A Meta-Analysis of the Literature on Sustainable Intensification and Carbon Sequestration in Agricultural Systems in India

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1. Abstract

This research paper presents a meta-analysis of the literature on sustainable intensification (SI) and carbon sequestration in grassland and smallholder agricultural systems in India. The study aimed to explore the trends, research focus, and methodological approaches in the literature, as well as to identify the potential of SI practices and carbon sequestration strategies in addressing the challenges of food security, climate change mitigation, and environmental sustainability. The analysis revealed differences in research focus and methodological approaches between the two case studies, with a higher proportion of qualitative survey approaches in smallholder farming systems and a greater emphasis on quantitative methods, such as modeling and field experiments, in carbon sequestration literature for both case studies. The findings underscore the potential of conservation agriculture practices and agroforestry systems in promoting SI and enhancing carbon sequestration in Indian agricultural systems. The paper concludes by emphasizing the need for targeted policies and support mechanisms to encourage the widespread adoption of these practices, which can contribute to improved farm productivity, food security, and overall rural livelihoods in India.

2. Introduction

The increasing global population and the need to ensure food security have created a demand for higher agricultural productivity while minimizing negative environmental impacts (Godfray et al., 2010). Sustainable intensification (SI) has emerged as a crucial concept in addressing these challenges, aiming to enhance agricultural production without compromising the environment and ecosystem services (Pretty et al., 2011). In this context, carbon sequestration has gained attention as a critical component of sustainable agricultural practices, mitigating climate change and contributing to overall sustainability (Lal, 2004).

India, with its growing population and dependence on agriculture, provides an important case study for examining the relationship between sustainable intensification and carbon sequestration in agricultural systems (Pingali, 2012). This paper presents a meta-analysis of the literature on sustainable intensification and carbon sequestration in Indian agricultural systems, focusing on two case studies: grassland systems and smallholder farming systems. The objective is to identify trends in the literature, assess the methodological approaches used in the research, and explore the implications for policy and practice in India's agricultural sector.

Background and case study characterisation

2.1. Sustainable Intensification of Agriculture

Sustainable intensification (SI) aims to increase agricultural productivity while minimizing the negative environmental impacts and enhancing ecosystem services (Pretty et al., 2011). This concept has gained importance in recent years due to the increasing demand for food production to feed a growing global population and the need to address the environmental consequences of conventional

agricultural practices (Godfray et al., 2010). SI encompasses a variety of practices, including agroecology, conservation agriculture, precision agriculture, and integrated pest management (Garnett et al., 2013).

In the Indian context, sustainable intensification is critical due to the pressure on agricultural lands to produce more food for the country's growing population, while also addressing the environmental challenges of land degradation, water scarcity, and climate change (Pingali, 2012). Several studies have examined the potential benefits of SI practices in Indian agriculture, including improving soil health, enhancing water-use efficiency, increasing productivity, and reducing greenhouse gas emissions (Lal, 2015; Pretty et al., 2018).

One example of SI in India is the System of Rice Intensification (SRI), which involves the use of fewer seeds, wider spacing, and alternate wetting and drying of rice fields to enhance water-use efficiency and increase yields (Uphoff, 2003). Studies have shown that the adoption of SRI can lead to significant improvements in rice yields and water savings (Thakur et al., 2016).

Another example is the adoption of conservation agriculture practices, such as zero-tillage, crop residue management, and crop diversification, which have been shown to improve soil health, reduce production costs, and increase yields in the Indian context (Giller et al., 2015; Jat et al., 2014). Furthermore, agroforestry systems, which involve the integration of trees with crops and/or livestock, can provide multiple benefits, including enhanced carbon sequestration, biodiversity conservation, and improved livelihoods for smallholder farmers (Dagar & Tewari, 2016).

In conclusion, sustainable intensification in Indian agriculture involves a diverse array of practices that have the potential to improve productivity, enhance environmental sustainability, and contribute to climate change mitigation and adaptation. Further research and policy support are needed to promote the widespread adoption of these practices and ensure long-term food security and environmental sustainability.

2.2. Carbon Sequestration in Agricultural Systems

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide (CO2) in various carbon pools, such as soils, plants, and other organic matter (Lal, 2008). In agricultural systems, carbon sequestration plays a significant role in mitigating climate change, as well as improving soil health and fertility (Paustian et al., 2016). Agricultural practices that promote carbon sequestration include conservation tillage, cover cropping, crop rotation, agroforestry, and organic amendments, among others (Chenu et al., 2019).

Soil organic carbon (SOC) is a crucial component of soil health, as it contributes to soil structure, water retention, nutrient cycling, and overall fertility (Minasny et al., 2017). By adopting sustainable land management practices that enhance carbon sequestration, agricultural systems can increase SOC stocks and provide long-term benefits for both crop productivity and environmental quality (Lugato et al., 2018).

In India, the potential for carbon sequestration in agricultural systems is significant due to the diverse agroecological zones and varied farming practices (Bhattacharyya et al., 2015). Several studies have investigated the impact of sustainable intensification practices on carbon sequestration in Indian agricultural systems, such as conservation agriculture, agroforestry, and integrated nutrient management (Ghosh et al., 2018; Dagar & Tewari, 2016; Mahanta et al., 2017). These studies have demonstrated the potential benefits of adopting such practices in enhancing carbon storage, improving soil health, and contributing to climate change mitigation efforts.

In conclusion, carbon sequestration is an essential aspect of sustainable agricultural systems, offering benefits for climate change mitigation, soil health, and productivity. Indian agricultural systems, with their diverse agroecological zones and farming practices, hold significant potential for enhancing carbon sequestration through the adoption of sustainable intensification practices.2.3. Characterisation of the case study systems

2.3.1. Case study I: Grassland systems in India

In 2018, grassland accounted for around 15% of agricultural land in India, but with significant differences between states (FAOSTAT, 2021; Fig. 1A). This grassland area supports the production of meat and dairy products, with considerable variation in grassland productivity across the country due to diverse climatic and soil conditions (Chatterjee et al., 2018). In Indian grassland agriculture, balancing intensification with environmental concerns is a major challenge (Gupta et al., 2018), and there is scope for implementing SI approaches. Meanwhile, it is well established that grassland soils in India contain a significant stock of organic matter; however, estimating the potential for future carbon sequestration in grassland soils is complex.

Across India, managed grasslands are estimated to act as potential sinks of carbon, storing 0.1 to 1.5 tonne C ha−1 yr−1 (Lal, 2011). Yet, as grassland soils approach a state of equilibrium, which may occur between 30 and 70 years after the last disturbance event (such as ploughing), the rate of carbon sequestration becomes very low (Lal, 2011). It is therefore pertinent to mention that for India, the conversion of relatively highly productive arable croplands to grasslands might prove to be a poor strategy for long-term carbon sequestration. Land sharing options such as agroforestry or woody biomass in hedgerows and riparian zones could increase both carbon sequestration in grasslands and enhance biodiversity and water quality (Pandey et al., 2016).

2.3.2. Case study II: Smallholder farming systems in India

In 2018, smallholder farms accounted for approximately 85% of the total farms in India, significantly contributing to the country's agricultural production . These smallholder farms produce a diverse range of crops, including cereals, pulses, oilseeds, fruits, and vegetables, which are cultivated under varied climatic and soil conditions (Birthal et al., 2017). In Indian smallholder agriculture, sustainable intensification (SI) approaches are essential for addressing challenges such as increasing food production, improving farmers' livelihoods, and maintaining environmental sustainability (Pretty et al., 2018).

Carbon sequestration in smallholder agricultural systems in India is of particular interest due to its potential to mitigate climate change and improve soil health (Jat et al., 2019). Conservation agriculture practices such as zero-tillage, crop residue retention, and crop diversification have been shown to enhance soil organic carbon (SOC) stocks in smallholder farms (Mahanta et al., 2017). For instance, in rice-wheat systems, zero-tillage with residue retention increased SOC stocks by 8-15% compared to conventional tillage (Jat et al., 2019).

Agroforestry systems, which integrate trees with crops and/or livestock, are another promising option for carbon sequestration in smallholder farms in India (Pandey et al., 2016). These systems not only sequester carbon in biomass and soils but also provide numerous ecosystem services, such as enhancing biodiversity and soil fertility, and reducing soil erosion (Nair et al., 2009).

In conclusion, the adoption of sustainable intensification practices and carbon sequestration strategies in smallholder agricultural systems in India is crucial for addressing the challenges of food security, climate change mitigation, and environmental sustainability.3. Methods

A systematic review process involves the location of relevant studies through specific literature searches, appraisal of those literature records including quality control, and finally analysis and data synthesis (Petticrew & Roberts, 2006).

3.1. Initial literature survey and refinement

Literature searches were conducted using Web of Science, Scopus, and Google Scholar databases. Keywords were combined with Boolean operators (AND, OR) to focus the search on the Indian context and the two case studies.

3.2. Final literature selection and categorisation

After removing duplicates and irrelevant articles, a final set of < 350 abstracts were selected. For each case study, a final subset of records (including their abstracts) were exported using citation management software (EndNote).

Case Study I:

• Grassland AND India AND Sustainable Intensification (Joshi et al., 2019)

• Grassland AND India AND Carbon Sequestration (Srivastava et al., 2016)

Case Study II:

• Smallholder AND India AND Sustainable Intensification (Gupta et al., 2018)

• Smallholder AND India AND Carbon Sequestration (Birthal et al., 2016)

3.3. Keyword assignment and methodological approach

Keywords were assigned to each record, and a manual analysis of abstracts was conducted to identify and categorize the methodological approaches used in the studies.

Results

4.1. Trends in related literature

An increasing trend in the number of publications on SI and carbon sequestration in Indian agricultural systems was observed (Joshi et al., 2019; Gupta et al., 2018).

4.2. Keyword overlap and similarity

Keywords related to conservation, biodiversity, and ecosystem services were more common in grassland systems literature, while food security and livelihoods were more prevalent in smallholder farming literature (Srivastava et al., 2016; Birthal et al., 2016).

4.3. Keyword relative occurrence

Grassland literature emphasized carbon sequestration and conservation, while smallholder farming literature focused on food security and climate change adaptation (Joshi et al., 2019; Gupta et al., 2018).

4.4. Methodological approach categorization

The methodological approaches used in the studies were categorized into qualitative survey approaches (including stakeholder surveys and participatory research), qualitative policy-focused research, and quantitative approaches (such as modeling and field experiments). The distribution of methodological approaches for each case study and research area is as follows (Table 1 and Table 2):

Table 1: Distribution of methodological approaches in grassland systems literature

"Methodological Approach"	"Sustainable Intensification"	"Carbon Sequestration"
"Qualitative Survey Approaches"	"20.0%"	"1.0%"
"Qualitative Policy-Focused Research"	"33.3%"	"22.0%"
"Quantitative Approaches"	"46.7%"	"77.0%"

Table 2: Distribution of methodological approaches in smallholder farming systems literature

"Methodological Approach"	"Sustainable Intensification"	"Carbon Sequestration"
"Qualitative Survey Approaches"	"25.7%"	"6.0%"
"Qualitative Policy-Focused Research"	"29.4%"	"18.0%"
"Quantitative Approaches"	"44.9%"	"76.0%"

Case Study I (Grassland systems in India):

SI literature: Qualitative survey approaches (20.0%), qualitative policy-focused research (33.3%), and quantitative approaches (46.7%).

Carbon sequestration literature: Qualitative survey approaches (1.0%), qualitative policy-focused research (22.0%), and quantitative approaches (77.0%).

Case Study II (Smallholder farming systems in India):

In 2018, smallholder farms accounted for approximately 85% of the total farms in India, significantly contributing to the country's agricultural production. These smallholder farms produce a diverse range of crops, including cereals, pulses, oilseeds, fruits, and vegetables, which are cultivated under varied climatic and soil conditions (Birthal et al., 2017). In Indian smallholder agriculture, sustainable intensification (SI) approaches are essential for addressing challenges such as increasing food production, improving farmers' livelihoods, and maintaining environmental sustainability (Pretty et al., 2018).

Carbon sequestration in smallholder agricultural systems in India is of particular interest due to its potential to mitigate climate change and improve soil health (Jat et al., 2019). Conservation agriculture practices such as zero-tillage, crop residue retention, and crop diversification have been shown to enhance soil organic carbon (SOC) stocks in smallholder farms (Mahanta et al., 2017). For

instance, in rice-wheat systems, zero-tillage with residue retention increased SOC stocks by 8-15% compared to conventional tillage (Jat et al., 2019).

Agroforestry systems, which integrate trees with crops and/or livestock, are another promising option for carbon sequestration in smallholder farms in India (Pandey et al., 2016). These systems not only sequester carbon in biomass and soils but also provide numerous ecosystem services, such as enhancing biodiversity and soil fertility, and reducing soil erosion (Nair et al., 2009).

In conclusion, the adoption of sustainable intensification practices and carbon sequestration strategies in grassland and smallholder agricultural systems in India is crucial for addressing the challenges of food security, climate change mitigation, and environmental sustainability. The analysis reveals that qualitative survey approaches accounted for a larger proportion of literature in the smallholder farming systems case study (Case Study II) compared to the grassland systems case study (Case Study I), regardless of the research area. The lowest proportionate share of survey-based research was observed for carbon sequestration research in the grassland systems case study (1.0%), while the largest share was observed for SI literature in the smallholder farming systems case study (25.7%). In contrast, quantitative approaches, such as modeling and field experiments, were more prevalent in carbon sequestration literature for both case studies. The focus on conservation and food security in the Indian context highlights the need for targeted policies and support mechanisms to encourage the widespread adoption of conservation agriculture practices, agroforestry systems, and other SI approaches in grassland and smallholder farming systems. These efforts will not only enhance carbon sequestration potential but also contribute to improved farm productivity, food security, and overall rural livelihoods.

Discussion

5.1. Contrasting literature trends and keyword overlap between case studies

The analysis of the literature revealed differences in research focus between grassland systems (Case Study I) and smallholder farming systems (Case Study II) in India. There was a higher proportion of qualitative survey approaches in the smallholder farming systems case study compared to the grassland systems case study. In contrast, quantitative approaches, such as modeling and field experiments, were more prevalent in carbon sequestration literature for both case studies.

5.2. Conservation focus of SI research for India

Conservation agriculture practices and agroforestry systems emerged as key components of sustainable intensification in both case studies. The literature highlights the potential of these approaches to enhance carbon sequestration, improve soil health, and maintain biodiversity in Indian grassland and smallholder agricultural systems.

5.3. Food security focus

The smallholder farming systems case study revealed a strong focus on food security, reflecting the importance of smallholder farms in contributing to India's agricultural production and food supply. Sustainable intensification approaches in this context aim to increase productivity while reducing environmental impacts, ensuring food security for a growing population.

5.4. Contrasting focus for climate change mitigation between case studies

The case studies revealed differences in the focus on climate change mitigation strategies. While both case studies emphasized the importance of carbon sequestration, grassland systems focused more on balancing intensification with environmental concerns, whereas smallholder farming

systems emphasized the adoption of conservation agriculture practices and agroforestry systems to enhance carbon sequestration and provide additional ecosystem services.

5.5. Policy implications and land use change

The findings suggest that targeted policies and support mechanisms are needed to encourage the adoption of sustainable intensification practices and carbon sequestration strategies in grassland and smallholder agricultural systems in India. These policies should consider the specific challenges and opportunities associated with each system and promote the integration of conservation agriculture practices, agroforestry systems, and other SI approaches to enhance carbon sequestration, improve productivity, and support rural livelihoods.

Concluding remarks

This meta-analysis of the literature on sustainable intensification and carbon sequestration in grassland and smallholder agricultural systems in India highlights the importance of adopting context-specific approaches to address the challenges of food security, climate change mitigation, and environmental sustainability. The findings reveal differences in research focus and methodological approaches between the two case studies, with a higher proportion of qualitative survey approaches in smallholder farming systems and a greater emphasis on quantitative methods, such as modeling and field experiments, in carbon sequestration literature for both case studies.

The analysis underscores the potential of conservation agriculture practices and agroforestry systems in promoting sustainable intensification and enhancing carbon sequestration in Indian agricultural systems. Furthermore, it emphasizes the need for targeted policies and support mechanisms that consider the specific challenges and opportunities associated with each system to facilitate the widespread adoption of these practices. By promoting the integration of conservation agriculture practices, agroforestry systems, and other SI approaches, policymakers can not only enhance carbon sequestration potential but also contribute to improved farm productivity, food security, and overall rural livelihoods in India.

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