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Bibliometric analysis of research on land fallow in cropping systems: Measures to enhance food security and sustainability

Dolapo B. Adelabu

Department of Sustainable Food Systems and Development, Faculty of Natural and Agricultural Sciences, University of the Free State, P.O. Box 339, Bloemfontein 9300, South Africa

***Corresponding author: Dolapo B. Adelabu**

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Abstract: Fallow land practices are crucial for ensuring food security through the intersection of crop productivity, technological advancements, and sustainable environmental practices. We examined global trends and research activities related to fallow in cropping systems (FCS) by analyzing research publications from Google Scholar, Web of Science, and Scopus databases, using the bibliometric R-package, and VOS viewer software. Research hotspots were identified based on keywords and prolific research titles spanning over three decades (1990 to 2023). Key research themes in FCS-related studies include governmental policies on land use, fallow efficiency, duration, fallow management, climate change, tillage management, and farmers' perceptions of fallow land. Most FCS-related research is conducted in developed countries with established land fallow policies while developing countries are underrepresented. There is a lack of clarity and adequacy in land fallow research. The current trend is towards adopting improved fallow systems to enhance food security, climate change mitigation, and adaptation globally. This study provides a comprehensive understanding of fallow systems, serving as a scientific reference for researchers and policymakers.

Keywords: Farming practices, Food security, Land policy, Research, Soil degradation.

Abbreviations: APSIM_Agricultural Production Systems Simulator; FCS_fallow in cropping systems; GIS_Geographical Information Systems; PRISMA_Preferred Reporting Items for Systematic Reviews and Meta Analyses; TLS_Total link strength; VOS viewers_ Visualization of similarities viewers; WOS_Web of Science.

Introduction

There is growing consensus that agronomic practices harming soil health could threaten food security in the future, exacerbating the impact of climate change (Pervaiz et al., 2020). Soil degradation pose a significant threat to food security and crop productivity influenced by various factors such as land use, soil acidification, salinization, soil organic matter, soil inherent properties and biodiversity (Gomiero, 2016). Agricultural management practices often disrupt energy flows and nutrient cycles, leading to soil degradation through processes like loss of soil cover, erosion, salinification, acidification, and compaction, commonly associated with farm intensification. Continuous cropping systems characterized by reduced of the fallow periods, soil fertility management, mechanization, and crop-livestock integration, labour, capital investment, and land tenure systems (Giller et al., 2021), contribute to soil degradation. Pervaiz et al. (2020) explained that the use of agro-chemicals, machinery, tillage, and irrigation systems, in continuous cropping can lead to soil autotoxicity, altered soil biota (Chen et al., 2023b), reduced biodiversity, soil aggregation and physico-chemical properties essential for soil fertility, health, and crop yield (Haq et al., 2023). Inappropriate use of inorganic fertilizers increases the risk of soil degradation, while erosion and salinification intensification have caused farmland abandonment in many regions (Gomiero, 2016). Raising production and management costs (Giller et al., 2021). Concerns about soil degradation have prompted a focus on conserving biodiversity and promoting sustainable food production, leading to the development of sustainable farming practices and approaches by research institutions, policymakers, and farmers (Muhie, 2022).

Land fallow is a key strategy for soil restoration and conservation, enhancing cropping systems' resilience, through nutrient recycling, biodiversity management, integrated pest and disease control (Zeleke, 2017). Conventional fallow involves sacrificing one season's production for increased crop yield the next season. However, some fallow approaches might not effectively conserve soil due to low precipitation storage impacting the soil properties (Ruis et al., 2023). Additionally, Garba et al. (2022a) indicated that conventional fallows have low efficiency; the proportion of precipitation stored in the soil during fallow that is converted to plant-available water was low, and repeated fallows could be associated with decreased soil organic matter. Adekiya et al. (2021) observed that the duration of fallow is key determinant in soil fertility restoration. Further research revealed that replacing conventional fallow with cover crop fallow or intensifying crop fallow systems, or implanting short-season cropping might increase soil infiltration by enhancing soil organic content, available water, and hydraulic conductivity (Ruis et al., 2023). However, the use of cover crop has raised concerns in water-limited regions where soil water intended for the following cropping season is depleted, leading to yield reduction in subsequent crops. There have been contrasting findings on the effectiveness of fallow land in mitigating soil degradation in across regions (Oke, 2012; Qing and Hualin, 2017; Cann et al., 2020; Garba et al., 2022b). Mitigating soil degradation through the land fallow approach requires a holistic strategy that includes gathering information on the beneficial roles of land fallow in cropping systems.

Research on the role of fallow in cropping systems is limited and requires further investigative to improve soil degradation through crop management practices (fallow). Collating and sharing research findings can help enhance soil health and crop productivity. It is important to map the available scientific knowledge on fallow systems within different regions to address soil degradation at national and local levels. This study is closely aligned with sustainable development goals, as indicated by calls for papers from leading journals in sustainable cropping. To identify important research themes, patterns, activities, and research institutions for future planning, a bibliometric analysis was conducted using tools like VOS viewer and Biblioshiny in RStudio (Adelabu and Franke, 2023). This study assessed the current research on the fallow system during cropping. The objectives were to evaluate research trends, drivers, and future directions in land fallow under cropping systems. The paper provides insights for researchers, farmers, and policymakers on global research trends and themes relating to land fallow in cropping systems.

Results

Description of the publications

A total of 3822 publications on land fallow in cropping systems were identified after removing duplicates. The distribution of publications included 74.7% research articles (n = 2855), 2.0% review articles (n = 77), 18.7% book chapters (n = 716), and 4.5% conference proceedings (n = 174). The annual growth rate of publications related to land fallow in cropping systems was 5.5% from 1990 to 2023 (Table 1; Figure 1).

Research analysis of top cited and relevant FCS-related articles

Supplementary Table 1 listed the top 20 research articles relevant to fallow system studies. Research by West and Post (2002) titled "Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation" which obtained 2793 citations, analyzed 67 long-term agricultural experiments. It showed that agricultural practices like land fallow can increase soil carbon sequestration rates. Their study explained that transitioning from conventional tillage to no-tillage can peak soil carbon sequestration rates in 5 - 10 years, reaching a new equilibrium in 15-20 years. The research article by Bandick and Dick (1999) titled" Field Management Effects on Soil Enzyme Activities" has received 1762 citations. The study explores the impact of fertilizer amendments and crop rotations on soil enzyme activities. Results show that cover crops and organic fertilizer enhance enzyme activities compared to systems with reduced carbon inputs (winter fallow) and inorganic fertilizers. Enzyme activity was lowest in soil under vegetable cover crops and crop rotation in winter wheat-summer fallow trials. The third most cited article on land fallow was by Paustian et al. (1997) titled "Agricultural soils as a sink to mitigate CO_2 emissions", which received 1297 citations. They found that water is the main limiting factor for non-irrigated systems in temperate semi-arid regions. The practice of lengthy bare fallow to accumulate soil water for subsequent cropping, can be improved by increasing cropping frequency with nitrogen-fixing forage species and reducing fallow periods. Reduced fallow periods and no-till practices enhance soil carbon in warmer semi-arid environments, allowing for more water storage and water use efficiency (Supplementary table 1). The research findings by Dabney et al. (2001), titled "Using winter cover crops to improve soil and water quality," received 1050 citations. They found that grass-legume mixtures of cover crops can replace fallow periods, increase solar energy harvest, carbon flux into the soil, promote soil biota, reduce sediment production, and improve soil water quality.

Table 1. Details of the number of relevant data available on land fallow in cropping systems.

Main information	Results
Timespan	1990-2023
Research articles	2855
book chapter	716
conference paper	174
Review articles	77
Annual Growth Rate	5.5%
Average citations per doc	30.8
Keywords Plus (ID)	10014
Author's Keywords (DE)	9134
Authors	12042
Authors of single-authored docs	208
International co-authorships	30.7%

However, the cost of establishing cover crops is a limiting factor. Another interesting research article was published by Tonitto et al. (2005) titled "Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics", which received 979 citations. Their analysis revealed that non-legume cover crop management practices were not significantly different from conventional, bare fallow systems. Between 2001 and 2012, approximately 7.6 Mha of farmland were abandoned primarily in Eastern Europe, Southern Scandinavia, and Europe's mountain regions. However, recultivation efforts have also been significant, with up to 11.2 Mha reclaimed during the same period, mainly in Eastern Europe. Supplementary Table 1 listed other top relevant publications related to FCS research.

Organization collaboration network and spatial distribution of SUC publications

The co-authorship network identified 11,185 organizations conducting research on fallow within cropping systems, with the largest set of connections among 9986 organizations. The top 1,000 organizations with strong total link strengths (co-authorship linkage) were selected, including influential institutions or organizations with 45 total link strength (TLS) like Botswana International University of Science and Technology, and CAAS Beijing, China. Other notable organizations in fallow cropping system research are CABI Accra, Ghana, CABI Delémont, Switzerland, CIFOR-ICRAF Lusaka, Zambia, Crop Research Institute Prague Croatia. Department of Biological and Environmental Sciences, University of Jyväskylä, Jyväskylä, Finland (43 TLS) and Alberta Agriculture and Rural Development, Edmonton, Alberta, Canada (38 TLS). Since 2000, CSIRO Agriculture & Food, Canberra, ACT, Australia, LoOA-IRR project Luang Prabang Laos, and the International Centre for Agricultural Research in the Dry Areas and United States Department of Agriculture Soil Conservation have significantly contributed to FCS research. By 2009, research strides have increase from institutions in Africa such as the Department of Crop, Soil, and Pest Management, Federal University of Akure, Nigeria, and institutions from Europe like the Scottish Crop Research Institute, Invergowrie, Dundee Scotland, and the Faculty of Life Sciences at the University of Manchester. By 2020, was an increase in institutions focusing on this research area (Supplementary figure 1, Table 2).

Our analysis identified 149 countries actively participating in FCS-related research. The USA ranked first with 999 publications, 47253 citations, and 851 TLS. Other notable contributors included Australia (498 publications, 27392 citations, and 628 TLS), China (708 publications, 16786 citations, and 536 TLS), France (198 publications, 11525 citations, and 442 TLS), Germany (200 publications, 9072 citations, and 407 TLS), the Netherlands (153

Table 2. The topmost cited organization and their countries in FCS-related research.

No	Organization	Country	Total link strength
1	Botswana International University of Science and Technology, Palapye	Botswana	45
2	CAAS, Beijing	China	45
3	CABI, Accra	Ghana	45
4	CABI, Delémont,	Switzerland	45
5	CIFOR-ICRAF, Lusaka, Zambia	Zambia	45
6	Crop Research Institute, Prague, Croatia	Croatia	45
7	CSIRO agriculture and food, Brisbane, Queensland	Australia	35
8	Department of Biological and Environmental Sciences, University of jyväskylä, jyväskylä, Finland	Finland	43
9	Alberta Agriculture and Rural Development, Edmonton, AB, Canada	Canada	38
10	School of Environmental and Forest Sciences, University of Washington, Seattle.	USA	38
11	Aalto University School of Science, Espoo, Finland	Finland	27
12	Crop Systems and Global Change Research Unit, USD-ARS, Beltsville, MD, United States	USA	38
13	IITA, Cotonou, Benin	Benin	45
14	Department of Biology, Lund University, Lund, Sweden	Sweden	43
15	Michigan State University, east Lansing, MI, United States	USA	45
16	Nanjing Agricultural University, Nanjing, China	China	45
17	North-West University, Potchefstroom, South Africa	South Africa	45
18	University of California Davis	USA	43
19	Queensland Department of Environment & Science, Qld, Australia	Australia	38
20	Land and Water Management Department, IHE Delft Institute for Water Education, Delft, Netherlands	Netherlands	38

Table 3. Countries with high research activities on land fallow in cropping system within 1990- 2023.

No	Country	Document	Citations	Total link strength
1	United States	999	47253	851
2	Australia	498	27392	628
3	China	708	16786	536
4	France	198	11525	442
5	Germany	200	9072	407
6	Netherlands	153	8800	394
7	Kenya	154	7174	367
8	United Kingdom	182	10899	355
9	India	423	9502	316
10	Canada	176	8528	237
11	Italy	127	5049	296
12	Denmark	53	3452	105
13	Ghana	43	702	117
14	Burkina Faso	37	1060	126
15	Brazil	158	5776	143
16	Belgium	49	3062	144
17	Bangladesh	69	2648	120
18	Ethiopia	59	1351	114
19	Nigeria	86	1592	135
20	Denmark	53	3452	105

publications, 8800 citations, and 394 TLS), and Kenya (154 publications, 7174 citations, and 367 TLS) (Supplementary figure 2; Table 3). Research link strength and networking began to strengthen in 2014, with the USA, Australia, China, France, and Germany showing the strongest links. By 2020, more countries such as including China, Algeria, Ireland, Romania, Poland, Morocco were involved in studies on land fallow to improve crop productivity.

Thematic keyword used in the FCS-related research

The analysis identified 7195 keywords within the threshold of FCS research, grouped into six clusters based on research themes. The keywords with the highest number of occurrences (626 - 98) and total link strength (10988 - 2140) were selected (Figure 2).

Cluster one (red) was the largest cluster, with 394 keywords, 30-35 word occurrences, and a total link strength ranging from 200 - 280. The main themes in this cluster are related to soil fallow studies via agricultural productivity, crop improvement, farming systems (smallholder farming, profitability, environmental degradation), integrated approach, soil fertility, cropping practices, and management such as shifting cultivation, zero tillage, intercropping, and conservation tillage. In addition, responses to global food security through adaptive strategies such as cover cropping (*Tithonia diversifolia,*) fodder, crop-livestock farming, and agroforestry (*Leucaena leucocephala, Tephrosia vogelii*) were highlighted in this cluster. Major crops with high research impact in the field were cereals such as *Zea mays*, Oryza sativa, Fabaceae, *Arachis hypogaea*, brassica, and underutilized crops (*Lablab purpureus, Phaseolus vulgaris, Manihot esculenta, Hordeum vulgare, Pennisetum glaucum, Sorghum bicolor, Vigna unguiculata, Vigna radiata*). The cluster covers governmental policies, research and development, resource management, and risk assessments was also included. The prominent countries in this research theme are in Asia, North America, Australia, and Africa.

Cluster two (green) consists of 208 keywords, related to soil microbial community, species diversity, soil microbiology, colonization, biota abundance, microflora, integrated pest management, herbicides, soil health, root systems, infiltration, crop management, seedling establishment, nutrient cycling, nutrient dynamics, physical chemistry, soil restoration, plant water use, genotype-environment interactions, global change, and sustainable agriculture. Prominent crops are rapeseed and wheat (Figure 2).

Cluster three (blue) comprises 191 keywords associated with soil quality, soil aggregate stability,agricultural machinery, carbon sequestration, carbon management indices, soil biochemical compositions, cation exchange capacity, soil physical properties, bulk density, soil structure, organic amendments, soil ecosystems, water retention and infiltration, amino acids, greenhouse gas emissions, conventional tillage, and crop diversification influenced by soil conservation. Common crops include corn, cotton, crotalaria, cover crops, *Arachis hypogaea, Brassica oleracea*, *Cajanus cajan*, southern *vigna unguiculata, Sesbania seban,* and horticultural crops. Long-term experiments related to soil fertilization and management are conducted in Brazil, Argentina, the Himalayas, and India.

Cluster four (yellow): comprises 147 keywords related to FCS research focusing on land use changes, land abandonment, landforms, and farming systems. It includes themes such as crop productivity, agricultural modeling using APSIM, climate and crop modeling, algorithm, crop database management, decision support systems, digital storage, environment stress, GIS, remote sensing, satellite imagery, regression analysis, spatiotemporal analysis, groundwater, irrigation system, water conservation, water use efficiency, soil moisture, soil temperature, water consumption, rain-fed agriculture, carbon cycle, light use efficiency, agricultural modeling, summer fallow. Common crops mentioned are wheat, *Solanum tuberosum,* Alfalfa, Medicago sativa, and potatoes. Key countries studied are China, Brazil, Iowa, and Argentina, with a focus on .combating land degradation through innovative approaches.

Cluster five (purple) includes 135 keywords related to nitrogen use efficiency, nitrous oxide emissions, nitrate loss, uptake, food quality, nitrogen mineralization, nitrification, volatilization, chemical fertilizer, carbon footprint, catch crops, carbon budget, residue management, soil emission, soil pollution, soil respiration, greenhouse gas emissions, and global warming. Common crops in this cluster are include rice, spring wheat, chickpeas, *Trifolium pratense*, Brassica, *Avena sativa, Raphanus sativus, Lycopersicon esculentum, Hordeum vulgare, Lolium multiflorum, Lolium perenne, Vicia sativa, Secale cerale*, and various vegetables. The main countries in this cluster are the United Kingdom, Bangladesh, and Japan (Figure 2).

Cluster six (light blue) consists of 54 keywords related to bioenergy, drought stress, risk factor, seeding, dryland cropping, feedstocks, economic analysis, economic and social effects, energy efficiency, sustainable development, tolerance, water use efficiency, and yield components. Common cropsin this cluster are canola, camelina, wheat, pulse, chickpeas, lentils, oilseeds, *Brassica juncea, Cicer arietinum, Brassica napus, Helianthus annuus, Lens culinaris, Pisum sativum,* and *Vicia faba.* The prevailing countries in this cluster are Canada, Germany, and Pakistan

Timeline view of the keywords

The overlay visualization of keyword occurrences in fallow-related studies from 1990 to 2023 shows a shift in research focus over time. In the 1990s, there were fewer studies with no clear trend in keywords. From 2000 to 2010, research focused on GIS integration, soil acidification, mitigation, improving soil microorganisms, and erosion control in various regions (Figure 3). Around 2010, there was a surge in research on land fallow management, use of cover crops and fodder crops like *Cajanus cajan, Cicer arietinum, Zea mays, Pisum sativum, Vigna unguiculata,* and *Lens culinaris.* Post-2010, research expanded to include risk assessment in soil degradation, environmental stress, weed management (invasive species), sustainable innovations, crop modelling, big data analytics, climate modeling, biodiversity of the agroecosystem, pest control, improving soil biology via inoculation and soil biota (earthworms), and soil water management Studies from countries like Bangladesh, Italy, Australia, and China were prominent (Figure 6). Groundnut, sugarcane, and Camelina were commonly studies in fallow systems during the years.

By 2020, research keywords focused on adaptive approaches like reduced tillage, crop diversification, sustainable intensification, biological nitrogen fixation, soil nutrition, soil carbon sequestration, seedling germination, food quality, smallholder farmers' contribution, soil arthropods, microbial communities, organic farming, yield components, crop breeding with high yielding crop breeding, crop water productivity, and climate change mitigation. Post-2020, common keywords included microbiome (soil health), agrobiodiversity, soil pore size in fallow, soil sedimentation, system productivity with organic fertilizer, and integrated soil fertility management. There was a rise in research keywords related to socio-human perception, farmer attitudes on land fallow management, and simulation models for fallow management.

Based on the above-mentioned keywords, the key research themes and drivers in FCS-related research include land use change, governmental policy, cropping systems, climate change mitigation, soil carbon sequestration, tillage systems, crop diversification, integrated pest management, farmers' perceptions, sustainable intensification, conservation farming, weed management, soil biodiversity and health, and crop simulation and modeling.

Discussion

Governmental policies on land use and fallow across regions

Concerns about food security, population growth, and land use issues have led to policies and initiatives aimed at improving land use efficiency and soil restoration (Veste et al., 2024). For instance, in South Asia, land reform legislation has resulted in some landowners to keeping their lands fallow instead of leasing them to sharecroppers (Childress et al., 2022). Qing and Hualin (2017) explained that China's land fallow policy includes evaluation systems, and subsidy standards with options for compulsory or voluntary participation in fallow programs. These policies regulates land use (Niu et al., 2022), enhance environmental awareness (Johnson et al., 2016), and influence farmers' production behaviours (Zhang et al., 2023). Some countries offer subsidies for fallow farmlands, like China. In 2016, the Chinese government initiated a pilot program to explore and implement cultivated land rotation and fallow systems in areas with groundwater depletion, heavy metal contamination, and degraded ecological environments to enhance soil restoration (MARA of China, 2019). However, the effectiveness of these policies on food security remains inconclusive. Yang et al. (2019) found that the current policy of cultivated land fallow in China have not significantly reduce the pressure on cultivated land.

Similarly, in Europe until 2015, fallow land declined steadily, but the implementation of greening measures which require leaving 5% of arable land as ecological focus areas is enhancing biodiversity (Yu et al., 2022). However, incentives for fallow land have not been sufficient to make unproductive fallows appealing to farmers. In Australia, many farmers often opt for planting nitrogen-fixing and catch crops, instead of leaving the land fallow. They choose to plant break crops such as lentils, chickpeas, and canola in a rotational

Table 4. The most commonly used cover crops used in land fallow for cropping system.

Regions	Cover crops	Period of planting
Temperate	*Brassica juncea* L., *Cicer arietinum* L, *Lens culinaris*, *Pisum sativum* L, *Pisum sativum* L, *Vicia benghalensis* L., *Lotus corniculatus* L., *Avena sativa* L, Leguminous cover crops (*Gliricidia sepium* and *Acacia colei,* hairy vetch (Vicia villosa Roth*),* bigflower vetch (*Vicia grandiflora*), wooly-pod vetch (*Vicia dasycarpa*), arrowleaf clover (*Trifolium vesiculosum*), berseem clover (*Trifolium alexandrinum L.*), red clover (*Trifolium pratense L.*), sweet clover (*Melilotus officinalis*), crimson clover (*Trifolium incarnatum L.),* subterranean clover (*Trifolium subterraneum L.),* bell bean (*Vicia faba L.),* field pea (*Pisum sativum L.*), and alfalfa (*Medicago sativa L.)*	Autumn-winter
Sub-tropical	*Sorghum bicolor, Vigna unguiculata, Trifolium fragiferum, Fagopyrum esculentum, Dactylis glomerata, Ceratochloa carinata,*	Spring-summer
	Pennisetum glaucum, Tithonia diversifolia, Pennisetum purpureum) Sorghum bicolor, and *Crotalaria juncea.* Arachis spp., *Cajanus cajan,Cassia spp., Centrosema spp., Clitoria ternatea*	Spring-summer
Semi-Arid and Arid	*Medicago* spp, *Trifolium subterraneum, Secale cereale, Raphanus sativus*	All season

sequence (Dunsford et al., 2019). Australian farmers use some type of conservation farming such as minimum soil disturbance, stubble retention, and rotations with legumes (Walsh et al., 2019).The response to land fallow management varies across regions. In the dry temperate zones of the USA, tilled summer fallow is used to maintain moisture in the seed zones due to low rainfall and its variability (Wuest, 2010). In Latin America, rainfed cropping alternating with unmanaged fallow is common while, In Africa, the lack of effective policies incentivizing good land management, leads to excessive pressure on land in densely populated areas. Improved fallows are common in Southern and Eastern Africa (Partey et al., 2017) (Supplementary table 2), but scaling up is hindered by constraints such as land tenure issues and social capital deficiencies. Policymakers need to address market failures and disincentives to promote the adoption and scaling up of land fallow practices.

Land fallow in cropping systems

Traditional fallow practices like summer fallow; and bush fallow rotation, have been used for decades in cropping systems. More recent practices include improved fallow, grass/stubble fallow, cover crop fallow, and film mulching in fallow. Rotational bush fallow, shifting cultivation, or slash-and-burn farming is a traditional method used in the humid tropical regions like India, West and Central Africa to replenish nutrients in the soil before continuous cropping (Oke, 2012). Common plant species used in fallow in West Africa include *Tithonia diversifolia, Chromolaena odorata, Mucuna pruriens, Leucaena leucocephala, Gliricidia sepium* (Table 4).

Farmers in central Amazonian Peru rotate bush fallow for 2-5 years with fields of maize-cassava-Musa relay cropping of 18-30 months (Tables 3 and 4). This rotation is done to maintain a balance between cropland and fallow land. The challenge of providing sufficient soil nitrogen and phosphorus during cropping systems, particularly in sub-Saharan Africa where production inputs are not easily accessible is predominant, has not been addressed by bush-fallow rotations. As a result, farmers have turned to improved fallow practices, such as deliberate planting of leguminous species that can quickly replenish soil fertility.

Fast-growing nitrogen-fixing crops are enhancing productivity in many parts of Africa. For instance, Hall et al. (2006) discovered that soil under *Gliricidia sepium* fallow had higher levels of soil organic carbon compared to soil under traditional fallow and continuously cultivated areas. However, the soil improvement effects of trees in fallows vary depending on the crop species, duration of fallow period, tillage management, residue management, and climate. Cover crops are integrated into the fallow system to enhance the physical, chemical, and biological soil properties, and optimize nutrient use efficiency (Scavo et al., 2022). Consequently, the

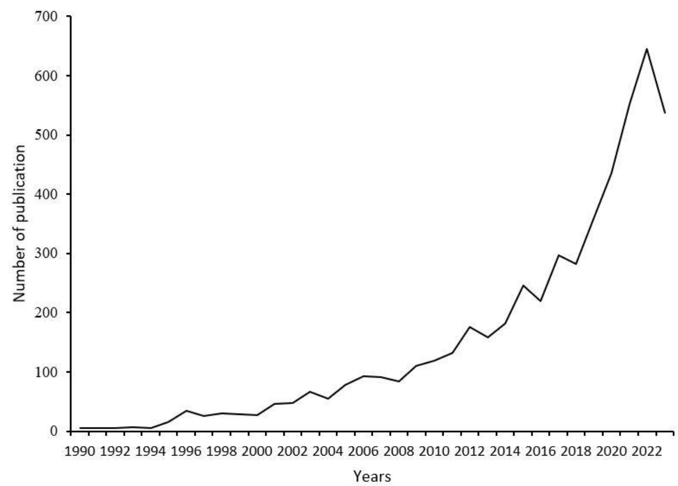

Figure 1. Number of research publication on FCS related research from 1990 to 2023.

relationships between cover crops, soil, and plant nutritional status are quite complex.

Fallow management in cropping systems

Proper management of cover crops, involves selecting the right type, species and cultivars, as well as deciding on species mixtures, termination methods, and seeding timing. Elhakeem et al. (2023) discovered that using mixed species with complementary traits, such as those that capture more nitrogen accumulate more biomass, have higher residues, and lower C: N ratios would mineralize faster. This approach is recommended to reduce nitrogen leaching in the autumn and provide mineral nitrogen in the spring. Radish (*Raphanus sativus*), vetch (*Vicia sativa*) and oats (*Avena strigosa*) are commonly used cover crops in temperate regions (Scavo et al., 2022) while *Crotalaria juncea*, *Arachis* spp., *Cajanus* are more prevalent in sub-tropical regions (Leite et al., 2021). *Medicago* spp, *Trifolium subterraneum,* and *Secale cereale* are frequently used in semi-arid climates (Jones et al., 2020). While cover crops offer many benefits to cropping systems, their impact on soil water is debated. In arid and semi-arid environments, fallow with stubble that conserves soil moisture increases the soil water requirement for crop production(Zeleke et al., 2014).

Zero-till management with stubble retention in the field can increase soil organic carbon in cropping soils compared to conventional tillage. The rotation of managed perennial grass or grass-legume mixtures (ley) with annual crops enhance soil quality, farming productivity, profitability, and sustainability. This practice is common in temperate North America, Australia, sub-tropical

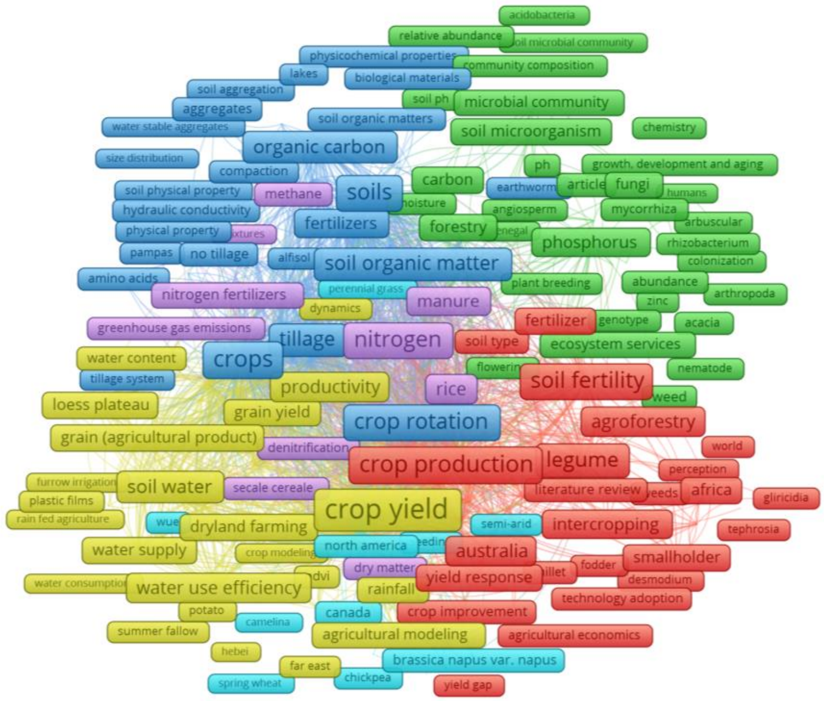

Figure 2. Predominant keywords in FCS-related research between 1990-2023.

Figure 3. The timelines for the predominants keywords in FCS related research from 1990- 2023.

South America, and Europe (Wortmann et al., 2021). Loch (1994) explained that in Queensland, stubble fallow could increase steady infiltration rates by 15-42 mm per hour causing the soil to receive low-energy rain. Similarly, a study on stubble management in fallow wheat rotation over 4 years at two sites in North-west Victoria, Australia revealed that stubble retention further increased yield compared to fields without stubble. Additionally, the combination of zero tillage with stubble retention improved water reserves in the soil profile (O'leary and Connor, 1997). Minimizing wind erosion on agricultural fields, especially in semi-arid regions is of great interest to farmers. After harvest, a low vegetation cover can be inevitable, and the amount of stubble that remains on a field depends on the crop type and land management (Vos et al., 2022).

Commonly used stubble for soil restoration and water retention includes perennial ryegrass (*Lolium perenne L.),* cocksfoot (*Dactylis glomerata L.*), phalaris (*Phalaris aquatica L.*) and tall fescue (*Lolium arundinaceum* Darbysh.). However, the effectiveness of these practices can vary depending on the cropping system, climate, and soil type, making it difficult to quantify regional carbon changes. Plastic film mulching is also commonly used in arid and semi-arid regions to increase crop yields, reducing soil exposure, minimizing evaporation, improving soil moisture, promotes early crop growth, and enhancing crop yields (Zhang et al., 2020).

Fallow duration in cropping systems

fallow areas are decreasing due to increased land use intensity or competing land uses (Aguilera et al., 2013). Long fallow periods, which renew soil fertility, and biodiversity, are being replaced with short to medium-fallow systems worldwide (Wood et al., 2017). In the Western United States, a long fallow of over 14 months is common (Nielsen and Vigil, 2018). Long fallow can reduce the risks of losing crop yield and income during drought, but its effectiveness depends on rainfall and soil conditions. Since the late 1990s, farming systems have shifted towards pulse and canola crops replacing pastures and long fallowing, in southern Australia's medium-rainfall zone (Chen et al., 2023a). Minimum tillage practices are becoming common in this region. A three-month summer fallow period is common on the Loess Plateau of China between the late June harvest and late September planting of winter wheat (Wang et al., 2011). Cultivating cover crops is a promising method for carbon sequestration as it offset mineralization, prevent carbon from escaping, reduce soil erosion, and enhance ecosystem biodiversity (Lal, 2016). It is noteworthy that continuous usage of agricultural land over decades leads to poor soil fertility affecting the profitability of the land, hence forcing farmers to leave the land fallow.

The fallow efficiency amidst changing climatic conditions.

The crop species, management practices, soil characteristics, and climatic conditions during land fallow could cause variations in soil carbon and water fluxes. Climate change alters soil respiration and management decisions like crop rotations, tillage, and fallow (Chi et al 2017). Thus, the efficiency of fallow varies with climatic and soil conditions, but its effectiveness in conserving soil water and increasing organic matter in conventional dryland cropping systems is relatively low (Adil et al 2022). As a result, semi-arid and sub-tropical dryland areas are incorporating cover crop functional traits to enhance soil organic matter and improve fallow efficiency (Garba et al., 2022b). For example, the dry region of the inland Pacific Northwest in the United States utilizes annual fallow and irrigation to ensure sufficient water for farming with 39% of cropping areas being fallowed and 16% irrigated (Chi et al., 2017). Improving soil fertility through carbon sequestration is a key strategy in mitigating climate change and is the objective of most enhanced fallow systems. Research studies have shown that proper agronomic management, can increase soil fertility, improve nutrient use efficiency, and enhance the adaptive capacity of agroecosystems in the face of a changing climate. This ultimately led to reduced yield losses (Lin, 2011; Partey et al., 2017; Lin et al., 2023). Various cropping systems incorporate fallow management into their rotation strategies, utilizing leguminous crops or other plant species, with leguminous crops fix atmospheric nitrogen into the soil, and other crop species contribute different rooting patterns and nutrient requirements to the systems. However, in areas with high atmospheric temperatures, the land may still become dry in the subsequent season due to excessive evaporation under bare and tilled soil conditions (Hatfield and Dold, 2019).

Materials and Methods

The study employed a two-phased approach; firstly, by conducting a database-based descriptive bibliometric analysis to identify all the drivers or themes of land fallow in cropping systems. The study further identifies and discusses the major themes of land fallow in the cropping systems.

Literature database-based descriptive bibliometric review

A bibliometric analysis was conducted to examine peer-reviewed articles on soil restoration and soil degradation mitigation using fallow in cropping systems. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting model and checklist were followed to ensure unbiased reporting (Moher et al., 2015). Articles were retrieved from Google Scholar, Scopus, and Web of Science (WOS) databases, focusing on publications from 1990 to 2023. Search queries targeted titles, abstracts, and keywords to exclude articles where the search terms only appeared in reference lists. The predetermined queries were derived from the Scientific Conceptual Framework for Land Degradation Neutrality, which aims to prevent overall loss of healthy and productive land (Cowie, 2020). The search queries include the following: ("fallow in cropping", OR "types of fallow", OR "cover crop fallow", OR "land use", OR "benefit of fallow", OR "cropping management system", "fallow AND food security", "fallow crops", OR" land abandonment" OR "fallow duration" OR "Bush-Fallow", OR "soil restoration", OR" soil degradation, OR "land use AND fallow" and "land fallow AND soil health",) in numerous amalgamations.

Data collection, cleaning and validation

To ensure the results were focused and traceable, only conference proceedings, original articles, review literature, and books were included, excluding other document types. The documents related to fallow land in cropping systems were labeled as "FCS". The initial search, yielded 5793 results in WOS, 1204 in Scopus, and 127 hits in Google Scholar. Relevant articles were identified by screening the titles, keywords, and abstracts in the WOS database, Scopus, and Google Scholar (Supplementary figure 3**)**. The search queries were validated by reviewing the top 50 cited documents in the FCS field and excluding irrelevant results. The data from the three databases were merged, deduplicated, and converted into bibliographic data frame using RStudio. Bibliometric analysis was performed using Biblioshiny bibliometrix package in RStudio v.3.4.1, and network visualization maps using VOS viewer software. Co-authorship, citation analysis, co-occurrence, co-citation, and bibliographic coupling were analyzed and visualized using Biblioshiny in R software.

Identifying and discussing the major driver of land fallow in the cropping system.

This study examines key trends important and drivers influencing land fallow in cropping systems across various regions, identifies research gaps, and offers recommendations for future directions.

Recommendation for future research on land fallow

The key issues and research gaps identified can be summarized as follows:

Supportive governmental policies: Effective policies that enhance the intensification of fallow management are crucial, especially among land use systems in developing countries. While plot-level research has shown promising results, governmental policies encouraging fallow practices would impact its acceptance and farmers' decisions at any level.

Farmers' decision-making: Farmers' land-use decisions, management strategies and motivations are influenced by agroecological, climatic, and political factors, leading to varying levels of willingness to implement fallow practices. There is need to developing effective ways to improve the fertility of weaker soils during their fallow period as well as classification, selection, and development of multi-species mixtures suitable for fallow in various agroecosystems.

Research networking between developed and developing institutions: Research findings indicate various fallow management strategies, but specific operational guidelines tailored to specific regions are lacking. Therefore, institutional collaboration between regions can facilitate the documentation of successful practices and create a platform for knowledge transfer and strategies that support fallow management.

Sustainability in fallow management: Research is needed to improve soil fertility in less productive soils during fallow periods. This includes identifying suitable fallow spies and vegetation for sustainable crop rotation. Current information on fallow management practices is inconsistence across regions, leading to conflicting findings on its impact on soil restoration.

Conclusion

This paper presents a bibliometric literature review, on land fallow for cropping systems, highlighting the main research themes and gaps in the field. The analysis shows a steady increase in research on land fallow since 2000, with a significant surge in studies between 2018 and 2022.

Research on land fallow in cropping systems has predominantly been conducted in developed countries such as United States, Australia, China, and France, with limited representation from developing countries. Fallow efficiency and dynamics vary based on climatic and soil conditions with higher efficiency observed in wetter regions but inconsistent ability to break disease cycles. Improved fallow systems have the potential to enhance food security, climate mitigate change, and aid in adaptation efforts globally. This study offers valuable insights into the impact of fallow systems and serves as a reference for researchers and policymakers, underscoring the importance of collaborative research on improved fallow management, climate change mitigation, soil carbon sequestration, and tillage practices during fallow periods. Effective governmental policies are crucial for the successful implementation of fallow management strategies worldwide.

Author Contributions

Conceptualization, writing the original draft, data collection, data analysis, writing review, and editing were done by D.B.

Declaration of competing interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

The datasets used for the current study are available from the corresponding author upon reasonable request.

Consent for publication.

Not applicable

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