early stages of adoption but decrease with time
Machinery and compaction	Freewheeling ofarm machinery,increasd soil compaction	Controlled traffic, compaction in tramline, no compaction in crop area

II. CONSERVATION AGRICULTURE PRINCIPLES AND TECHNIQUES

A. *Principles of conservation agriculture*

CA is defined by the Food and Agriculture Organization [8] as “a sustainable agricultural production system for the protection of water and agricultural soil that integrates agronomic, environmental and economic aspects”. In addition, CA is a strategy for managing agro-ecosystems with the aim of improving and sustaining productivity, increasing profits, and ensuring food security while simultaneously preserving and enhancing the environment and resource base. Moreover, CA is characterized by the practical application of three interconnected principles, along with other complementary agricultural practices for harvest and production management. These principles are as follows:

- Principle 1: Maintain minimal or no mechanical disturbance of the soil. This is achieved through practices such as no-till seeding or broadcasting of harvest seeds, directly placing planting material into untilled soil, and minimizing soil disturbance during cultural operations, harvest, and farm traffic [7].
- Principle 2: Establish a continuous biomass soil mulch cover on the soil surface. This involves retaining harvest biomass, root stocks, stubbles, cover crops, and other sources of biomass on the ground to protect the soil [9].
- Principle 3: Promote harvest species diversification. This is implemented by adopting cropping systems that involve harvest rotations, sequences, and associations with a mix of annuals and perennial crops, including a balanced combination of legume and non-legume crops [4].

According to the study conducted by [7], an analysis was carried out on the global adoption of CA during the years 2015–2016. The analysis utilized data and statistics obtained from various sources, including no-till farmer organizations, ministries of agriculture, non-governmental organizations, and research and development organizations.

The distribution of CA globally reveals distinct patterns across different regions. Notably, South and North America emerge as the predominant adopters, dedicating 69.9 and 63.2 million hectares (M ha) to CA, comprising 38.7% and 35.0% of total cropland under CA, respectively.

However, there's a divergence in the proportion within the Americas, with South America accounting for a substantial 63.2%, whereas North America contributes 28.1%. In Australia/New Zealand and Asia, CA covers 22.7 and 13.9 M ha, representing 12.6% and 7.7% of total cropland. Contrastingly, CA usage in Russia/Ukraine, Europe, and Africa shows a declining trend, ranging from 5.7 to 1.5 M ha, constituting 3.6% to 1.1% of total cropland in these regions.

Globally, the cumulative cropland under CA is 180.4 M ha, equivalent to 12.5% of the total cropland worldwide. This diverse landscape underscores the varying degrees of CA adoption, with the Americas leading and other regions contributing to a noteworthy global presence, reflecting a dynamic interplay between agricultural practices and regional contexts [10].

The table II provides a comprehensive overview of the regional distribution, showcasing the varying degrees of CA adoption and the significant global presence of this agricultural practice.

TABLE II. ADOPTION OF CONSERVATION AGRICULTURE AROUND THE WORLD

Region	**CA Cropland (M ha)**	**Percentage of Total Cropland**
South America	69.9	38.7%
North America	63.2	35.0%
Australia/New Zealand	22.7	12.6%
Asia	13.9	7.7%
Russia/Ukraine	5.7	3.6%
Europe	3.6	2.0%
Africa	1.5	1.1%
Global Total	**180.4**	**12.5%**

In summary, the table illustrates the global distribution of conservation agriculture (CA). The Americas, in particular South America and North America, lead the way in CA adoption, with a combined contribution of 133.1 million hectares. South America stands out with 63.2% of its land under CA. Australia/New Zealand and Asia also makes significant contributions.

By contrast, Russia/Ukraine, Europe and Africa show a downward trend in CA use. The global total of 180.4 million hectares underlines the substantial presence of conventional agriculture worldwide, reflecting the dynamic interaction between local contexts and the widespread adoption of conservation practices. This underlines the need for adapted agricultural policies, considering regional variations, for sustainable land management.

B. *Conservation agriculture techniques*

CA involves a set of farming techniques and practices that aim to promote sustainable and environmentally friendly agriculture. These techniques are designed to minimize soil disturbance, maintain soil cover, and rotate crops, with the goal of improving soil health, reducing erosion, conserving water, and enhancing long-term agricultural sustainability. Fig. 2 illustrates some key conservation agriculture techniques [11].

These conservation agriculture techniques vary in their application depending on the specific agricultural context and the goals of the farmer. The combination of these practices can lead to more sustainable and resilient farming systems that are better for the environment and for long-term agricultural productivity.

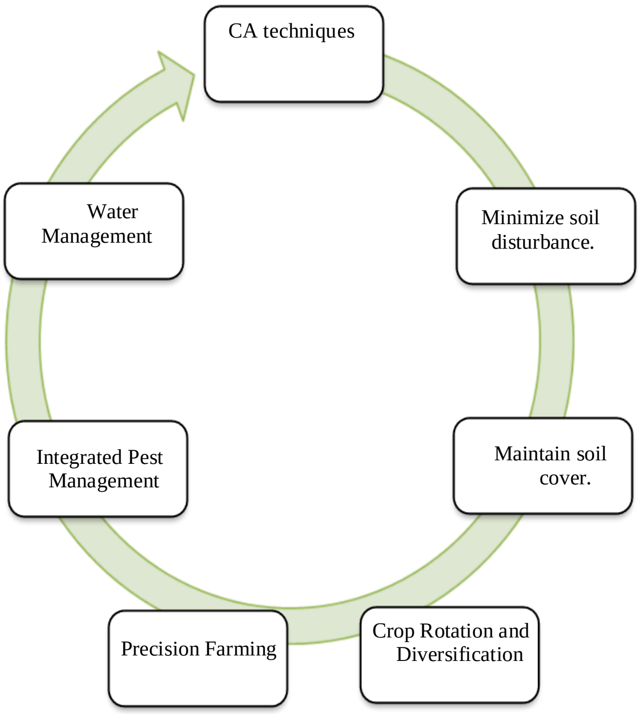

Fig. 2. *Conservative agriculture techniques*

III. BARRIERS TO IMPLEMENTING CONSERVATION AGRICULTURE TECHNIQUES AND MULTI-CAPITAL SUSTAINABILITY

A. Advantages and disadvantages of conservative agriculture

Climate change exerts a profound and disruptive influence on global agriculture [5]. The spectrum of climate variations, encompassing heat waves, droughts, floods, and unpredictable weather events, directly impinges on agricultural production. In the face of these changing conditions, farmers grapple with unpredictable yields, crop losses, water shortages, and alterations in crop growth patterns. Such climatic instability poses a substantial challenge to the overarching goal of global food security. Table III systematically outlines the advantages and disadvantages of CA as a sustainable farming approach [11].

TABLE III. ADVANTAGES AND DISADVANTAGES OF CONSERVATIVE AGRICULTURE

Advantages of (CA):	**Disadvantages (CA):**
✧ Soil Health Improvement	✧ Initial Investment:
✧ Water Conservation	✧ Weed Management:
✧ Reduced Soil Erosion By minimizing soil disturbance and using crop residues as cover.	✧ Pest and Disease Challenges.
✧ Enhanced Crop Yields	✧ Learning Curve:
✧ Biodiversity Promotion	✧ Crop Rotation Complexity
✧ Lower Greenhouse Gas Emissions.	✧ Market Access
✧ Resource Efficiency	✧ Cultural Resistance
✧ Improved Resilience	✧ Variable Success.
✧ Enhanced Pest Management:	✧ Timing and Adaptation
✧ Long-Term Sustainability: long-term well-being of farming systems and ecosystems	✧ Risk Perception:

In light of this reality, the imperative lies in the development and adoption of innovative agricultural technologies and practices aimed at bolstering the resilience of agricultural systems. This comprehensive approach encompasses climate-adapted farming methods, the implementation of more efficient water management techniques, and a dedicated effort to curtail greenhouse gas emissions originating from agricultural activities. Cutting-edge innovations, including but not limited to drought-resistant crop varieties, precision micro-irrigation systems, and the integration of agro-forestry, emerge as pivotal elements in the arsenal against the adverse impacts of climate change on agriculture. These forward-thinking solutions not only address the immediate challenges but also contribute to the sustainable evolution of agricultural practices in the face of a changing climate.

However, in many regions, particularly in developing countries, the adoption of these innovations is hindered by various factors. Farmers may lack the financial resources to invest in new technologies, the knowledge to implement them, and institutional support to assist them. Moreover, agriculture is often a vital livelihood in these regions, and vulnerability to climate impacts is exacerbated by other issues such as poverty and food insecurity.

Hence, the pressing challenge of adapting agriculture to climate change is notably more urgent in developing countries [12]. These nations grapple with a dual imperative: meeting the escalating food demands of their populations while simultaneously navigating the disruptions caused by climate variations. Addressing these complex challenges demands synchronized global endeavors, focusing on the development and widespread dissemination of suitable technologies, the enhancement of farmers' capabilities, and the implementation of supportive policies fostering the seamless transition towards climate-resilient agriculture.

B. Barriers to implementing conservation agriculture

Navigating the intricacies of implementing sustainable agriculture necessitates addressing a set of challenges rather than confronting a single, isolated obstacle. The intricate tapestry of challenges arises from a myriad of interacting factors, providing a nuanced perspective on the hurdles encountered in the pursuit of sustainable agricultural practices. Fig. 3 offers an illustrative overview of these challenges, categorizing them into four distinct and interconnected domains.

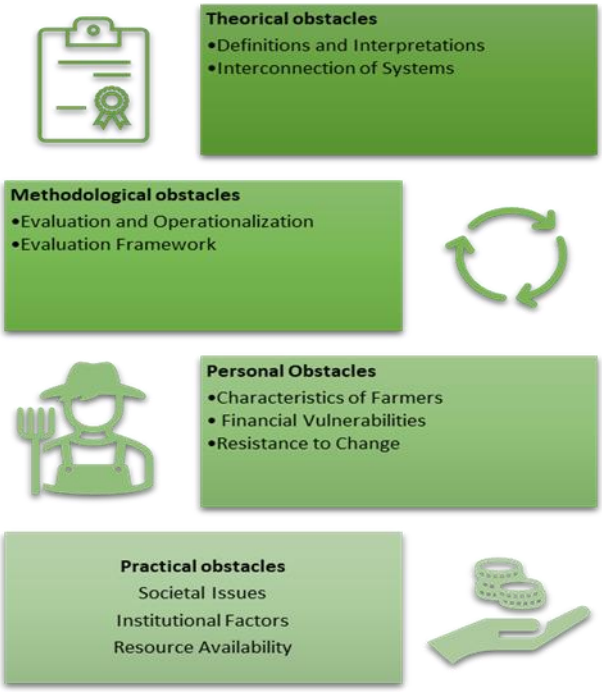

Fig. 3. *Overview of possible obstacles to the implementation of sustainable agriculture [11]*

The theoretical obstacles encountered in sustainable agriculture are deeply rooted in its foundational principles, encompassing challenges related to the conceptualization, definitions, and interpretations of this holistic approach. The intricate conceptual nuances inherent in sustainable agriculture pose formidable obstacles that necessitate meticulous consideration and strategic resolution. Addressing these theoretical intricacies is imperative to ensure a unified and effective implementation of sustainable agricultural practices.

The methodological obstacles are centered on the assessment and operationalization of sustainable agriculture, involving the intricate task of developing robust methodologies for measuring sustainability and translating theoretical frameworks into practical applications in the field. Bridging the gap between theoretical conceptualizations and workable methodologies is of paramount importance for the successful adoption of sustainable farming practices. This entails not only the refinement of assessment tools but also the establishment of effective protocols that ensure the seamless integration of sustainable principles into actionable, on-the-ground methods.

The personal barriers emerge from the inherent characteristics of individuals, with a particular focus on farmers, whose roles are pivotal in determining the sustainability of farming practices. These barriers encompass critical factors like farmers' awareness, education, and their willingness to both adopt and adapt to sustainable farming methods. Resolving these personal barriers is indispensable for nurturing a collective commitment to sustainability within the farming community. By enhancing awareness, providing education and fostering a mindset open to change, a more sustainable and resilient farming ethos can be cultivated among individuals, ensuring a harmonious integration of sustainable practices into agricultural landscapes.

The practical barriers, distinguished from the initial three categories, are intricately linked with societal challenges or impediments that impede the implementation and adaptation to a more sustainable agricultural landscape. These practical obstacles can manifest as economic constraints, political limitations, or overarching societal attitudes that significantly influence the feasibility and scalability of sustainable farming practices. Successfully surmounting these practical hurdles necessitates a paradigm shift and collaborative endeavors among diverse stakeholders. Achieving systemic change involves not only addressing economic and political constraints but also fostering a collective shift in societal perspectives to establish a more conducive environment for the widespread adoption of sustainable farming practices.

In summary, the complex landscape of sustainable agriculture is shaped by theoretical, methodological, and personal barriers, each influencing fundamental aspects and prerequisites for implementation. However, it is the practical barriers that distinctly impede the actual application and adaptation of practices towards enhanced sustainability. Recognizing and addressing each category of barrier is imperative to formulate comprehensive strategies that foster the widespread adoption of sustainable agricultural practices. This holistic approach ensures that interventions not only target theoretical foundations and methodological intricacies but also account for the nuanced personal and societal dimensions, creating a more resilient and sustainable agricultural paradigm.

C. Adoption of conservation agriculture

The challenges inherent in Conventional-Till (CT) agriculture [13] within the context of the Regenerative Watershed (RW) system are multi-faceted. They encompass a reduction in the productivity of input factors, a contraction of farm income resulting from elevated labor and fuel expenses, a decline in the availability of groundwater, and the repercussions of evolving climatic conditions. These difficulties are expected to be magnified by the projected risks associated with natural resource degradation and the far-reaching consequences of climate change [6]. Here are several strategies suggested to ease the adoption of CA:

- The adoption of CA practices in irrigated growth points (IGPs) can be influenced by several primary determinants [14].
- Access to Information and Awareness: Farmers need to be aware of CA practices and their benefits. Access to information through extension services, training programs, and communication channels plays a crucial role in promoting CA adoption.
- Financial Resources: Farmers often need financial resources to invest in CA practices, such as purchasing no-till equipment or cover crop seeds. Access to credit or funding mechanisms can facilitate this.
- Technical Knowledge and Skills: Farmers require the technical knowledge and skills to implement CA effectively. Training and capacity-building programs can help farmers acquire these skills [1,4].
- Local Adaptability: The suitability of CA practices for local conditions and crops is essential. Farmers are more likely to adopt CA if they believe it will work well in their specific environment and with their chosen crops [14].
- Market Access: Access to markets that reward CA-produced goods or provide a premium for sustainable agriculture can incentivize farmers to adopt CA practices [4].
- Demonstration and Peer Influence: Seeing the positive results of CA on neighboring farms or participating in demonstration plots can influence farmers to try CA themselves. Peer-to-peer learning and knowledge sharing are powerful drivers of adoption.
- Farm Size and Type: The size and type of farm can impact CA adoption. Larger commercial farms might find it easier to invest in CA equipment, while smallholders may need different types of support [15].
- Environmental Conditions: The local environmental conditions, such as climate and soil type, can affect the suitability of CA practices. Some CA practices may be better suited to certain environments than others [16, 17].
- Risk Perception: Farmers' perception of the risks and benefits associated with CA practices can influence their willingness to adopt them. Clear evidence of reduced risk or improved yield stability can encourage adoption [10].
- Social and Cultural Factors: Social norms, cultural beliefs, and traditional farming practices can influence farmers' decisions. Efforts to integrate CA into existing cultural practices may facilitate adoption [15].
- Infrastructure and Access to Resources: Adequate infrastructure, including access to irrigation water and transportation, can enable CA adoption by providing the necessary resources and support [18].
- Long-term sustainability goals: Farmers with a strong commitment to sustainable agriculture and environmental management are potentially more willing to adopt CA practices that are consistent with these goals [16].
- The combination and interaction of these determinants can vary from one region to another, making it important for policymakers, agricultural extension services, and organizations to tailor their strategies to the specific context and needs of the IGPs in which they are promoting conservation agriculture [19]

Indeed, addressing the challenges of conventional agriculture within regenerating watersheds requires a holistic and comprehensive approach. The adoption of conservation agriculture in irrigated growing areas is influenced by a multitude of factors, including access to information, financial resources, technical knowledge, local adaptability, market access, demonstration and peer influence, farm size, environmental conditions, risk perception, social and cultural factors, infrastructure, and long-term sustainability goals. Thus, to effectively promote conservation agriculture in diverse regions with varying determinants, it is imperative to employ tailored and suitable strategies. Recognizing the regional variability of these factors underscores the need for adaptive and targeted approaches. A profound understanding of this intricate interplay of elements is crucial to achieving widespread adoption and fostering sustainable farming practices. This comprehensive approach ensures that interventions are nuanced, context-specific, and aligned with the diverse challenges and opportunities presented by different agricultural landscapes.

IV. Conclusion

The successful implementation of sustainable agriculture is recognized as a complex endeavor, influenced by a multitude of interrelated obstacles. These challenges, categorized into theoretical, methodological, personal, and practical types, underscore the intricate nature of the transition to sustainable agricultural practices. Theoretical obstacles emanate from the foundational concept of sustainable agriculture, necessitating a meticulous examination of its definitions and interpretations. Methodological challenges are intricately linked to the assessment and implementation of sustainable agriculture, demanding the development of robust evaluation frameworks. Personal obstacles emphasize the pivotal role of individual farmers and their characteristics in shaping the sustainability of farming practices. On the opposite end of the spectrum, practical obstacles, distinct from the aforementioned types, encompass societal issues and barriers that impede actions necessary for achieving agricultural sustainability. Addressing these challenges necessitates a comprehensive approach that integrates diverse perspectives, engages stakeholders, and fosters innovative solutions. Addressing theoretical challenges requires continual dialogue and the continuous refinement of the conceptual underpinnings of sustainable agriculture. Methodological obstacles demand the creation of comprehensive assessment tools and practical frameworks to guide implementation. Consequently, recognizing and understanding the diverse characteristics of farmers is pivotal for surmounting personal barriers, highlighting the imperative for tailored strategies and supportive systems. Tackling practical barriers requires collaborative efforts to address societal issues hindering the transition to sustainable farming practices. This holistic perspective ensures that interventions are nuanced, adaptable, and consider the multifaceted nature of challenges in the pursuit of sustainable agriculture.

This paper highlights the complexity of the transition to sustainable agriculture and proposes tangible solutions to navigate the associated obstacles. In future research, our approach encompasses four interlinked tasks aimed at transforming the agri-food supply chain of small farmers, with a steadfast focus on the principles of conservation agriculture and multi-capital sustainability. The initial task involves a comprehensive literature review, delving into the disruptions experienced by smallholder farmers' supply chains. This initial investigation forms the cornerstone for building a comprehensive understanding of the present challenges. Moving forward, the second task entails proposing innovative scenarios tailored to the specific contexts of Tunisia, France, Italy, and Spain, seamlessly integrating the principles of conservation agriculture. The third task aspires to craft a novel concept of a sustainable agro supply chain, meticulously designed to align with the unique characteristics of the Mediterranean context. Lastly, the fourth task is dedicated to the practical validation of this concept through a case study in Tunisia, offering practical insights to guide potential implementations. These tasks are intricately interdependent, collectively contributing to a holistic vision for fostering a more sustainable and resilient agriculture.

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