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Integrating Land Use Planning with Regenerative Agriculture: A Synergistic Approach to Enhance Sustainable Agricultural Productivity and Ecosystem Resilience

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Abstract. *Land-use planning and regenerative agriculture are increasingly recognised as complementary strategies for addressing declining soil quality, land degradation, and the need for more resilient food systems. The present study investigates the manner in which the integration of regenerative practices within land-use planning frameworks contributes to sustainable agricultural productivity and ecosystem stability. A bibliometric analysis of 70 publications from 2015–2025 using VOSviewer has identified key thematic clusters, including climate–resilience, sustainable productivity, spatial governance, green infrastructure, and environmental monitoring. The findings show that regenerative practices, such as no-till systems, cover cropping, diversified rotations, and agroforestry, support soil restoration, carbon accumulation, and water retention. Land-use planning provides the spatial, institutional, and regulatory mechanisms needed to align these practices with land suitability, environmental carrying capacity, and regional planning objectives. Evidence from marginal lands (S2 and S3) highlights the effectiveness of regenerative methods in enhancing productivity when integrated with suitability assessments and long-term planning. A case study of Brazil's Carbon Farming Initiative demonstrates how coordinated land-use policies, spatial data, and public–private partnerships can scale regenerative systems and reduce greenhouse gas emissions. The analysis further shows that this integration supports multiple Sustainable Development Goals, particularly those related to food security, clean water, climate action, and terrestrial ecosystem conservation. Key barriers, including policy fragmentation, limited farmer adoption, and technological constraints, are addressed through recommendations involving financial incentives, farmer training, geospatial monitoring, and precision agriculture tools. The study provides a comprehensive understanding of how land-use planning can operationalise regenerative agricultural strategies to enhance landscape resilience, improve resource efficiency, and strengthen long-term sustainability across agricultural regions.*

Keywords: *climate-smart agriculture; ecosystem resilience; policy integration; SGDs; sustainable productivity.*

Type of the Paper: Review Article.

1. Introduction

Rising global demand for food, coupled with mounting environmental pressures, requires a fundamental shift in the way agricultural landscapes are managed. Conventional agricultural practices, characterised by intensive land use, monocultures, and heavy dependence on external inputs, have accelerated soil degradation, biodiversity loss, water contamination, and greenhouse

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gas emissions [1]. These environmental consequences highlight the necessity for novel approaches that address productivity, ecological integrity, and climate resilience simultaneously [2]. Land-use planning has emerged as a strategic framework capable of guiding agricultural development toward sustainability by optimising spatial resource allocation, reducing ecological risks, and ensuring that land utilisation aligns with its biophysical capacity.

Regenerative agriculture is a proposed ecological pathway to reverse environmental degradation by restoring soil health, enhancing biodiversity, and strengthening natural nutrient and water cycles. In contradistinction to conventional intensification, regenerative agriculture practices position soil health as the foundation of sustainable food production [3], employing natural processes to increase soil organic matter, improve infiltration, and sequester atmospheric carbon [4]. The transition toward regenerative systems becomes significantly more effective when supported by robust land-use planning. The integration of regenerative agriculture into spatial planning frameworks ensures that land allocations, zoning regulations, and landscape-level interventions are aligned with ecological suitability, environmental carrying capacity, and long-term productivity objectives. In this manner, land-use planning fulfils a dual role as both a regulatory mechanism and a strategic enabler, determining the locations and methods through which regenerative agriculture can achieve optimal ecological and agronomic benefits.

The current scholarship on regenerative agriculture and sustainable land management has a tendency to treat these domains separately. Agronomic research focuses on soil and crop processes, while planning studies concentrate on zoning, spatial optimisation, and environmental protection. This separation creates a conceptual and empirical gap with regard to the manner in which land-use planning can systematically encourage the adoption and scaling of regenerative agricultural practices. The present review attempts to address this gap through a combined bibliometric and systematic analysis, which also is the review's novel contribution. It provides an integrated understanding of how land-use planning frameworks can operationalise regenerative agriculture to enhance sustainable agricultural productivity and strengthen ecosystem resilience. By connecting planning principles with regenerative farming strategies, the review contributes updated conceptual insights and identifies evidence-based pathways for embedding regenerative practices within land-use planning across multiple spatial scales.

2. Materials and Methods

The present study applied a systematic literature review combined with bibliometric analysis to examine global research dynamics concerning land-use planning, regenerative agriculture, ecosystem resilience, and sustainable agricultural development. The bibliographic data were exclusively retrieved from the Scopus database, which is acknowledged for its comprehensive coverage of peer-reviewed publications across environmental science, agricultural systems, and spatial planning. The search strategy employed the core terms 'land-use planning', 'ecosystem resilience', and 'sustainable agriculture', and was restricted to journal articles and review papers published between 2015 and 2025 and written in English.

The initial search yielded 84 documents, which were subsequently subjected to a screening process based on titles, abstracts, and keywords. This process resulted in a refined dataset of 70 publications that aligned with the conceptual focus of regenerative agricultural transitions and integrated land management approaches. These records were exported in RIS and CSV formats and curated using Mendeley Reference Manager. This curation process entailed verifying metadata consistency, removing duplicates, and standardising author and journal names. The inclusion of refined and validated data ensured the reliability of subsequent bibliometric computations.

Bibliometric mapping and network visualisation were conducted using VOSviewer, version 1.6.20. This software enables the construction of co-authorship networks, co-citation structures, and keyword co-occurrence clusters. This facilitates the identification of dominant themes, which, in the present study, were sustainable land management, nature-based solutions, green infrastructure, land-use change, and resilience-oriented agricultural practices. These dominant themes were indicated by keyword link strengths and cluster formations (e.g., agriculture, ecosystem services, resilience, sustainable development). The additional link data supported the identification of thematic interconnections across concepts such as resilience, climate change, nature-based solutions, and sustainable land management.

The key bibliometric indicators that were assessed included publication volume, citation patterns, thematic density, and author collaboration. This assessment was conducted to uncover the knowledge structures and emergent research frontiers. Integrating systematic review with bibliometric analysis enabled a comprehensive evaluation of how land-use planning and regenerative agricultural strategies interact to enhance ecosystem resilience and promote sustainable agricultural productivity at global and regional scales.

3. Results and Discussion

3.1.Scientific Publication Distribution by Year

The distribution of scientific publications from 2015 to 2025 shows a clear and structured progression of research endeavours concerning the integration of land-use planning with regenerative agriculture (Fig. 1). The earlier years (2015–2017) display a limited number of publications, indicating that scholarly attention to the linkage between spatial planning, ecological restoration, and sustainable farming systems was in its infancy. In this phase, studies were chiefly concerned with fundamental aspects, such as land-use change, biodiversity protection, and preliminary approaches to climate-responsive agricultural strategies.

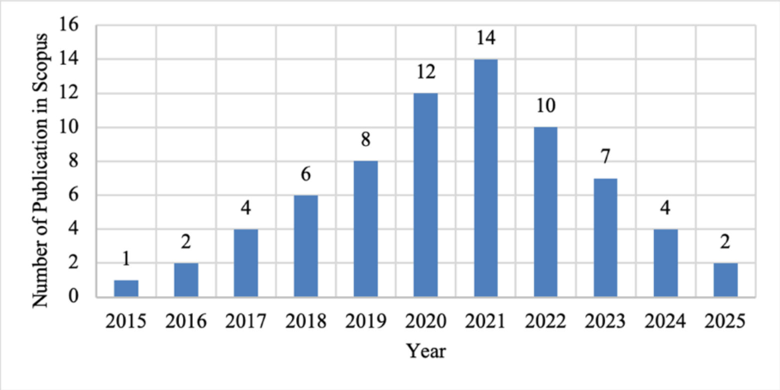

Fig. 1. Scientific publication distribution by year

A significant increase in publication output was observed between 2018 and 2021, with the highest concentration of publications appearing in 2020 and 2021. This increase corresponds to heightened global concern regarding climate change and the strengthening of international commitments to environmental sustainability, including the Sustainable Development Goals (SDGs). During this period, the themes of ecosystem services, green infrastructure, resilience, and nature-based solutions had been recurrent themes. This suggests that research began to adopt more integrated perspectives. Scholars increasingly recognised that regenerative agriculture, when coupled with coherent land-use planning, can restore soil function, enhance carbon storage, and reinforce the stability of agroecosystems under climatic stress.

Following 2021, there was a decline in the number of publications, yet the content of these publications reflected deeper and more specialised inquiry rather than diminished interest. Research articles published between 2022 and 2025 predominantly emphasise interdisciplinary methods, incorporating geospatial analysis, remote sensing, and landscape modelling to assess regenerative farming within broader land-management frameworks. The articles published during the period also highlight the importance of aligning agricultural practices with spatial planning policies to improve productivity, promote ecological resilience, and support long-term sustainability objectives.

The distribution pattern demonstrated an expanding and increasingly sophisticated body of knowledge. The gradual rise and refinement of research themes affirm the scientific significance of integrating land-use planning with regenerative agriculture as a strategy for enhancing sustainable agricultural productivity and strengthening ecosystem resilience in the face of accelerating climate pressures. This pattern emphasises the relevance and necessity of the present study within the global discourse on sustainable landscape transitions.

3.2. Scientific Publication Distribution by Country

The distribution of scientific publications by country reflects the breadth of global engagement in research linking land-use planning with regenerative agriculture and ecosystem resilience (Table 1). The United States was the leading contributor, supported by strong institutional capacity and extensive research programmes focused on sustainable land management, ecosystem services, and regenerative farming innovations. The scientific community of this country has produced influential work connecting spatial planning frameworks with agricultural resilience strategies.

Table 1. Scientific publication distribution by country

No.	Country	Number of Publications	Percentage (%)	Notes
1	USA	12	17.1	Strong contributions to regenerative agriculture, ecosystem services, and climate resilience
2	China	11	15.7	High output on land-use change, spatial planning, and sustainable land management
3	India	10	14.3	Active in promoting sustainable agriculture and developing climate-resilient farming systems
4	UK	7	10.0	Focus on green infrastructure, nature-based solutions, and planning policy
5	Australia	6	8.6	Leading research on landscape resilience, rangeland management, and biodiversity
6	Indonesia	5	7.1	Rising output with regard to landscape governance and climate-resilient agriculture
7	Germany	5	7.1	Contributions to ecosystem modelling and land-use policy
8	Netherlands	4	5.7	Strong research foundation in the area of integrated land-use systems and agroecological design
9	Canada	4	5.7	Greater emphasis on climate adaptation and sustainable resource planning
10	Japan	3	4.3	Studies on the integration of agricultural sustainability and spatial planning

China followed closely, driven by rapid environmental transformation, land-use pressures, and national priorities related to food security and climate adaptation. Research conducted in China frequently integrates spatial modelling, land-use optimisation, and sustainable agricultural intensification, constituting an important contribution to the body of knowledge on landscape-level agricultural transitions. The significant number of publications from India reflects the country's pressing climatic vulnerabilities and the need for resilient agricultural practices. These publications often highlight the use of agroecological approaches, soil rehabilitation, and community-based land management systems.

The United Kingdom and Australia have contributed extensively to research in the domain of nature-based solutions, green infrastructure, and ecological restoration in agricultural landscapes. Their research has provided conceptual and policy-oriented insights into how spatial planning instruments can support regenerative practices. Meanwhile, the scientific landscape has been enriched by contributions from Indonesia, Germany, the Netherlands, Canada, and Japan. Indonesia’s increasing publication output aligns with its national interest in promoting climate-smart agriculture and land governance reforms. Germany and the Netherlands have contributed advanced ecosystem modelling and integrative land-use policy frameworks, while Canada and Japan have offered perspectives on sustainable resource planning and rural landscape resilience.

This distribution shows that research on integrating land-use planning with regenerative agriculture has been conducted across multiple regions and scientific traditions. The presence of contributions from both developed and developing countries has enriched the field by capturing a broad range of ecological conditions, socio-economic contexts, and governance structures. Such diversity contributes to the scientific depth of the topic and reinforces the relevance of studying the potential of coordinated land-use strategies and regenerative agricultural practices to improve sustainable agricultural productivity and fortify ecosystem resilience across different environmental settings.

3.3. Thematic Groups Identified

The thematic structure presented in Table 2 reflects the intellectual organisation of research related to the integration of land-use planning and regenerative agriculture over the period 2015–2025. The thematic group with the highest ranking, 'Climate Resilience and Ecosystem Stability', demonstrated the highest occurrences and total link strength, indicating its centrality within the scientific discourse. The prominence of keywords associated with climate change, resilience, and ecosystem functioning suggests that scholarly attention has been strongly directed toward understanding how regenerative agricultural practices can restore ecological stability and enhance adaptive capacity in landscapes facing accelerating climate pressures.

Table 2. Thematic Groups Identified Through VOSviewer Keyword Analysis (2015–2025)

Rank	Thematic Group	Occurrences	Total Link Strength
1	Climate–Resilience and Ecosystem Stability	33	42
2	Sustainable Agriculture and Food Systems	27	36
3	Landscape Governance and Spatial Planning	24	34
4	Nature-Based and Green Infrastructure Approaches	21	30
5	Environmental Monitoring and Analytical Tools	13	18

The thematic group with the second-highest ranking, 'Sustainable Agriculture and Food Systems', also exhibited substantial keyword frequency and connectivity. This highlights a consistent research focus on agricultural productivity, soil health, and food security. The strong linkages within this group imply that regenerative agriculture has been increasingly viewed not only as an ecological intervention but also as a viable pathway for maintaining yield stability and supporting long-term agricultural performance. This theme has been shown to span both ecological and agronomic dimensions, reinforcing the relevance of integrated land-use strategies for the sustenance of productive farming systems.

The thematic group, 'Landscape Governance and Spatial Planning', which was ranked third, encompassed keywords related to land-use change, spatial management, and planning frameworks. These keywords are indicative of the importance of effective governance mechanisms and spatial planning instruments for enabling regenerative agricultural transitions. This finding aligns with the study's central argument that regenerative practices achieve greater impact when embedded within coherent land-use planning policies that regulate land allocation, ecological zoning, and development pressures.

The thematic group ranked fourth, 'Nature-Based and Green Infrastructure Approaches', reflects the growing adoption of ecological engineering and restoration-based solutions within landscape management. The presence of nature-based solutions and green infrastructure concepts shows the increasing incorporation of regenerative agriculture within broader sustainability agendas, aimed at developing multifunctional and climate-resilient landscapes. Finally, the thematic group 'Environmental Monitoring and Analytical Tools' was ranked fifth, illustrating the supporting role of remote sensing, spatial analytics, and monitoring technologies. These tools provide essential empirical evidence for evaluating land-use dynamics, assessing ecological outcomes, and guiding planning decisions. The thematic groups illustrate a well-connected research landscape in which land-use planning and regenerative agriculture converge to enhance sustainable agricultural productivity and strengthen ecosystem resilience across diverse agroecological settings.

3.4. Clustering Analysis

The cluster classification presented in Table 3 outlines the conceptual architecture of the scientific literature connecting land-use planning and regenerative agriculture (Fig. 2). The first cluster, centred on climate resilience and ecosystem stability, reveals the dominant focus on understanding the responses of agricultural landscapes to climatic pressures. Keywords such as 'resilience', 'climate change', and 'ecosystem services' reflect a robust research orientation toward ecological restoration, adaptive capacity, and long-term stability. This cluster of publications highlights that regenerative agriculture is positioned as a nature-based mechanism capable of enhancing landscape resilience through soil improvement, biodiversity enhancement, and carbon retention.

The second cluster, with focus on agricultural productivity and food systems, aligns with the operational dimension of sustainable agriculture. The presence of terms such as 'agriculture', 'sustainable agriculture', and 'food security' signifies that research in this cluster has examined the practical outcomes of regenerative practices, including yield performance, soil fertility, and the stability of food production systems. This cluster has situated regenerative agriculture within broader food-system challenges and underscores the importance of integrating planning frameworks to support sustainable productivity.

Table 3. Cluster Classification, Representative Keywords, and Thematic Interpretation

Cluster	Representative Keywords	Thematic Interpretation	Contribution to the Study
Cluster 1: Climate Resilience and Ecosystem Stability	Resilience, climate change, biodiversity, ecosystem services, sustainable development goals	Focusing on ecological stability, climate-risk reduction, biodiversity maintenance, and long-term ecosystem functioning	Explaining how regenerative agriculture contributes to climate adaptation and ecosystem resilience through soil restoration and ecological diversification
Cluster 2: Agricultural Productivity and Food Systems	agriculture, food security, sustainable agriculture	Highlighting sustainable food production, crop performance, soil fertility, and agricultural sustainability pathways	Showing how land-use planning can support regenerative practices to ensure stable yields and enhance food security
Cluster 3: Nature-Based and Green Infrastructure Solutions	Green infrastructure, nature-based solutions, sustainable land management	Emphasising landscape restoration, ecological engineering, and nature-based approaches to land stewardship	Strengthening the arguments on the integration of regenerative agriculture into broader ecosystem management frameworks
Cluster 4: Spatial Dynamics and Land-Use Change	Land use change, urbanization, remote sensing	Addressing landscape modification, spatial expansion, monitoring technologies, and land-use transformation	Demonstrating the importance of spatial tools for aligning land-use planning with regenerative agricultural strategies
Cluster 5: Integrated Planning and Environmental Policy	Ecosystem services, sustainable development, governance-related terms (implied)	Focusing on policy integration, landscape multifunctionality, and the governance dimension of sustainability	Showing how policy and planning coherence determine the success of regenerative agriculture at landscape scale

The third cluster, 'Nature-Based and Green Infrastructure Solutions', reflects the increasing integration of ecological engineering and landscape restoration into agricultural planning. Keywords such as 'green infrastructure' and 'nature-based solutions' signify a shift toward multifunctional landscapes. In these landscapes, regenerative agriculture acts as a part of a more extensive ecological infrastructure, which contributes to flood regulation, habitat enhancement, and improved ecosystem connectivity. The fourth cluster, 'Spatial Dynamics and Land-Use Change', highlighted the spatial and analytical dimensions of the field. The terms associated with land use change, urbanization, and remote sensing demonstrate the importance of spatial diagnostics and mapping tools in assessing land-use patterns and informing planning decisions. This cluster of publications illustrates how geospatial analysis supports the alignment of regenerative interventions with broader land-use strategies.

The final cluster, 'Integrated Planning and Environmental Policy', underscores the governance perspective. By connecting ecosystem services with planning and policy frameworks, this cluster emphasises the necessity of coherent regulatory frameworks and cross-sectoral coordination to scale regenerative agricultural practices. These clusters reveal a research landscape where ecological, agronomic, spatial, and policy dimensions intersect, reinforcing the need for integrated land-use planning to maximise the benefits of regenerative agriculture for sustainable productivity and ecosystem resilience.

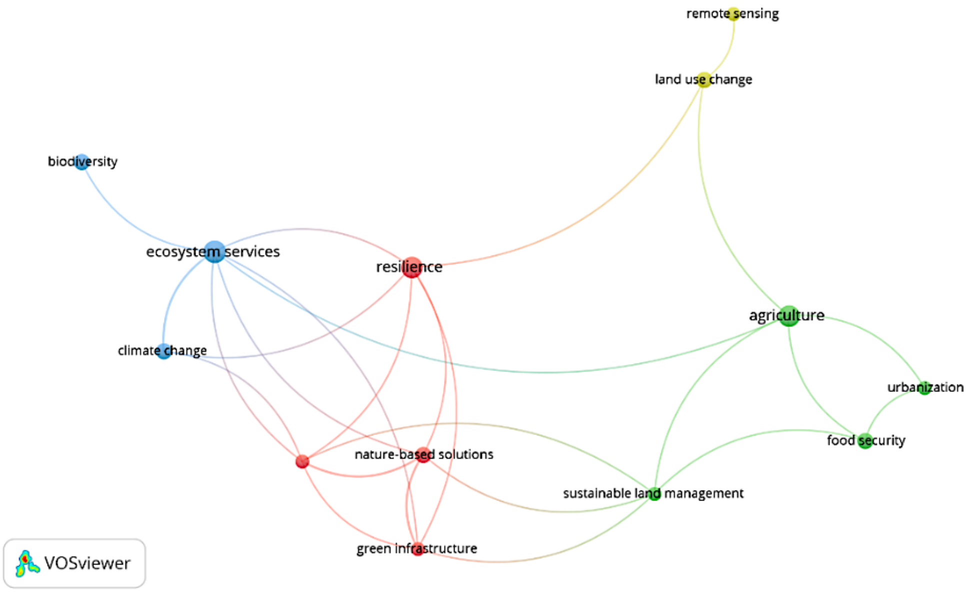

Fig. 2. VOSviewer keyword mapping

3.5. Marginal Land Management in Climate-Resilient Regenerative Systems

Marginal lands classified as S2 (moderately suitable) and S3 (less suitable) present both biophysical limitations and strategic opportunities for climate-resilient agriculture [5]. The limitations of the lands arise from the restrictive soil properties, which include the texture, structure, drainage, and effective depth of the soil. Additionally, chemical imbalances, such as an unfavourable pH, nutrient depletion, salinity, and the presence of toxic elements, contributes to the limitations. Climatic stresses, such as irregular rainfall, extreme temperatures, and prolonged drought, also play a role in the limitations.

In light of the findings pertaining to the climate resilience thematic group, these lands are highly sensitive to degradation but concurrently, highly responsive to improved management. Regenerative agriculture is a viable pathway to transform S2 and S3 land into productive and resilient systems. This transformation can be achieved by rebuilding soil structure, increasing organic matter, enhancing water-holding capacity, and improving nutrient cycling. Practices such as no-till, cover cropping, diversified rotations, livestock integration, and organic amendments address multiple constraints simultaneously, reducing environmental risk while increasing yield stability. In the present study, marginal land management becomes a strategic entry point to demonstrate how regenerative systems can convert vulnerability into resilience and contribute to sustainable intensification rather than land abandonment.

3.6. Principles of Land Use Planning and Sustainable Agricultural Landscapes

Land use planning has emerged as a core theme in the clusters related to landscape governance and spatial planning. Effective planning is not confined to spatial allocation; rather, it integrates environmental, social, and economic dimensions to support long-term agricultural sustainability [6–8]. The principles of efficiency, sustainability, land suitability, and environmental carrying capacity offer a normative framework for guiding decisions. Land use efficiency focuses on the maximisation of output per unit area, while minimising resource inputs and waste [7,8]. Sustainability requires the management of land in a manner that fulfils current needs without compromising future possibilities [9]. Land capability and suitability assessments are assessments of the biophysical potential of land, the purpose of which is to ensure that specific agricultural activities are sited where they can perform well without causing irreversible degradation [10–12]. The concept of environmental carrying capacity adds a threshold perspective, reminding planners that land can only support a finite level of intensity before ecological functions undergo decline. Within the present study, these principles support the argument that regenerative agriculture should be guided by systematic land evaluation, rather than being an arbitrary process. Aligning regenerative practices with land suitability, carrying capacity, and spatial zoning is imperative to ensure that any enhancement in productivity is not at the expense of ecosystem integrity and biodiversity conservation.

3.7. Effect of Land Management on Agricultural Productivity

The thematic group on sustainable agriculture and productivity is reflected in the multi-dimensional influence of land management on soil fertility, water availability, farmland accessibility, and input use efficiency. Soil fertility is directly influenced by the decisions made regarding land management. Conservation practices such as no-till, cover crops, and crop rotation enhance soil aggregation, organic matter content, and nutrient retention, while reducing erosion and compaction. In contrast, monoculture and intensive tillage deplete organic matter, weaken soil structure, and reduce yields. Regenerative agriculture, with its emphasis on ecological intensification, is particularly relevant for tropical and subtropical regions where soil degradation is pervasive [13].

Water availability is equally critical. Strategic land use planning that promotes rainwater harvesting, water storage infrastructure, and efficient irrigation can substantially improve water supply in rainfall-limited areas. At the field scale, the implementation of regenerative practices enhances infiltration and water retention, reduces runoff, and improves water quality. Evidence from semi-arid systems indicates that supplemental irrigation, mulching, and improved soil management increase yields and nitrogen use efficiency while reducing water stress [14,15]. The accessibility of farmland links land use planning to the social and economic dimensions of productivity. The accessibility of inputs, markets, and services for farmers is determined by transport infrastructure, rural roads, and clear land tenure arrangements. A well-planned zoning scheme that protects agricultural land from uncontrolled urban encroachment fosters efficient farm operations, timely harvesting, and reduced transaction costs [16,17].

Input use efficiency is linked to both environmental and economic performance. Land use planning that encourages precision agriculture, resource optimisation, and integrated farming systems helps reduce waste and environmental impacts. The 4R nutrient management principle (Right Source, Right Rate, Right Time, Right Place) and advanced monitoring technologies improve fertiliser and water use efficiency, lowering external input dependency while maintaining or increasing yields [18–20]. The collective manifestation of these four dimensions illustrates the manner in which land management decisions translate into tangible changes in productivity and resource-use efficiency, as conceptually summarised in Fig. 3.

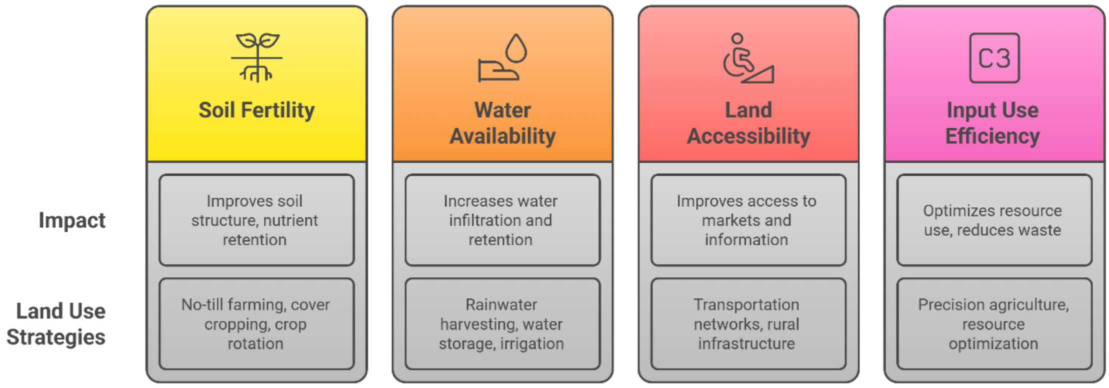

Fig. 3. Effect of land management on agricultural productivity (Source: primary data)

3.8. Interconnection of Land Use Planning, Ecosystem Resilience, and Productivity

The thematic group on climate resilience and ecosystem stability is closely connected to the interrelationship between land use planning and agricultural productivity. Strategic land use planning influences soil quality, water regulation, microclimate, and habitat configuration, all of which shape crop performance and system resilience [21–24]. As illustrated in Fig. 4, evaluating land capability and suitability allows planners to align crops with appropriate agroecological niches, circumventing the cultivation of crops in areas susceptible to high levels of erosion or flooding. This approach facilitates the conversion of such areas into protected or low-impact uses. When combined with regenerative agricultural practices conservation tillage, diversified rotations, integrated pest management, and agroforestry planning decisions can simultaneously enhance yields, reduce land degradation, and maintain ecosystem services [7,25–27]. Land use planning fulfils a preventive function by steering development away from high-value agricultural land and limiting deforestation. This, in turn, preserves critical ecosystem functions and carbon stocks. In this manner, planning acts as a bridge between local farm-level interventions and landscape-scale resilience outcomes.

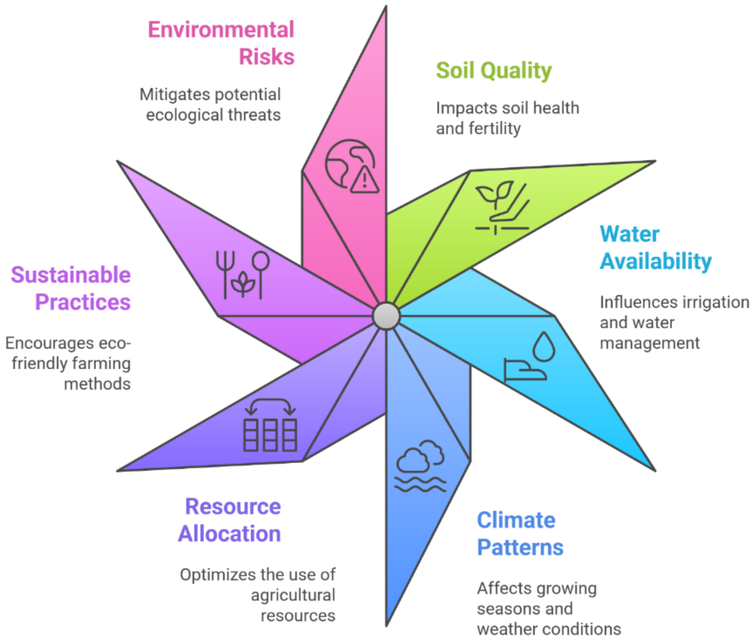

Fig. 4. Enhancing agricultural productivity through the implementation of land use planning (Source: primary data)

3.9. Addressing Land Use Challenges Through Regenerative Agriculture

The cluster on nature-based and green infrastructure approaches is closely linked to the discussion on land use challenges and regenerative agriculture. Conventional land use models have often prioritised short-term agricultural expansion and urban growth, leading to deforestation, habitat loss, soil degradation, and increased greenhouse gas emissions [28,29]. Regenerative agriculture offers an alternative land management paradigm that enhances, rather than depletes, natural capital [3,4,7,30,31]. Through the process of rebuilding soil organic matter, enhancing biodiversity, and improving water regulation, regenerative systems contribute to both mitigation and adaptation. The utilisation of these practices has the potential to reduce reliance on synthetic inputs and promote ecological harmony and can be adopted across various levels, from individual farms to entire food systems [4,7].

Regenerative agriculture is conceptually grounded in and operationally linked to other sustainable systems such as organic, integrated, conservation, and precision agriculture. Its deliberate focus on the social, cultural, community, and indigenous dimensions places it within the broader socio-ecological systems thematic group. Agroforestry, a central component in regenerative strategies, exemplifies the potential for integrating the provision of regulating and supporting ecosystem services with enhanced productivity [3,32]. Regenerative agriculture is conceptualised as a nature-based solution that addresses challenges related to land use by restoring ecosystem services while maintaining or increasing yields. This approach reinforces the central thesis of synergistic benefits between land use planning and regenerative practices.

3.10. Alignment of Regenerative Agriculture with Sustainable Development Goals (SDGs)

The integration of Sustainable Development Goals (SDGs) into agricultural studies is essential for understanding how farming systems contribute to broader global sustainability commitments. Sustainable agriculture is directly connected to the realisation of several SDGs, particularly those related to food security, access to clean water, climate action, and ecosystem conservation. As indicated by SDGs, the need for resilient and productive food systems is emphasised in SDG 2 (Zero Hunger), while the importance of reducing chemical runoff and improving water quality, challenges commonly associated with conventional farming, is highlighted in SDG 6 (Clean Water). In a similar manner, SDG 13 (Climate Action) and SDG 15 (Life on Land) underscore the critical function of soil carbon sequestration, erosion control, and biodiversity protection in ensuring the long-term agricultural viability. By aligning agricultural development with these goals, land-use planning and regenerative practices emerge as strategic instruments for promoting resource-efficient, climate-resilient, and ecologically balanced farming systems. Therefore, the incorporation of the SDG framework within the present study provides a comprehensive lens through which to evaluate how regenerative agriculture and land-use planning contribute not only to local productivity improvements but also to global sustainability targets.

The SDG-related thematic group links regenerative agriculture and land-use planning directly to global sustainability agendas by demonstrating how field-level practices contribute to multiple Sustainable Development Goals (Table 4). Practices such as soil restoration, conservation tillage, and organic amendments support SDG 15 (Life on Land) through land rehabilitation, reduced erosion, and the reversal of soil degradation, while simultaneously contributing to SDG 13 (Climate Action) via increased soil carbon sequestration and reduced greenhouse gas emissions from the land sector [2,13,33]. Agroforestry and tree-based systems further strengthen these contributions by enhancing habitat connectivity and landscape diversity. This, in turn, supports land restoration and conservation in terrestrial ecosystems. As summarised in Table 4, these interventions align with indicators such as reduced proportion of degraded land (SDG 15.3.1) and climate-related disaster preparedness and mitigation (SDG 13.1.1).

Regenerative agriculture is also pivotal to the advancement of SDG 2 (Zero Hunger), by promoting adaptive and productive food systems. Diversified crop rotations, intercropping, and integrated farming systems can increase the productivity and income of small-scale food producers while ensuring the maintenance of long-term soil fertility and water-use efficiency, in accordance with indicators on sustainable agriculture and smallholder productivity (SDG 2.3.1; SDG 2.4.1). Concurrently, the reduction of synthetic fertilisers and pesticides contributes to SDG 6 (Clean

Water and Sanitation) by limiting chemical runoff, improving surface- and groundwater quality, and supporting indicator 6.3.1 on water quality improvement.

Table 4. Integration of Regenerative Agriculture with Sustainable Development Goals (SDGs)

Planning Intervention	Supported SDGs	Related Indicators
Soil restoration and conservation tillage	SDG 15 (Life on Land); SDG 13 (Climate Action)	Reducing land degradation and erosion; increasing soil carbon stocks and ecosystem functions (e.g. SDG 15.3.1; SDG 13.2.1).
Agroforestry and tree-based systems	SDG 13 (Climate Action); SDG 15 (Terrestrial Ecosystems); SDG 2 (Zero Hunger)	Enhancing carbon sequestration, habitat connectivity, and diversified food and income sources (e.g. SDG 13.1.1; SDG 15.1.1; SDG 2.3.1).
Adaptive and diversified food systems (crop rotation, intercropping, integrated farming)	SDG 2 (Zero Hunger)	Increasing productivity and resilience of small-scale producers and expanding sustainably managed agricultural area (e.g. SDG 2.3.1; SDG 2.4.1).
Reduction of synthetic chemical inputs (fertilisers and pesticides)	SDG 6 (Clean Water and Sanitation)	Lowering nutrient and pesticide runoff, improving surface- and groundwater quality (e.g. SDG 6.3.1).

Beyond the biophysical outcomes, regenerative agriculture has important social implications. The implementation of targeted farmer training programmes, the provision of extension services, and the stablishment of participatory learning platforms advance SDG 4 (Quality Education) by strengthening capacities in sustainable land management and climate-smart farming. When these initiatives prioritise smallholder households and actively involve women, they also support SDG 1 (No Poverty) and SDG 5 (Gender Equality) by improving livelihood opportunities, enhancing access to productive resources, and increasing the decision-making roles of women in agricultural innovation [33]. Programmes such as Zero Budget Natural Farming in India and women-focused training schemes in Kenya illustrate how reduced dependence on external inputs can raise net farm income while empowering marginalised groups.

Land-use planning based on spatial data, land capability assessment, and predictive models further expands the contribution of regenerative agriculture to SDGs. Initiatives focused on carbon farming, such as those implemented in Brazil, demonstrate how a coordinated approach to land use planning, the incorporation of financial incentives, and the establishment of monitoring systems can optimise the allocation of land for carbon-negative agriculture and integrate climate objectives into national development strategies [8,13]. These practices are closely related to SDG 13 (particularly indicator 13.2.1 on integrating climate measures into policies and planning) and SDG 17 (Partnerships for the Goals), as they rely on collaboration between governments, private actors, research institutions, and local communities to design inclusive, evidence-based policy frameworks. The integration of regenerative agriculture and land-use planning offers a multi-dimensional contribution to SDGs 1, 2, 4, 5, 6, 13, 15, and 17 by linking adaptive and productive food systems, clean water, climate mitigation and adaptation, terrestrial ecosystem restoration, poverty reduction, gender equality, and multi-stakeholder partnerships within a unified land-management paradigm.

1.7. Implementation of Regenerative Agriculture

The thematic group on environmental monitoring and analytical tools is reflected in the implementation pathways for regenerative agriculture. The Carbon Farming Initiative exemplifies how land use planning can be aligned with regenerative principles by promoting crop rotations, cover crops, and diversified cropping to build soil organic carbon content, reduce emissions, and support biodiversity (Fig. 5) [13]. In order to facilitate broader adoption, not only in Brazil but in a global scale, the discussion highlights several points. In order to ensure that regenerative practices are context-appropriate, local condition assessment must integrate edaphoclimatic analysis, existing farming systems, and infrastructure mapping. The development of policy and the implementation of incentives, including sustainable agriculture policies, input subsidies, and carbon market access, should provide the necessary conditions for farmers to adopt regenerative practices.

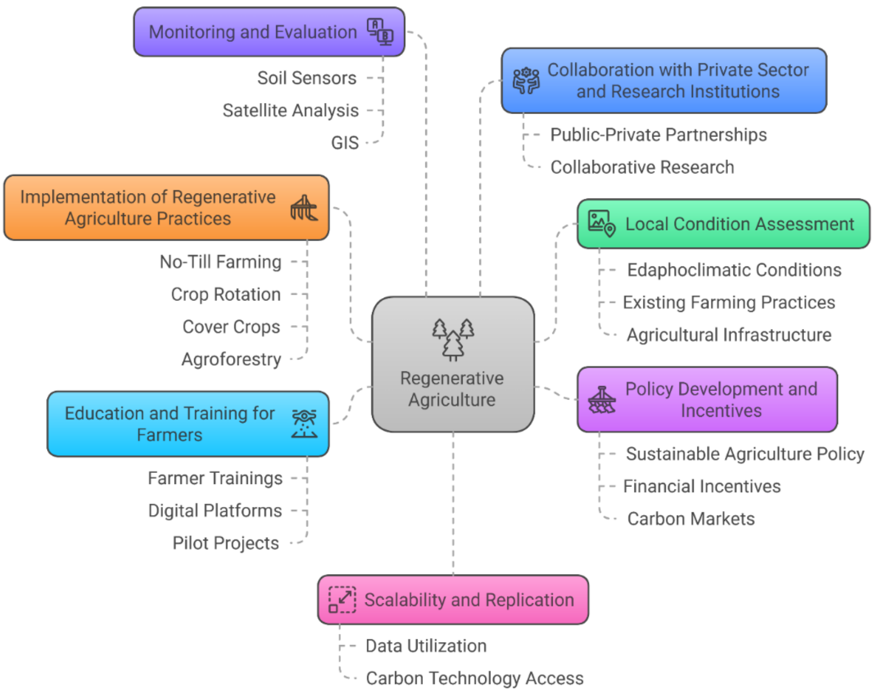

Fig. 5. Implementation of regenerative agriculture (Source: primary data)

Education and training through field schools, digital platforms, and pilot projects have been demonstrated to address knowledge gaps and demonstrate tangible benefits. Collaboration with the private sector and research institutions has the potential to support technology diffusion, data-driven modelling, and long-term monitoring of soil health, productivity, and carbon stocks. The implementation of core practices, including no-till, cover cropping, crop diversification, and agroforestry, operationalises the principles of regenerative agriculture at both farm and landscape scales. Monitoring and evaluation, which use soil sensors, remote sensing, and GIS, establish an empirical basis for adaptive management and policy refinement, while scalability strategies ensure that successful pilots expand to larger regions. In this framework, land use planning functions as the organising mechanism, which coordinates these elements, allowing regenerative agriculture to be integrated into national and regional strategies for climate mitigation, food security, and rural development [13,21–24,34]. These thematic strands show that integrating land use planning with regenerative agriculture offers a coherent and scientifically grounded pathway to enhance sustainable agricultural productivity and strengthen ecosystem resilience across marginal and productive landscapes alike.

4. Conclusions

This bibliometric review shows that strategic land-use planning is central to optimising marginal lands by integrating ecological sustainability principles, land suitability assessments, and environmental carrying capacity into agricultural decision-making. The analysis reveals strong thematic linkages between regenerative agriculture, ecosystem resilience, and spatial planning, with increasing scientific attention toward practices such as no-till systems, agroforestry, and organic amendments that improve soil health, resource-use efficiency, and long-term productivity in S2 and S3 landscapes. These findings highlight several policy implications, namely that land-use regulations should incorporate incentives for soil-restorative practices, climate-resilient planning strategies, and zoning mechanisms that prevent ecological degradation while promoting sustainable intensification. The successful implementation depends on the enhancement of institutional collaboration that aligns governmental planning frameworks with the needs of community and national sustainability goals. It is recommended that future research examine how specific land-use planning models can accelerate the adoption of regenerative farming at landscape scale. Furthermore, the long-term ecological and socio-economic benefits of embedding regenerative practices within formal planning processes should be evaluated. Finally, it is advised that the use of geospatial modelling, remote sensing, and participatory planning in evidence-based land management be expanded. These directives underscore the critical function of land-use planning in fostering sustainable agricultural productivity, while enhancing ecosystem resilience over the long term.

Abbreviations

GIS	Geographic Information Systems
SDGs	Sustainable Development Goals
SOC	Soil Organic Carbon
GHG	Greenhouse Gas

Data Availability Statement

Data will be shared upon request by the readers.

CRediT Authorship Contribution Statement

Ahmad Arif Darmawan: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – Original draft, Writing – Review & Editing, Validation. **Suntoro Suntoro**: Conceptualization, Validation, Supervision, Review & Editing. **Eni Kusumawati**: Conceptualization, Data curation, Writing – Review & Editing.

Declaration of Competing Interest

The authors of this manuscript declare no conflict of interest or competing interest.

Declaration of Use of AI in the Writing Process

Nothing to disclose

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References

[1] Qu B, Xiao Z, Upadhyay A, Luo Y. Perspectives on sustainable food production system: Characteristics and green technologies. J Agric Food Res 2024;15:100988. https://doi.org/10.1016/j.jafr.2024.100988.

[2] Shah F, Wu W. Soil and Crop Management Strategies to Ensure Higher Crop Productivity within Sustainable Environments. Sustainability 2019;11:1485. https://doi.org/10.3390/su11051485

[3] Schreefel L, de Boer IJM, Timler CJ, Groot JCJ, Zwetsloot MJ, Creamer RE, et al. How to make regenerative practices work on the farm: A modelling framework. Agric Syst 2022;198:103371. https://doi.org/10.1016/j.agsy.2022.103371

[4] Dudek M, Rosa A. Regenerative Agriculture as a Sustainable System of Food Production: Concepts, Conditions, Perceptions and Initial Implementations in Poland, Czechia and Slovakia. Sustain 2023;15. https://doi.org/10.3390/su152215721

[5] Razvanchy HAS, Fayyadh MA. GIS and AHP Based Techniques for Agricultural Land Suitability Assessment in Erbil Province, Kurdistan region, Iraq. Basrah J Agric Sci 2022;35:140–57. https://doi.org/10.37077/25200860.2022.35.1.06

[6] Bhat SA, Bashir O, Ul Haq SA, Amin T, Rafiq A, Ali M, et al. Phytoremediation of heavy metals in soil and water: An eco-friendly, sustainable and multidisciplinary approach. Chemosphere 2022;303. https://doi.org/10.1016/j.chemosphere.2022.134788

[7] Shahmohamadloo RS, Febria CM, Fraser EDG, Sibley PK. The sustainable agriculture imperative: A perspective on the need for an agrosystem approach to meet the United Nations Sustainable Development Goals by 2030. Integr Environ Assess Manag 2022;18:1199–205. https://doi.org/10.1002/ieam.4558

[8] Morales F, De VWT. Establishment of land use suitability mapping criteria using analytic hierarchy process (AHP) with practitioners and beneficiaries. Land 2021;10:1–19. https://doi.org/10.3390/land10030235

[9] Abubakar MS, Attanda ML. The concept of sustainable agriculture: Challenges and

prospects. IOP Conf Ser Mater Sci Eng 2013;53. https://doi.org/10.1088/1757-899X/53/1/012001
[10] Çakmakçı R, Salık MA, Çakmakçı S. Assessment and Principles of Environmentally Sustainable Food and Agriculture Systems. Agric 2023;13:1–27. https://doi.org/10.3390/agriculture13051073
[11] Sen TK, Chatterji S. Land Use Planning: Basics and Approaches 2018:471–88. https://doi.org/10.1007/978-3-319-78711-4_23
[12] Alrawi AK, Qasim SS. Urban Management of City Centers the Road to the Sustainable Development (Sustainable Land Use Management). IOP Conf Ser Earth Environ Sci 2022;961. https://doi.org/10.1088/1755-1315/961/1/012090
[13] Cherubin MR, Pinheiro Junior CR, Alves LA, Bayer C, Cerri CEP, Barioni LG, et al. Carbon farming initiative: A national-scale public-private partnership to promote regenerative agriculture in Brazil. Exp Agric 2024;60:1–11. https://doi.org/10.1017/S0014479724000255
[14] Bazrafkan K, Valizadeh N, Khannejad S, Kianmehr N, Bijani M, Hayati D. What drives farmers to use conservation agriculture? Application of mediated protection motivation theory. Front Psychol 2022;13:1–14. https://doi.org/10.3389/fpsyg.2022.991323
[15] Fageria NK, Baligar VC. Enhancing Nitrogen Use Efficiency in Crop Plants. Adv Agron 2005;88:97–185. https://doi.org/10.1016/S0065-2113(05)88004-6
[16] Xia Y, Liu D, Liu Y, He J, Hong X. Alternative zoning scenarios for regional sustainable land use controls in China: A knowledge-based multiobjective optimisation model. Int J Environ Res Public Health 2014;11:8839–66. https://doi.org/10.3390/ijerph110908839
[17] Diaconu LI, Covaliu-Mierlă CI, Păunescu O, Covaliu LD, Iovu H, Paraschiv G. Phytoremediation of Wastewater Containing Lead and Manganese Ions Using Algae. Biology (Basel) 2023;12. https://doi.org/10.3390/biology12060773
[18] Arriaga FJ, Guzman J, Lowery B. Conventional Agricultural Production Systems and Soil Functions. Elsevier Inc.; 2017. https://doi.org/10.1016/B978-0-12-805317-1.00005-1
[19] Darko RO, Yuan S, Hong L, Liu J, Yan H. Irrigation, a productive tool for food security – a review. Acta Agric Scand Sect B Soil Plant Sci 2016;66:191–206. https://doi.org/10.1080/09064710.2015.1093654
[20] Gawande V, Saikanth DRK, Sumithra BS, Aravind SA, Swamy GN, Chowdhury M, et al. Potential of Precision Farming Technologies for Eco-Friendly Agriculture. Int J Plant Soil Sci 2023;35:101–12. https://doi.org/10.9734/ijpss/2023/v35i193528
[21] Mufungizi AA, Musakwa W, Gumbo T. A land suitability analysis of the Vhembe District, South Africa, the case of maize and sorghum. Int Arch Photogramm Remote Sens Spat Inf Sci - ISPRS Arch 2020;43:1023–30. https://doi.org/10.5194/isprs-archives-XLIII-B3-2020-1023-2020
[22] Raza A, Shahid MA, Safdar M, Zaman M, Sabir RM, Muzammal H, et al. Impact of Land Use and Land Cover Change on Agricultural Production in District Bahawalnagar, Pakistan 2024:46. https://doi.org/10.3390/ecrs2023-16644.
[23] Zarei S, Bozorg-Haddad O, Singh VP, Loáiciga HA. Developing water, energy, and food sustainability performance indicators for agricultural systems. Sci Rep 2021;11:1–14. https://doi.org/10.1038/s41598-021-02147-9
[24] Moteva M, Marinova B. Agricultural land protection by spatial planning in Bulgaria. Geomatics Environ Eng 2020;14:89–105. https://doi.org/10.7494/geom.2020.14.3.89
[25] Nha D V. The Role of Land-Use Planning on Socioeconomic Development in Mai Chau District, Vietnam. vol. 2. Elsevier Inc.; 2017. https://doi.org/10.1016/B978-0-12-805453-6.00007-3.
[26] Nguyen GNT, Sarker T. Sustainable coffee supply chain management: a case study in Buon Me Thuot City, Daklak, Vietnam. Int J Corp Soc Responsib 2018;3:1–17. https://doi.org/10.1186/s40991-017-0024-x.
[27] Kanianska R. Agriculture and Its Impact on Land-Use, Environment, and Ecosystem

Services. Landsc Ecol - Influ L Use Anthropog Impacts Landsc Creat 2016:3–26. https://doi.org/10.5772/63719
[28] Yu J, Guo S, Wang S, Luo Y. Multi-Scenario Simulation of Land Use Change and Ecosystem Health Assessment in Chengdu Metropolitan Area Based on SD-PLUS-VORS Coupled Modeling. Sustain 2025;17. https://doi.org/10.3390/su17073202.
[29] Pareek A, Dhankher OP, Foyer CH. Mitigating the impact of climate change on plant productivity and ecosystem sustainability. J Exp Bot 2020;71:451–6. https://doi.org/10.1093/jxb/erz518.
[30] Lasco RD, Delfino RJP, Catacutan DC, Simelton ES, Wilson DM. Climate risk adaptation by smallholder farmers: The roles of trees and agroforestry. Curr Opin Environ Sustain 2014;6:83–8. https://doi.org/10.1016/j.cosust.2013.11.013.
[31] Loring PA. Regenerative food systems and the conservation of change. Agric Human Values 2022;39:701–13. https://doi.org/10.1007/s10460-021-10282-2.
[32] Elevitch CR, Mazaroli ND, Ragone D. Agroforestry standards for regenerative agriculture. Sustain 2018;10:1–21. https://doi.org/10.3390/su10093337.
[33] Mudombi-Rusinamhodzi G, Rusinamhodzi L. Food sovereignty in sub-Saharan Africa: Reality, relevance, and practicality. Front Agron 2022;4:1–7. https://doi.org/10.3389/fagro.2022.957011.
[34] Neupane J, Guo W. Agronomic basis and strategies for precision water management: A review. Agronomy 2019;9. https://doi.org/10.3390/agronomy9020087.