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The Role of Legume Cover Crops in Enhancing Climate Resilience and Water Use Efficiency in South African Grassland Systems. A Review

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Review

The Role of Legume Cover Crops in Enhancing Climate Resilience and Water Use Efficiency in South African Grassland Systems. *A Review*

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Abstract: The purpose of this review is to investigate the role of legume cover crops in improving climate adaptability and water use efficiency in South African grassland systems. Climate change is posing significant obstacles to agricultural systems all over the world, which includes South Africa, where shortages of water and fluctuations are significant issues. Legume cover crops are growing in popularity as a long-term and cost-effective solution to these problems. The purpose of this review is to demonstrate the possible advantages of legume cover crops for enhancing climate resilience and water use efficiency in South African grassland systems, as well as the fundamental processes and present study findings. According to the outcomes, legume cover crops may boost soil water availability, nutrient cycling, carbon sequestration, and overall ecosystem productivity, resulting in increased climate resilience and water use efficiency. However, a variety of factors, including species selection, management practices, and environmental conditions, can all have an impact on the effectiveness of legume cover crops. With the concerted efforts, adaptation strategies of livestock farmers that seeks to maximise the potential of legume cover crops in South African grassland systems, it is critical to consider site-specific factors when establishing them. This review offers significant insights into the role of legume cover crops in climate resilience and water use efficiency, laying the groundwork for future research and agricultural practices.

Keywords: legume cover crops; climate resilience; water use efficiency; South African grassland systems

1. Introduction

South Africa, like many other parts of the world, is feeling the effects of climate change, which are posing serious difficulties to its agricultural systems. Extreme weather events, extended droughts, and unreliable patterns of precipitation are all having a significant impact on agricultural productivity and accessibility to water in South African grassland systems (Scholes *et al.*, 2015). Furthermore, in response to these difficulties, strengthening climate resilience and water use efficiency have emerged as critical priorities for sustainable agriculture. South African grassland systems are critical to livestock production, ecosystem services, and food security. However, because of their reliance on rainfall and constrained irrigation infrastructure, they have become especially vulnerable to variations in the climate and change (Xenarios *et al.*, 2019). As a result, it is critical to investigate novel strategies for increasing the resilience of these grassland systems to climate-related stresses while optimising water use efficiency (Kansiime *et al.*, 2016). Therefore, the integration of legume cover crops into grassland systems is one such strategy that is gaining traction. According to *Datta et al.* (2022) legume cover crops, such as clover, vetch, and lablab, have the potential to provide several advantages in terms of climate resilience and water use efficiency. In addition, legumes have

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the unique ability to fix atmospheric nitrogen via symbiotic relationships with nitrogen-fixing bacteria, improving soil fertility and reducing the need for synthetic nitrogen fertilisers (Delgado *et al.,* 2021). Furthermore, legume cover crops increase soil moisture retention, reducing the effects of drought and enhancing water use efficiency (Scavo *et al.,* 2022). Also, recognising the significance of legume cover crops in improving climate resilience and water use efficiency in South African grassland systems is critical for long-term agricultural practices (Daryanto *et al.,* 2018). We can gain knowledge about the prospective benefits, difficulties, and drawbacks of legume cover crops in this context by reviewing existing literature, studies, and experimental evidence. In addition, recognising knowledge shortages and identifying areas for additional research and adoption can assist policymakers, agricultural practitioners, and researchers in developing successful approaches for mitigating the effects of climate change on grassland systems (Perrone *et al.,* 2020). The purpose of this review is to investigate current knowledge about the role of legume cover crops in improving climate resilience and water use efficiency in South African grassland systems. It will also investigate the relationships among legume cover crops and climate variables, emphasizing their ability to improve grassland system resilience to changing climatic conditions. The review will additionally address the difficulties and constraints associated with introducing legume cover crops in South Africa, as well as recommendations for future research and adoption. This review aims at contributing to an improved comprehension of sustainable agricultural practices that can improve climate resilience and water use efficiency in South African grassland systems by synthesizing existing knowledge. Subsequently, such understanding may assist in shaping policy decisions, encourage farmers to implement best practices, and contribute to the development of resilient and sustainable agricultural systems in the face of climate change.

2. Methodology

To gather the information for the literature review on the role of legume cover crops in enhancing climate resilience and water use efficiency in South African grassland systems. *The following steps were taken.*

- **Identification of Relevant Sources**: The Google search engine on various academic databases, such as PubMed, Scopus, Web of Science, and agricultural databases, was searched to identify relevant scholarly articles, research papers, conference proceedings, and reports. Additionally, reputable online repositories and institutional websites were accessed to gather relevant information.
- Selection of Keywords: A set of keywords and search terms related to the topic were identified. These keywords included "legume cover crops," "climate resilience," "water use efficiency," and "South African grassland systems." The keywords were used in combination with Boolean operators (such as AND, OR) to refine the search and ensure the retrieval of relevant literature.
- **Screening and Evaluation**: The search results were screened based on the titles and abstracts to assess their relevance to the research topic. Non-relevant or duplicate articles were excluded at this stage. The remaining articles were selected for a full-text review.
- **Full-Text Review**: The selected articles underwent a thorough full-text review. The content of each article was examined to extract relevant information and key findings related to the role of legume cover crops in climate resilience and water use efficiency in South African grassland systems. Information on legume species, experimental methodologies, outcomes, and recommendations was extracted.
- **Data Synthesis and Analysis**: The extracted information and findings were synthesized and organized based on subtopics and themes relevant to the research objectives. Patterns, trends, and gaps in the literature were identified and analyzed to derive meaningful insights.
- **Critique and Evaluation**: The reviewed literature was critically evaluated for the quality and reliability of the research methodologies, data collection techniques, and analysis methods employed in each study. Limitations and biases within the literature were acknowledged and considered during the review process.

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- Summarization and Writing: The key findings, concepts, and insights from the reviewed literature were summarized and synthesized. The information was then used to address the research objectives, subtopics, and research gaps identified in the review.

Overall, a systematic and rigorous approach was employed to gather information for the literature review. Multiple sources were explored, and a thorough evaluation process was followed to ensure the reliability and relevance of the information obtained.

3. Climate Resilience in South African Grassland Systems

- **Climate change impacts grassland ecosystems**

Climate change is having an enormous effect on grassland ecosystems, influencing their makeup, structure, function, and overall ecological dynamics (Zhang *et al.*, 2023). Because of their sensitivity to changes in temperature, precipitation patterns, and extreme weather events, grassland ecosystems, which include both natural grasslands and managed agricultural grasslands, are particularly vulnerable to the effects of climate change (Ramesh *et al.*, 2019). Guhathakurta *et al*. (2011) further reported that climate change alters rainfall patterns, which includes an increase in the frequency and severity of droughts and heavy rainfall events. Moreover, these variations in rainfall have the potential to upset the natural hydrological balance of grassland ecosystems, influencing soil moisture availability, groundwater recharge, and plant water stress (Guhathakurta *et al.*, 2011). Drought conditions can reduce grass productivity, alter species composition, and make plants more susceptible to wildfires (Halofsky *et al.*, 2020). Furthermore, temperature increases can have an impact on the development and growth of plants, alter the distribution of species patterns, and increase evapotranspiration rates (Joyce *et al.*, 2016). In addition, temperature regime shifts can also interfere with the phenological cycles of grasses and other plant species, impacting reproductive success, relationships with pollinators, and overall ecosystem dynamics (Hoffmann *et al.*, 2019).Also, climate change has the potential to alter the distribution and makeup of plant species in grassland ecosystems. Muluneh (2021) certain species may be more effectively adjusted to more humid and warmer conditions, whereas others may struggle to survive or migrate to more suitable habitats. These alterations have an opportunity to alter relationships between species, competitive dynamics, and biodiversity loss. Similarly, grassland ecosystems are important for carbon sequestration and the global carbon cycle (Zhou *et al.*, 2020). Nevertheless, climate change can have an impact on the carbon dynamics in grasslands. However. temperature, precipitation, and plant productivity can all have an impact on carbon uptake, storage, and release processes (Zhou *et al.*, 2020). Additionally, changes in species composition and disruption regimes can also influence grassland ecosystems' long-term carbon sequestration potential (Enright *et al.*, 2015). Therefore, to tackle the effects of climate change on grassland ecosystems, an in-depth comprehension of the ecological processes, species interactions, and feedback mechanisms at work is required. Furthermore, adaptive management approaches that consider expected climate changes can help preserve the efficiency and ecological integrity of grassland systems.

- **Importance of climate resilience in agriculture**

Because of the growing impact of climate change on agricultural productivity, food security, and rural livelihoods, adaptation to climate change is critical in agriculture (Yadav *et al.*, 2019). Climate change, on the other hand, presents serious threats to crop yields, livestock production, and fisheries. Furthermore, significant shifts in patterns of precipitation and temperature, and the spread of pests and diseases can all disrupt agricultural systems and jeopardize food production (Pathak at al., 2018). Equally, Yadav *et al.* (2019) increasing climate resilience allows agricultural systems to better endure and recuperate from climate-related unexpected events, maintaining a secure and predictable food supply for communities and nations. Climate change presents new and unanticipated obstacles to agriculture, necessitating the adaptation of farmers and agricultural systems to changing conditions (Aguilera *at al.*, 2020). Whereas climate versatility permits farmers to foresee, prepare for, and deal with climate-related risks efficiently. Furthermore, it entails implementing water management strategies, embracing innovative farming practices, expanding crops and livestock, and including

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climate information in decision-making processes (Balasundram *et al.,* 2023). Likewise, improving climate resilience in agriculture protects and sustains rural livelihoods by decreasing exposure to climate-related shocks, ensuring stable incomes, and promoting equitable growth in agricultural communities (Muluneh, 2021). Producers may mitigate the destruction of the environment, safeguard ecosystem services, and preserve agricultural landscape productivity and health through the adoption of climate-resilient practices such as soil conservation, efficient water use, and biodiversity conservation (Aguilera *at al.,* 2020). Climate resilience encourages sustainable farming practices that reduce greenhouse gas emissions, preserve natural resources while contributing to climate change mitigation (Singh and Singh, 2017). Moreover, agriculture contributes significantly to greenhouse gas emissions, but climate-resilient agricultural practices can help minimize the effects of climate change (Enright *et al.,* 2015). Besides, implementing agroforestry systems, enhancing soil management techniques, and carrying out viable water management practices, for example, can sequester carbon, reduce emissions, and improve agricultural landscapes' carbon storage capacity (Scavo *et al.,* 2022). Overall, climate adaptation in agriculture encourages low-carbon, climate-resilient agricultural systems and supports long-term climate change mitigation measures. Finally, by increasing climate resilience in agricultural systems, we can improve farmers' and communities' ability to deal with climate-related difficulties while sustaining viable agricultural practices amid climate change.

4. Water Use Efficiency in South African Grassland Systems.

- **Water scarcity and its implications for agricultural productivity.**

The shortage of water is a pressing global issue with grave consequences for agricultural productivity. In addition, with increasing water requirements from numerous industries, combined with the effects of climate change, many regions are facing a shortage of water, which means that available water resources are not adequate to meet the needs of all users, including agriculture (Umesha *et al.,* 2018). Water scarcity reduces the amount of water accessible for irrigation, which is necessary for crop growth and productivity to be sustained (Rosa *et al.,* 2020). Uniquely, inadequate water supply during critical growth stages can result in lower crop yields, lower quality produce, and even crop failure. In addition, a shortage of water frequently forces farmers to make challenging choices about which crops to prioritize for irrigation, resulting in decreased diversity and agricultural output (Umesha *et al.,* 2018). Additionally, farmers may need to switch to crops that need less water or are better suited to arid conditions. In short, this can lead to changes in agricultural landscapes, with less water-demanding crops preferred over water-intensive ones. According to Nikolaou *et al.* (2020) a shortage of water has an impact not only on crop production but also on livestock farming. In general, water is essential for animals for drinking, cooling, and hygiene. Constrained water availability in water-stressed areas can cause water stress in livestock, jeopardizing their health, growth, and productivity (Nikolaou *et al.,* 2020). As a result, long-term shortages of water in areas that depend heavily on groundwater for irrigation may give rise to over-extraction of groundwater resources (Umesha *et al.,* 2018). Continuous pumping might deplete aquifers, lowering groundwater levels and possibly leading to land subsidence. This can harm agricultural infrastructure such as wells and irrigation systems, exacerbating the problem of water scarcity. Water shortages in agriculture can have negative environmental consequences. Farmers may resort to detrimental practices such as over-irrigation or the use of low-quality water sources in some cases, resulting in water pollution and the deterioration of water ecosystems (Mancosu *et al.,* 2015). Furthermore, decreased accessibility to water can disrupt the ecological equilibrium of wetlands, rivers, and other freshwater habitats, threatening biodiversity, and ecosystem health (Chartzoulakis and Bertaki, 2015). Combating the shortage of water in agriculture necessitates an integrated strategy that involves water resource management, enhanced irrigation techniques, water-efficient farming practices, and policy interventions (Chai *et al.,* 2016). Water-saving technologies, such as drip irrigation and precision agriculture, can be used to optimize water use and reduce losses. Consequently, water storage and rainwater harvesting systems can be improved to offer other sources of water during dry periods. Incorporated water management approaches involving agriculture, government, and civil society stakeholders are critical for long-term water allocation and equitable access.

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- **importance of water use efficiency in agricultural systems.**

Water utilization efficiency is critical in agricultural systems because of a growing shortage of water and the need to control limited water resources sustainably (Kang *et al.*, 2017). Chen *et al.* (2018) report that agriculture is one of the world's biggest freshwater consumers, accounting for a sizable portion of total water withdrawals. Moreover, enhancing water use effectiveness in agricultural systems is critical for long-term water management (Pellegrini *et al.*, 2016). Producers may minimize water waste, reduce pressure on water sources, and guarantee an adequate supply of water for other sectors and ecosystems by maximizing the productivity of each unit of water used. Additionally, higher crop yield and productivity are directly related to efficient water use (Zahoor *et al.*, 2019). Water applied specifically and in the right amounts optimizes plant growth, nutrient uptake, and photosynthesis, resulting in higher crop yields (Farooq *et al.*, 2019). In addition, water-stressed plants are more vulnerable to diseases, pests, and deficiency of nutrients, which may decrease productivity even further. Improving water efficiency aids crop production and helps maintain food security (Walters and Midden, 2018). Improving water efficiency aids crop production and helps maintain food security. Furthermore, enhanced water-management practices can help safeguard soil health, hinder erosion, and reduce the need for chemical inputs (Kang *et al.*, 2017). Water conservation promotes sustainable farming practices that preserve multiple resources while also encouraging environmental stewardship. Altieri *et al.*, (2015) reported that water efficiency in agriculture can help reduce the environmental impacts of water consumption. Therefore, overuse of irrigation or ineffective water application can result in waterlogging, salinization, and water pollution from fertilizer and agrochemical runoff (Yurtseven and Randhir, 2020). Conversely, farmers can reduce these negative effects, protect water quality, and maintain aquatic ecosystems by optimizing water use. Enhancing water efficiency is an important adaptation strategy for dealing with changing climate conditions. In addition, successful techniques, such as drip irrigation or micro-sprinklers, allow for precise water application, decreasing water loss due to evaporation and enhancing soil moisture management (Kang *et al.*, 2017). Farmers can adapt to progressively attributed and undetermined access to water by using water efficiently. As revealed by Stuart *et al.* (2018) farmers can reduce production costs, boost profitability, and improve their resilience to variations in water availability and price by optimizing water use and reducing water inputs. As a result, successful irrigation practices also reduce the need for extra water investment in infrastructure such as dams or irrigation systems, saving both capital and operational costs (Cortignani *et al*,. 2021). Therefore, improving agricultural water use effectiveness encourages water equity and social considerations (Rogers *et al.*, 2021). In addition, water scarcity has a negative impact on vulnerable communities, especially small-scale farmers and rural populations who rely extensively on agriculture (Cortignani *et al*,. 2021). Moreover, enhancing water use efficiency ensures that water resources are distributed fairly, decreasing disparities and disputes over water access (Shi *et al.*, 2020). According to Li *et al.*, 2022 successful water use in agriculture is a multifaceted approach that includes using sophisticated methods for irrigation, carrying out water-saving technologies, promoting soil moisture management, and raising farmer awareness. Thereby, policy support, incentives, and capacity building are critical to promoting efficient water management practices across agricultural sectors. By improving water use efficiency, agricultural systems may become more ecologically sound, resilient, and capable of meeting rising global food demand while conserving water resources for future generations.

5. Legume Cover Crops

- **Role of legume cover crops in enhancing climate resilience.**

Legume cover crops are essential for increasing climate resilience in agricultural systems. Legume cover crops are well known for their distinctive capacity to fix atmospheric nitrogen via symbiotic relationships with nitrogen-fixing bacteria (Mahmud *et al.*, 2020). In addition, this process minimizes the need for synthetic nitrogen fertilizers, which require a lot of energy to make and contribute to greenhouse gas emissions. Conversely, farmers may decrease their reliance on external inputs, improve the accessibility of nutrients in the soil, and reduce the environmental impact of fertilizer use by relying on nitrogen fixation offered by legume cover crops (Pankievicz *et al.*, 2020). In agricultural systems, leguminous cover crops enhance soil health and increase carbon sequestration. In essence, their extensive root systems encourage the accumulation of organic matter, improve soil structure, and improve the ability to hold water (Navarro-Pedreño *et al.*, 2021). This reduces soil erosion, improves water infiltration, and increases soil moisture retention, all of which help mitigate the effects of climate change (Navarro-Pedreño *et al.*, 2021). Moreover, legume cover crops help to sequester carbon by incorporating organic matter into the soil, lowering the concentration of atmospheric carbon dioxide, a major greenhouse gas (Kleber *et al.*, 2021). Furthermore, legume cover crops can help agricultural systems use water more efficiently. Because their dense canopy reduces evaporation and soil moisture loss, helping to conserve water resources (Kleber *et al.*, 2021). As a result, their deep root systems gain access to water from deeper soil layers, making them more drought resistant (Carbonell-Bojollo *et al.*, 2021). Farmers can optimize water use, preserve soil moisture, and improve the overall water use effectiveness of the agricultural landscape through the integration of legume cover crops into rotation systems or intercropping (Tully and Ryals, 2017). Legume cover crops successfully mitigate erosion by protecting soil from wind and water erosion (Blanco-Canqui *et al.*, 2015). Their dense foliage intercepts rain, decreasing the effect of raindrops on the soil surface and hindering soil particle separation. Han *et al.* (2022) recommends legume cover crops to assist in preserving important topsoil, retain soil fertility, and protect agricultural productivity by reducing erosion, especially in areas subjected to excessive precipitation or sloping terrain. Likewise, legume cover crops help to promote biodiversity and resilience to climate change in agricultural landscapes. For instance, their flowers attract beneficial insects that include pollinators and natural pest enemies, which aid in pollination and biological pest control (Dunn *et al.*, 2020). Also, legume cover crops also increase the diversity of soil microbes and activity, which promotes beneficial soil organisms that aid in nutrient cycling, disease suppression, and in general ecosystem resilience (Dunn *et al.*, 2020). Therefore, integrating legume cover crops into crop rotation systems aids in the disruption of pest and disease cycles, lowering the risk of epidemics of pests and the need for chemical pesticides. Legume cover crops serve as trap crops, drawing in pests away from cash crops and acting as a natural pest management approach. This helps to maintain the agroecosystem's ecological balance, minimises dependency on synthetic pesticides, and encourages a more sustainable and resilient pest management strategy. Bringing together legume cover crops into farming practices improves agricultural systems' overall sustainability, productivity, and versatility in the face of climate change hardships.

Role of legume cover crops in improving water use efficiency.

Legume cover crops play an important role in increasing the efficiency of water use in agricultural systems by forming a protective covering on the soil surface, which results in a reduction in water evaporation (Kocira *et al.*, 2020). Secondly, their thick canopy protects the soil from direct sunlight, reducing water loss by means of evaporation. As revealed by Bwambale *et al.* (2022), soil moisture preservation guarantees that water is available for plant uptake, resulting in better water use efficiency. Furthermore, legume cover crops' root systems enhance soil structure and boost water infiltration rates. For instance, the roots improve the soil's capacity to absorb and retain water through the development of channels and pores in the soil (Sharma *et al.*, 2018). Therefore, this minimizes runoff and hinders water loss due to surface runoff or erosion, enabling more water to get into the soil and be accessible for plant use. Legume cover crops help improve soil water retention capacity. On the other hand, when legume cover crops break down, the organic matter generated enhances soil structure, resulting in more porous soil that can hold more water (Angers and Carter, 2020). Because of its greater water-holding capacity, water is available to plants for a longer period, lowering the frequency and amount of irrigation required. Moreover, because legume cover crops enhance water infiltration and soil water-holding ability, irrigation requirements are reduced (Kocira *et al.*, 2020). The incorporation of legume cover crops can reduce the amount of additional irrigation required for crop production substantially. This not only saves water but also minimizes the energy and cost of irrigation, leading to enhanced efficiency in water consumption. Also, legume cover crops can improve agricultural systems endurance to water stress and periods of drought (Nkomo *et al.*,

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2021). Legume cover crops' enhanced soil moisture conservation and deep rooting characteristics aid in maintaining adequate soil moisture levels during periods of water scarcity (Ahmad *et al.,* 2021). Likewise, this allows crops to cope with drought stress better, minimizing yield losses while preserving productivity in drought-stricken areas (Ahmad *et al.,* 2021). In a nutshell, legume cover crops strengthen agricultural water use efficacy by decreasing evaporation, preserving soil moisture, strengthening the absorption of water and soil water retention ability, decreasing irrigation demands, obtaining deep soil moisture, strengthening drought tolerance, promoting nutrient cycling, and maximizing nutrient use efficiency. Farmers can optimize water use, minimize water waste, and improve the sustainability and productivity of their operations by integrating legume cover crops into their agricultural practices.

- **Challenges and limitations on cover crop establishment.**
    - **Environment and Agronomic constraints**

Sulas (2019) alluded to the fact that environmental and agronomic constraints are important factors in ensuring the effective growth of legume cover crops in South African grassland systems. Consequently, these constraints can have an impact on the performance, efficacy, and overall results of using legume cover crops to improve climate resilience and water use efficiency (Wooliver and Jagadamm, 2023). South Africa has a wide range of climatic conditions, ranging from semi-arid to humid. The appropriateness and efficacy of legume cover crops may differ in accordance with the climate of a region (Sulas, 2019). Several legume species may be better adapted to certain climatic conditions than others, while others may struggle to establish or thrive. According to *Bowles et al.* (2017), soil variation is another important factor that may impact the success of legume cover crops. Concurrently, *Bowles et al.* (2017) further reported that soil texture, organic matter content, pH levels, and nutrient availability can all have an impact on legume growth and productivity. In addition, some legume species might do better with soil types, whereas others might find it difficult to adapt to or prosper in specific soil conditions (Abdalla *et al.,* 2019). A sufficient supply of water is critical for legume cover crop development and growth. Insufficient rainfall can limit legume establishment and productivity in areas with limited water resources or during droughts (Hofer et al., 2016). Therefore, understanding the water demands of various legume species, as well as their ability to withstand drought conditions, is critical for optimizing water use efficiency. A study by Justes *et al.* (2019) revealed that Legume cover crops are vulnerable to pests and diseases, which can reduce their efficiency and effectiveness. It was revealed that Nematodes, aphids, fungal infections, and viral diseases are prevalent diseases and pests in South African grassland systems, and they can affect legume growth, biomass production, and nitrogen-fixing abilities. Therefore, to mitigate potential losses, appropriate pest and disease management strategies must be implemented (Justes *et al.*, 2019). Likewise, in grassland ecosystems, leguminous cover crops must coexist with indigenous grasses and other vegetation. Therefore, in order to guarantee the efficacy and ecological sustainability of legume cover cropping, the competitiveness of legumes with existing grasses must be balanced (Justes *et al.,* 2012). As a result, careful legume species selection, planting densities, and management practices can all help to reduce concurrence and encourage mutually beneficial relationships. In addition, proper management practices are required for the effective implementation of legume cover crops. To maximize the efficiency and efficacy of legume cover crops, factors such as establishing timing, seedbed preparation, nutrient management, and weed control must be considered (Wallace *et al.,* 2017). The process of adoption and execution of appropriate management practices can be hampered by a lack of knowledge, technical skills, and resources. To maximize the benefits of legume cover crops in South African grassland systems, it is critical to comprehend and address these environmental and agronomic constraints. Combating these obstacles by means of research, extension services, and policy support may encourage feasible agricultural practices that strengthen climate resilience, water use efficiency, and overall resilience and productivity of South African agricultural systems.

- **Socio-economic consideration**

Research conducted by Mthembu *et al.* (2018) revealed that socioeconomic factors influence the acceptance and effective introduction of legume cover crops in South African grassland systems. It

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further alluded to the fact that these factors include a variety of social, economic, and cultural factors that can impact the acknowledgement, practicality, and flexibility of legume cover cropping practices. Also, comprehending and dealing with these socioeconomic considerations is critical for promoting the widespread utilization of legume cover crops and realizing their potential benefits (Mthembu *et al.,* 2018). Furthermore, farmers can comprehend the benefits, techniques, and management practices related to legume cover crops if they have access to information, training programs, and extension services. Raising consciousness can help people make more informed decisions and foster positive attitudes towards acceptance. For instance, farmers must evaluate the economic viability of implementing legume cover crops (Bergtold *et al.,* 2019). Also, recognizing possible expenses and benefits, such as the effect on crop yields, input costs, and profitability, can influence farmers' decisions to use legume cover crops (Craheix *et al.,* 2016). Furthermore, incentives from the government, such as subsidies, grants, or tax breaks, can help farmers embrace these practices even more. Adoption and implementation of legume cover crops can be influenced by the affordability and accessibility of necessary inputs such as quality seeds, fertilizers, and equipment. It is critical to ensure consistent and cost-effective access to these inputs, especially among small-scale farmers, to overcome possible obstacles and limitations. The practicability, and versatility of legume cover cropping can be influenced by land tenure arrangements and farm size (Parr *et al.,* 2020). Providing land for legume cover crops may be difficult for small-scale farmers with a limited amount of land. Combating land tenure issues, encouraging land consolidation, and investigating alternative land-use provisions can all help encourage the incorporation of legume cover crops into a variety of farming systems (Fischer *et al.,* 2021). Understanding prospective markets and developing suitable value chains for legume cover crops can help them become more economically viable. Increasing demand for legume cover crops through market incentives, the development of manufacturing and distribution infrastructure, and the promotion of value-added products can provide extra sources of revenue and make these practices more appealing to farmers (Fonjong and Gyapong, 2021). On the other hand, traditional farming practices, beliefs, and social norms, among other things, can influence the implementation of new agricultural practices (Fonjong and Gyapong, 2021). Recognizing and appreciating local knowledge and cultural practices can aid in the incorporation of legume cover crops into existing agricultural systems while upholding socio-cultural values and practices. Gender and social equity considerations are critical for encouraging broad and equitable legume cover crop adoption (Kerr *et al.,* 2022). Therefore, recognizing women's roles and contributions in agriculture, maintaining their availability of resources and decision-making processes, and addressing social inequalities can all help to ensure the effective execution and long-term success of legume cover cropping practices. Managing these socioeconomic concerns can encourage the adoption and long-term use of legume cover crops in South African grassland systems, is crucial improving the livestock productivity and address food insecurity. A comprehensive frameworks, interventions, and legislative efforts of relevant stakeholders, involving farmers, researchers, policymakers, and development organizations, is required for creating context-specific strategies that align with local socioeconomic dynamics, and improve farmer livelihoods while contributing to agricultural system resilience and sustainability.

- **Research gaps and future research directions**

Although the role of legume cover crops in improving climate resilience and water utilization effectiveness in South African grassland systems has shown promise, there are numerous research gaps and areas for further investigation. Combating these gaps will allow us to gain an improved comprehension of legume cover crops and optimize their use in agricultural practices. Long-term research is needed to determine the long-term impact of legume cover crops on climate adaptability and water use efficiency in South African grassland systems. Tracking the effects of legume cover crops over various growing seasons may offer knowledge about their long-term advantages and potential limitations. More research is needed to assess the efficiency of various legume species and cultivars in South African grassland systems. Recognizing the versatility, biomass production, nitrogen fixation rates, and overall efficacy of different legume species can help farmers choose the best options for specific situations. It is critical to investigate the relationships between legume cover

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crops and indigenous grasses found in South African grasslands. Recognizing how legume cover crops fit into existing grassland ecosystems, their impact on native species, and their possibility for increased biodiversity is critical for long-term success. To assess the extent to which water is preserved and effectively utilized, the water use efficiency of legume cover crops in South African grassland systems must be quantified. Water savings should be measured, optimal planting densities determined, and the impact of legume cover crops on water availability for subsequent crops evaluated. It is of the utmost importance to investigate the resilience of legume cover crops to extreme climate events such as droughts, heat waves, and heavy rainfall. Recognizing how legume cover crops behave during and recover from these events can shed light on their potential for climate-smart agriculture and their ability to minimize climate-related risks. The socioeconomic factors that influence the adoption of legume cover crops in South African grassland systems should be investigated. Evaluating the economic viability, farmer opinions, and possible obstacles to adoption can help guide the development of effective extension services, policies, and rewards to encourage widespread adoption. It is essential for carrying out studies to assess the possibility and adaptability of legume cover crops on larger agricultural landscapes. Considering the consequences at the regional level may offer perspectives on the wider advantages and possible obstacles associated with introducing legume cover crops throughout South Africa's various agro-ecological zones. Integrating legume cover crops with other feasible agricultural practices like conservation agriculture, precision irrigation, and agroforestry can provide holistic solutions to improving climate adaptation and water effectiveness in grassland systems. By focusing on these research deficiencies and seeking these future research directions, we can improve our comprehension of the role of legume cover crops in South African grassland systems. The resulting information can be used to educate evidence-based decision-making, policy development, and practical recommendations for farmers and stakeholders in South Africa, which will eventually contribute to enhanced climate resilience, water use efficiency, and feasible agricultural practices.

6. Conclusion

Legume cover crops are critical for improving climate resilience and water use efficiency in South African grasslands. These crops provide advantages such as nitrogen fixation, soil health improvement, and soil moisture retention. Additionally, there nevertheless exist environmental and agronomic constraints that must be addressed. Some of the challenges include soil conditions, climate variability, pests, diseases, weed competition, limited land accessibility, and combining existing practices. To overcome these constraints, tailored strategies are required, such as suitable oversight practices, pest and weed control measures, and enhanced availability of resources and knowledge. Despite these limitations, the possible benefits of legume cover crops are substantial. More research will be required to fill knowledge gaps and enhance comprehension of the socioeconomic factors that influence acceptance. By dealing with these gaps and limitations, legume cover crops can be successfully combined, thereby promoting agricultural sustainability, climate resilience, and water resource management in South African grassland systems.

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References

Abdalla, M., Hastings, A., Cheng, K., Yue, Q., Chadwick, D., Espenberg, M., Truu, J., Rees, R.M. and Smith, P., 2019. A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. *Global change biology*, *25*(8), pp.2530-2543.

Ahmad, H.T., Hussain, A., Aimen, A., Jamshaid, M.U., Ditta, A., Asghar, H.N. and Zahir, Z.A., 2021. Improving resilience against drought stress among crop plants through inoculation of plant growth-promoting rhizobacteria. *Harsh environment and plant resilience: molecular and functional aspects*, pp.387-408.

Aguilera, E., Diaz-Gaona, C., Garcia-Laureano, R., Reyes-Palomo, C., Guzmán, G.I., Ortolani, L., Sanchez-Rodriguez, M. and Rodriguez-Estevez, V., 2020. Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. *Agricultural Systems*, *181*, p.102809.

Altieri, M.A., Nicholls, C.I., Henao, A. and Lana, M.A., 2015. Agroecology and the design of climate change-resilient farming systems. Agronomy for sustainable development, 35(3), pp.869-890.

Angers, D.A. and Carter, M.R., 2020. Aggregation and organic matter storage in cool, humid agricultural soils. In *Structure and organic matter storage in agricultural soils* (pp. 193-211). CRC Press.

Balasundram, S.K., Shamshiri, R.R., Sridhara, S. and Rizan, N., 2023. The Role of Digital Agriculture in Mitigating Climate Change and Ensuring Food Security: An Overview. *Sustainability*, *15*(6), p.5325.

Blanco-Canqui, H., Shaver, T.M., Lindquist, J.L., Shapiro, C.A., Elmore, R.W., Francis, C.A. and Hergert, G.W., 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. *Agronomy journal*, *107*(6), pp.2449-2474.

Bergtold, J.S., Ramsey, S., Maddy, L. and Williams, J.R., 2019. A review of economic considerations for cover crops as a conservation practice. *Renewable Agriculture and Food Systems*, *34*(1), pp.62-76.

Bergstrom, D.M., Guerin, G.R., Sparrow, B., Joseph, L. and Hill, S.J., 2019. Impacts of recent climate change on terrestrial flora and fauna: Some emerging Australian examples. Austral

Bwambale, E., Abagale, F.K. and Anornu, G.K., 2022. Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. Agricultural Water Management, 260, p.107324.

Bowles, T.M., Jackson, L.E., Loeher, M. and Cavagnaro, T.R., 2017. Ecological intensification and arbuscular mycorrhizas: a meta-analysis of tillage and cover crop effects. *Journal of Applied Ecology*, *54*(6), pp.1785-1793.

Craheix, D., Angevin, F., Doré, T. and De Tourdonnet, S., 2016. Using a multicriteria assessment model to evaluate the sustainability of conservation agriculture at the cropping system level in France. *European Journal of Agronomy*, *76*, pp.75-86.

Carbonell-Bojollo, R.M., Friedrich, T. and Derpsch, R., 2021. Global Spread of Conservation Agriculture for Enhancing Soil Organic Matter, Soil. *Soil Organic Matter and Feeding the Future: Environmental and Agronomic Impacts*, *4*, pp.91-126.

Chartzoulakis, K. and Bertaki, M., 2015. Sustainable water management in agriculture under climate change. *Agriculture and Agricultural Science Procedia*, *4*, pp.88-98.

Chai, Q., Gan, Y., Zhao, C., Xu, H.L., Waskom, R.M., Niu, Y. and Siddique, K.H., 2016. Regulated deficit irrigation for crop production under drought stress. A review. *Agronomy for sustainable development*, *36*, pp.1-21.

Chen, B., Han, M.Y., Peng, K., Zhou, S.L., Shao, L., Wu, X.F., Wei, W.D., Liu, S.Y., Li, Z., Li, J.S. and Chen, G.Q., 2018. Global land-water nexus: Agricultural land and freshwater use embodied in worldwide supply chains. Science of the Total Environment, 613, pp.931-943.

Cortignani, R., Dell'Unto, D. and Dono, G., 2021. Paths of adaptation to climate change in major Italian agricultural areas: Effectiveness and limits in supporting the profitability of farms. *Agricultural Water Management*, *244*, p.106433

Datta, D., Ghosh, S., Saha, R. and Nath, C.P., 2022. Cover Crops: Potential and Prospects in Conservation Agriculture. In *Conservation Agriculture and Climate Change* (pp. 167-187). CRC Press.

Daryanto, S., Fu, B., Wang, L., Jacinthe, P.A. and Zhao, W., 2018. Quantitative synthesis on the ecosystem services of cover crops. *Earth-Science Reviews*, *185*, pp.357-373.

Delgado, J.A., Mosquera, V.H.B., Alwang, J.R., Villacis-Aveiga, A., Ayala, Y.E.C., Neer, D., Monar, C. and López, L.O.E., 2021. Potential use of cover crops for soil and water conservation, nutrient management, and climate change adaptation across the tropics. *Advances in Agronomy*, *165*, pp.175-247.

Dunn, L., Lequerica, M., Reid, C.R. and Latty, T., 2020. Dual ecosystem services of syrphid flies (Diptera: Syrphidae): pollinators and biological control agents. *Pest management science*, *76*(6), pp.1973-1979.

Fischer, G., Darkwah, A., Kamoto, J., Kampanje-Phiri, J., Grabowski, P. and Djenontin, I., 2021. Sustainable agricultural intensification and gender-biased land tenure systems: An exploration and conceptualization of interactions. *International Journal of Agricultural Sustainability*, *19*(5-6), pp.403-422.

Enright, N.J., Fontaine, J.B., Bowman, D.M., Bradstock, R.A. and Williams, R.J., 2015. Interval squeeze: altered fire regimes and demographic responses interact to threaten woody species persistence as climate changes. Frontiers in Ecology and the Environment, 13(5), pp.265-272.

Farooq, M., Hussain, M., Ul-Allah, S. and Siddique, K.H., 2019. Physiological and agronomic approaches for improving water-use efficiency in crop plants. *Agricultural Water Management*, *219*, pp.95-108.

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Fonjong, L.N. and Gyapong, A.Y., 2021. Plantations, women, and food security in Africa: Interrogating the investment pathway towards zero hunger in Cameroon and Ghana. *World Development*, *138*, p.105293.

Guhathakurta, P., Sreejith, O.P. and Menon, P.A., 2011. Impact of climate change on extreme rainfall events and flood risk in India. *Journal of earth system science*, *120*, pp.359-373.

Halofsky, J.E., Peterson, D.L. and Harvey, B.J., 2020. Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology*, *16*(1), pp.1-26

Hoffmann, A.A., Rymer, P.D., Byrne, M., Ruthrof, K.X., Whinam, J., McGeoch, M., Joyce, C.B., Simpson, M. and Casanova, M., 2016. Future wet grasslands: ecological implications of climate change. *Ecosystem Health and Sustainability*, *2*(9), p.e01240.

Ecology, *44*(1), pp.3-27

Li, D., Zuo, Q. and Zhang, Z., 2022. A new assessment method of sustainable water resources utilization considering fairness-efficiency-security: A case study of 31 provinces and cities in China. *Sustainable Cities and Society*, *81*, p.103839.

Lipińska, H., 2020. Legume cover crops as one of the elements of strategic weed management and soil quality improvement. A review. Agriculture, 10(9), p.394.

Kang, S., Hao, X., Du, T., Tong, L., Su, X., Lu, H., Li, X., Huo, Z., Li, S. and Ding, R., 2017. Improving agricultural water productivity to ensure food security in China under changing environment: From research to practice. *Agricultural Water Management*, *179*, pp.5-17

Kleber, M., Bourg, I.C., Coward, E.K., Hansel, C.M., Myneni, S.C. and Nunan, N., 2021. Dynamic interactions at the mineral–organic matter interface. *Nature Reviews Earth & Environment*, *2*(6), pp.402-421

Mahmud, K., Makaju, S., Ibrahim, R. and Missaoui, A., 2020. Current progress in nitrogen fixing plants and microbiome research. *Plants*, *9*(1), p.97.

Mancosu, N., Snyder, R.L., Kyriakakis, G. and Spano, D., 2015. Water scarcity and future challenges for food production. *Water*, *7*(3), pp.975-992.

Muluneh, M.G., 2021. Impact of climate change on biodiversity and food security: a global perspective—a review article. *Agriculture & Food Security*, *10*(1), pp.1-25.

Mthembu, B.E., Everson, T.M. and Everson, C.S., 2018. Intercropping maize (Zea mays L.) with lablab (Lablab purpureus L.) for sustainable fodder production and quality in smallholder rural farming systems in South Africa. *Agroecology and Sustainable Food Systems*, *42*(4), pp.362-382.

Walters, S.A. and Stoelzle Midden, K., 2018. Sustainability of urban agriculture: Vegetable production on green roofs. *Agriculture*, *8*(11), p.168.

Yurtseven, I. and Randhir, T.O., 2020. Multivariate assessment of spatial and temporal variations in irrigation water quality in Lake Uluabat watershed of Turkey. *Environmental Monitoring and Assessment*, *192*, pp.1-29

Navarro-Pedreño, J., Almendro-Candel, M.B. and Zorpas, A.A., 2021. The increase of soil organic matter reduces global warming, myth or reality?. *Sci*, *3*(1), p.18.

Nikolaou, G., Neocleous, D., Christou, A., Kitta, E. and Katsoulas, N., 2020. Implementing sustainable irrigation in water-scarce regions under the impact of climate change. *Agronomy*, *10*(8), p.1120.

Nkomo, G.V., Sedibe, M.M. and Mofokeng, M.A., 2021. Production constraints and improvement strategies of cowpea (Vigna unguiculata L. Walp.) genotypes for drought tolerance. *International Journal of Agronomy*, *2021*, pp.1-9.
Kleber, M., Bourg, I.C., Coward, E.K., Hansel, C.M., Myneni, S.C. and Nunan, N., 2021. Dynamic interactions at the mineral–organic matter interface. *Nature Reviews Earth & Environment*, *2*(6), pp.402-421
Scavo, A., Fontanazza, S., Restuccia, A., Pesce, G.R., Abbate, C. and Mauromicale, G., 2022. The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. *Agronomy for Sustainable Development*, *42*(5), p.93.

Perrone, S., Grossman, J., Liebman, A., Sooksa-nguan, T. and Gutknecht, J., 2020. Nitrogen fixation and productivity of winter annual legume cover crops in Upper Midwest organic cropping systems. *Nutrient Cycling in Agroecosystems*, *117*, pp.61-76.
Walters, S.A. and Stoelzle Midden, K., 2018. Sustainability of urban agriculture: Vegetable production on green roofs. *Agriculture*, *8*(11), p.168.

Yurtseven, I. and Randhir, T.O., 2020. Multivariate assessment of spatial and temporal variations in irrigation water quality in Lake Uluabat watershed of Turkey. *Environmental Monitoring and Assessment*, *192*, pp.1-29
Ramesh, T., Bolan, N.S., Kirkham, M.B., Wijesekara, H., Kanchikerimath, M., Rao, C.S., Sandeep, S., Rinklebe, J., Ok, Y.S., Choudhury, B.U. and Wang, H., 2019. Soil organic carbon dynamics: Impact of land use changes and management practices: A review. *Advances in agronomy*, *156*, pp.1-107.

Pathak, T.B., Maskey, M.L., Dahlberg, J.A., Kearns, F., Bali, K.M. and Zaccaria, D., 2018. Climate change trends and impacts on California agriculture: a detailed review. *Agronomy*, *8*(3), p.25.

Pellegrini, G., Ingrao, C., Camposeo, S., Tricase, C., Conto, F. and Huisingh, D., 2016. Application of water footprint to olive growing systems in the Apulia region: a comparative assessment. *Journal of Cleaner Production*, *112*, pp.2407-2418.

Singh, R. and Singh, G.S., 2017. Traditional agriculture: a climate-smart approach for sustainable food production. *Energy, Ecology and Environment*, *2*, pp.296-316.

Umesha, S., Manukumar, H.M. and Chandrasekhar, B., 2018. Sustainable agriculture and food security. In *Biotechnology for sustainable agriculture* (pp. 67-92). Woodhead Publishing.

Rosa, L., Chiarelli, D.D., Rulli, M.C., Dell'Angelo, J. and D'Odorico, P., 2020. Global agricultural economic water scarcity. *Science Advances*, *6*(18), p.eaaz6031.

Stuart, A.M., Pame, A.R.P., Vithoonjit, D., Viriyangkura, L., Pithuncharurnlap, J., Meesang, N., Suksiri, P., Singleton, G.R. and Lampayan, R.M., 2018. The application of best management practices increases the profitability and sustainability of rice farming in the central plains of Thailand. *Field Crops Research*, *220*, pp.78-87

Rogers, M.J., Lawson, A. and Kelly, K., 2017. Forage options for dairy farms with reduced water availability in the southern murray darling basin of australia. *Sustainability*, *9*(12), p.2369.

Shi, H., Luo, G., Zheng, H., Chen, C., Bai, J., Liu, T., Ochege, F.U. and De Maeyer, P., 2020. Coupling the water-energy-food-ecology nexus into a Bayesian network for water resources analysis and management in the Syr Darya River basin. *Journal of Hydrology*, *581*, p.124387.

Pankievicz, V., Irving, T.B., Maia, L.G. and Ané, J.M., 2019. Are we there yet? The long walk towards the development of efficient symbiotic associations between nitrogen-fixing bacteria and non-leguminous crops. *BMC biology*, *17*(1), pp.1-17.

Tully, K. and Ryals, R., 2017. Nutrient cycling in agroecosystems: Balancing food and environmental objectives. *Agroecology and Sustainable Food Systems*, *41*(7), pp.761-798.

Han, N., Zhao, Q., Ao, H., Hu, H. and Wu, C., 2022. Horizontal transport of macro-and microplastics on soil surface by rainfall induced surface runoff as affected by vegetations. *Science of The Total Environment*, *831*, p.154989.

Kocira, A., Staniak, M., Tomaszewska, M., Kornas, R., Cymerman, J., Panasiewicz, K. and

Sharma, P., Singh, A., Kahlon, C.S., Brar, A.S., Grover, K.K., Dia, M. and Steiner, R.L., 2018. The role of cover crops towards sustainable soil health and agriculture—A review paper. *American Journal of Plant Sciences*, *9*(9), pp.1935-1951.

Sulas, L., 2019. The future role of forage legumes in Mediterranean-climate areas. In *Grasslands: developments opportunities perspectives* (pp. 29-54). CRC Press.

Wooliver, R. and Jagadamma, S., 2023. Response of soil organic carbon fractions to cover cropping: A meta-analysis of agroecosystems. *Agriculture, Ecosystems & Environment*, *351*, p.108497.

Hofer, D., Suter, M., Haughey, E., Finn, J.A., Hoekstra, N.J., Buchmann, N. and Lüscher, A., 2016. Yield of temperate forage grassland species is either largely resistant or resilient to experimental summer drought. *Journal of Applied Ecology*, *53*(4), pp.1023-1034.

Justes, E.E., Rechauchère, O. and Chemineau, P., 2012. *The use of cover crops to reduce nitrate leaching: Effect on the water and nitrogen balance and other ecosystem services* (Doctoral dissertation, INRA).

Wallace, J.M., Williams, A., Liebert, J.A., Ackroyd, V.J., Vann, R.A., Curran, W.S., Keene, C.L., VanGessel, M.J., Ryan, M.R. and Mirsky, S.B., 2017. Cover crop-based, organic rotational no-till corn and soybean production systems in the mid-Atlantic United States. *Agriculture*, *7*(4), p.34.

Parr, J.F., Papendick, R.I., Youngberg, I.G. and Meyer, R.E., 2020. Sustainable agriculture in

Kerr, R.B., Young, S.L., Young, C., Santoso, M.V., Magalasi, M., Entz, M., Lupafya, E., Dakishoni, L., Morrone, V., Wolfe, D. and Snapp, S.S., 2022. Farming for change: developing a participatory curriculum on agroecology, nutrition, climate change and social equity in Malawi and Tanzania. In *Critical Adult Education in Food Movements* (pp. 29-46). Cham: Springer Nature Switzerland.

Zhou, W., Li, J., Yue, T., Zhou, W., Li, J. and Yue, T., 2020. Research progress of the grassland carbon cycle and grassland degradation in China. *Remote Sensing Monitoring and Evaluation of Degraded Grassland in China: Accounting of Grassland Carbon Source and Carbon Sink*, pp.1-16. Yadav, S.S., Hegde, V.S., Habibi, A.B., Dia, M. and Verma, S., 2019. Climate change, agriculture and food security. *Yadav SS, Redden RJ, Hatfield JL, et al., DH (ed) Food security and climate change, First Edit. John Wiley & Sons Ltd.*

Zahoor, S.A., Ahmad, S., Ahmad, A., Wajid, A., Khaliq, T., Mubeen, M., Hussain, S., Din, M.S.U., Amin, A., Awais, M. and Nasim, W., 2019. Improving water use efficiency in agr Zhang, S., Wang, Y., Wang, Y., Li, Z. and Hou, Y., 2023. Spatiotemporal evolution and influencing mechanisms of ecosystem service value in the Tarim River Basin, Northwest China. *Remote Sensing*, *15*(3), p.591.