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Systematic Review

Sustainable Nutrient Management Strategies for Enhancing Potato Production: The Role of Cover Crops—A Systematic Review

Sbonile Xaba [1,*], Zaid Bello [2,3], Monde Rapiya [4,5] and Nomali Ziphorah Ngobese [1]

[1] Unit for Environmental Sciences and Management, Faculty of Natural and Agricultural Sciences, North-West University, Potchefstroom 2530, South Africa; nomali.ngobese@nwu.ac.za
[2] Agricultural Research Council—Grain Crops Institute, Potchefstroom 2520, South Africa; belloz@arc.agric.za
[3] Centre for Global Change, University of Limpopo, Sovenga 0727, South Africa
[4] Department of Animal Science, University of Pretoria, Pretoria 0002, South Africa; u16400829@tuks.co.za
[5] Department of Agriculture and Rural Development, Agricultural Research Services, Potchefstroom 2520, South Africa
* Correspondence: amandaxaba199612@gmail.com

Abstract

The global demand for agricultural products, like potatoes, is increasing due to population growth, so we must use more sustainable farming methods. Traditional potato farming often relies too much on synthetic fertilisers, which can harm the environment and lead to inefficiencies. This study examines how different cover crops (like legumes) affect potato yields and quality, and their benefits for soil health. It also explores why farmers do not always use cover crops. This study found that using leguminous cover crops can increase potato yields by 12–38%, improve soil structure, reduce erosion and greenhouse gas emissions, and help with water retention. Cover crops also increase soil organic matter and help with nutrient cycling, making farming more sustainable. However, some farmers are hesitant to adopt cover crops because of concerns about yield risks and higher labour costs. To overcome these barriers, this study suggests educating farmers about the long-term benefits, providing financial incentives to help with the costs, and creating region-specific guidelines for using cover crops. Policymakers and agricultural organisations should encourage farming practices that focus on soil health and using resources efficiently. By addressing these challenges, we can make sustainable potato farming more common, helping ensure food security and environmental sustainability, especially with climate change.

Keywords: bibliometric analysis; rotation; food security; potato productivity; soil fertility

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1. Introduction

The global total demand for all agricultural products is predicted to increase by 1.1% per year, driven by population growth, which is expected to reach 9.7 billion by 2050 [1,2]. This increasing population underscores the need for sustainable, eco-friendly agricultural practices to meet the global food demands. Among primary food crops, potato (*Solanum tuberosum*) ranks fourth globally in importance, following rice, wheat, and maize [3]. However, the challenge of feeding a growing population is compounded by the need to balance productivity with ecological sustainability. Potatoes are usually cultivated in sandy loam soils that require substantial inputs, including mineral fertilisers, heavy soil tillage, irrigation, and short rotations with other crops [4]. Farmers often resort to the excessive use of synthetic fertilisers to improve yields and quality, a practice driven by poor soil fertility and low rainfall. However, over-fertilisation can delay crop maturity, lower yields, reduce nitrogen use efficiency (NUE), compromise crop quality, and diminish economic profitability [5,6].

According to Goulding [7], excessive fertiliser use can lead to nutrient losses, greenhouse gas emissions, and water contamination, as well as a decline in the economy since it costs farmers money. Additionally, a study by Wu [8] revealed that an implementation of nutrient management strategies can reduce greenhouse gas emissions by 19%, while also increasing crop yields. Consequently, optimising fertiliser use and adopting eco-friendly, sustainable nutrient management strategies, such as using cover crops, are essential for enhancing potato production. Using organic fertilisers, like cover crops, has become an important strategy for improving crop quality and productivity. These practices enhance soil health, improve NUE, and reduce environmental and health risks [9]. Cover crops, in particular, are essential to sustainable agriculture by reducing the need for synthetic nitrogen (N) fertilisers, promoting N fixation, and maximising the efficiency of resource utilisation [10,11]. Leguminous cover crops, such as red clover and alfalfa, with their low carbon-to-nitrogen (C:N) ratios, enhance N cycling, resulting in significant improvements in potato production [12]. For example, potato plants grown after common vetch and faba bean cover crops produced 12.7% and 15.0% higher tuber yields, respectively, compared to those grown after a winter wheat cover crop. The yield advantage of legume cover crops was most pronounced, 36–38% higher, when no N fertiliser was applied. Furthermore, the economically optimal N fertiliser rate for potatoes was reduced by 30 kg ha^{-1} when grown after legume cover crops compared to winter wheat, highlighting the efficiency of legumes in improving N availability. They improve water retention, nutrient cycling, weed suppression, erosion control, and biodiversity [13–15]. Additionally, the biomass from cover crops enriches soil carbon and N levels, providing lasting benefits to subsequent crops [16]. A study by Saliu [17] reported that cover cropping increased crop yields by an average of 14% while also improving soil organic matter and nutrient availability.

Studies on other crops, such as maize, further highlight the benefits of cover crops. Alletto [18] reported that maize grain yields were higher when cover crops were used, compared to bare soil. However, some cover crop species, particularly those terminated late, reduced soil moisture levels at the beginning of the growing season. Similarly, Quispe [19] demonstrated that corn grown in association with clover, vetch, and mulch achieved 44%, 37%, and 38% higher grain yields, respectively, compared to no cover crop. The use of clover, vetch, and vetch + oats as cover crops also increased soil organic matter and N input when their leaf biomass was incorporated into the soil. In many countries, cover crops are still not widely used, despite their advantages. Farmers often express concerns about possible yield losses and the expenses associated with implementing cover cropping systems [20]. Some larger farms have even discontinued using it, due to perceived limited benefits and the challenges of management [21]. Understanding the impacts of cover crops on agroecosystems and addressing these barriers are essential to promoting their use, particularly in potato production systems. Factors such as species selection, growth patterns matching, and termination methods significantly influence the success of cover crops in delivering environmental and agronomic benefits. Therefore, enhancing knowledge of cover crops' effects on soil health, water retention, and pest management is vital for improving the sustainability of potato farming systems.

This study aims to evaluate how different cover crop species impact potato yield and quality while exploring their role in improving soil health. This contribution builds on recent reviews that emphasise the multifaceted benefits of cover cropping, including increased soil carbon and nitrogen levels through biomass contributions and lasting improvements in crop productivity. Scholberg [22] and Van Eerd [23] noted that cover crops can significantly improve soil structure, reduce erosion, and enhance nutrient retention, collectively contributing to increased yields in subsequent crops, including potatoes. Koudahe [24] further emphasises that integrating cover crops into cropping systems can improve soil physical properties such as bulk density, structure, and water infiltration. Cover crops have also been shown to enhance soil microbial activity, abundance, and diversity, creating healthier and more resilient soil ecosystems. For example, Bilek [25] observed that cover crops can improve water-holding capacity, an important factor in maintaining soil moisture under variable climate conditions. Similarly, research by Dawadi [9] demonstrates that cover crops can reduce soilborne diseases by breaking host–pathogen cycles and promoting the growth of beneficial soil microbes.

The extent of these benefits, however, is influenced by factors such as the type of cover crop used, local environmental conditions, and the duration of cover cropping. Understanding these variables is essential to optimising the positive impacts of cover crops on soil health and agricultural productivity. Despite these advantages, many challenges persist regarding farmer perceptions and the practicalities of integrating cover crops into farming practices. Key barriers to widespread adoption involve crop rotation design, challenges in termination methods, additional costs, and uncertainties about economic returns [26–28]. Overcoming these obstacles will require targeted efforts to educate farmers about the long-term benefits of cover crops, provide sufficient government and institutional support, and refine management practices to suit diverse agricultural contexts.

Therefore, the objectives of this study are to evaluate how different cover crop species impact potato yield and quality, highlighting the benefits of this practice. Additionally, it aims to explore how cover crops improve soil health by enhancing organic matter, N availability, and overall fertility in potato farming systems. Lastly, this study seeks to identify the challenges and barriers farmers face in adopting cover crops for sustainable potato production. It also evaluates the upward trend in research publications related to potato production practices from 2003 to 2024, focusing on the increasing emphasis on sustainability and the impact of environmental factors. Additionally, a bibliometric analysis of potato research publications was conducted to assess authorship patterns, citation metrics, and the contributions of various countries to the field. Sustainable farming practices can help crops become more resilient to climate change and improve food security [29]. Agronomic practices, which use ecological methods to grow high-quality crops without harming the environment, can promote soil health, reduce climate change impacts, and boost biodiversity [30]. Sustainable agriculture is defined as farming that can continue over time without damaging the environment [31].

2. The Role of Cover Cropping System and Its Influence on NUE

In agricultural systems, cover crops play a pivotal role in enhancing soil health by reducing soil erosion, increasing soil organic matter, alleviating subsurface compaction, and suppressing weeds and pests. These benefits collectively improve N cycling, nutrient use efficiency (NUE), and overall crop yields [32–34]. Notably, integrating cover crops, particularly legumes, into potato production systems has been shown to enhance nutrient availability and efficiency without incurring additional fertiliser costs [35,36]. For example, in a four-year field study conducted in a dry sub-humid region with an average annual rainfall of 1000 mm, Gitari [37] found that potatoes with dolichos (*Lablab purpureus* L.) improved nitrogen use efficiency by 30% and phosphorus use efficiency by 21% compared to sole potato cropping. Leguminous cover crops, such as cowpea, significantly influence nutrient dynamics through biological N fixation, contributing to increased plant-available N and improved crop yields [38]. The enhanced soil N availability and yield potential associated with legume-based cover crops are critical factors influencing farmers' decisions to adopt these systems. A review by Blanco-Canqui [39] and meta-analyses by Bourgeois [40] have substantiated the yield-enhancing effects of legumes due to their positive impact on soil N dynamics. Furthermore, cover crop mixtures are increasingly recognised as a robust strategy to maximise subsequent crop productivity [41].

Plant-available N is primarily supplied to the soil through the decomposition of legume residues, including leaves and stems [42]. The rate of N release is accelerated when cover crop residues are incorporated into the soil, as opposed to being left on the soil surface, a practice particularly advantageous for short crop rotations, such as in potato cultivation [43,44]. However, the efficacy of cover crops in benefiting cropping systems is influenced by a myriad of factors. These include soil inorganic N levels, moisture variability, seasonal precipitation, temperature, growing season length, cover crop species selection, C:N ratios, biochemical composition, historical field management practices, and the method and timing of cover crop termination [45–48]. These factors underscore the complexity of optimising cover crop integration for sustainable agricultural production.

3. Cover Cropping on Soil Health/Fertility

Soil health plays a pivotal role in agricultural production, particularly in cropping systems such as potato cultivation, which presents several challenges due to intensive soil disturbance, short rotations, and minimal crop residue return. These factors contribute to a reduction in soil organic matter (SOM), which is crucial for maintaining soil fertility and structure [49]. To mitigate these challenges, cover crops, such as legumes, root crops, grains, and oil crops, offer diverse benefits for enhancing soil health, with each crop type supporting specific soil properties [50]. A study by Larkin [51] highlighted that sustainable practices such as using cover crops not only improve crop health and soil quality but also enhance long-term productivity and sustainability in potato cropping systems. The continued use of cover crops is linked to significant improvements in SOM, which is essential for promoting available N, enhancing soil fertility, and improving soil structure, all of which are vital for long-term agricultural productivity [52]. As agricultural intensification and the reliance on inorganic fertilisers deplete soil carbon reserves, the incorporation of cover crops helps restore and maintain the carbon pool, enhancing soil health and resilience. For instance, Soti [53] found that cover crops such as sunn hemp, pearl millet, lablab, and sudangrass in Texas positively impacted soil mycorrhizal density and structure, although the crop type did not influence mycorrhizal diversity. Moreover, the use of cowpea as a cover crop resulted in a 50–100% improvement in soil quality and a 34–84% increase in crop yields, further highlighting the potential of cover crops to enhance both soil health and agricultural output.

Cover crops are vital in improving soil structure and function by reducing soil compaction, enhancing water infiltration, and increasing soil organic matter. For example, fibrous roots from small grain cover crops help decrease compaction, while perennial forage crops minimise tillage [54,55]. Additionally, nitrogen-fixing legumes, such as cowpea, mung bean, black gram, and Bambara groundnut, have been traditionally used for soil fertility restoration. These legumes provide organic N to the soil and can be utilised as green manure or incorporated as living or dead mulch, thereby enhancing soil organic carbon content and supporting sustainable agricultural practices [56]. Thus, the integration of cover crops, particularly nitrogen-fixing legumes, offers a sustainable approach to improving soil fertility, enhancing soil structure, and promoting crop performance, which is essential for the long-term sustainability of agricultural systems.

Another significant environmental concern associated with potato production is the intensive use of herbicides and pesticides to manage weeds and soilborne pests. However, the integration of cover crops (CCs), such as rapeseed and ryegrass, has shown potential in reducing the reliance on chemical inputs by offering natural pest and disease suppression through bio fumigation [57,58]. Cover crops help suppress weed pressure by competing for essential resources like light, water, and nutrients, thereby significantly reducing weed growth and establishment. The biomass produced by cover crops also serves as a physical barrier, limiting weed seed contact with the soil surface and hindering germination, thereby enhancing overall weed suppression [59]. For instance, Campiglia [60] demonstrated that the use of rapeseed and ryegrass not only suppressed weed growth, resulting in less than 1% of total weed biomass, but also significantly reduced weed emergence in subsequent potato crops to 8.8 plants/m^2, compared to 25.5 plants/m^2 observed with other CCs. Moreover, leguminous cover crops like subclover and hairy vetch were able to maintain potato yields at 48.5 t/ha, comparable to yields obtained with mineral fertilisation, highlighting their contribution to enhancing soil nutrient availability.

Ryegrass also exhibited the lowest yield reduction (7.9%) under mechanical weed control, in contrast to the 23.6% yield reduction observed under mineral fertilisation, reflecting its role in maintaining soil functionality and supporting crop productivity. Similarly, Bernard [61] found that including rapeseed in crop rotations significantly reduced the incidence of various soilborne diseases, such as stem canker, black scurf, common scab, and silver scurf by 10% to 52%. Supporting these findings, Larkin [62] reported that rotating potato fields in Maine, USA, with CCs like rapeseed, ryegrass, canola, and barley reduced Rhizoctonia incidence by 15–50%. The incorporation of winter rye in the fall further reduced the incidence of both Rhizoctonia and common scab by an additional 5–20%. Conversely, the effectiveness of cover crops can vary depending on management practices. For example, a study by Jansson and Lecrone [63] found that potatoes grown after a sorghum–sudangrass cover crop planted in April or June exhibited higher wireworm larval densities and more severe feeding damage compared to potatoes following fallow. This pattern resembled wireworm infestations previously documented in cereal fields under conservation tillage [64]. Notably, when the same cover crop was planted in July, no increase in wireworm pressure was observed, underscoring the importance of appropriate planting and termination timing in cover crop management.

In addition to suppressing pests and weeds, cover crops with deep taproots play a vital role in nutrient cycling by scavenging mobile nutrients from deeper soil layers and redistributing them closer to the surface. These nutrients become more readily available to subsequent crops following the decomposition of cover crop residues. White and Weil [65] reported that the aboveground biomass of forage radish and rye, when managed for high dry matter production, can absorb substantial amounts of phosphorus (P). Over a three-year period of no-till forage radish cultivation, a moderate increase in topsoil phosphorus concentrations was observed. This enrichment was attributed to the ability of forage radish to mobilise P from the subsoil and concentrate it near the surface. Particularly high P concentrations were found in the zones surrounding decayed root channels, although the total quantity of phosphorus cycled remained relatively modest. Similarly, Eckert [66] demonstrated that rye cover crops enhanced the concentration of exchangeable potassium (K) near the soil surface by drawing it upward from deeper layers within the soil profile. These findings underscore the role of cover crops not only in improving soil health but also in enhancing nutrient availability for subsequent cash crops.

4. Role of Cover Cropping on Potato Production

Cover crops have the potential to enhance agricultural productivity by improving soil properties, increasing yields, and reducing pest and weed infestations (Table 1). However, the extent of these benefits can vary depending on factors such as cover crop species, the amount of biomass produced, and climatic conditions [56,57]. A meta-analysis by Chahal and Van Eerd [67] found that leguminous and mixed cover crops resulted in equal or higher yields compared to no cover crops, especially in low rainfall and fine-textured soils. The influence of N inputs and N cycling from cover crops on crop yields has been widely studied. Neeteson [12] demonstrated that potatoes following leguminous cover crops, which have a lower C:N ratio and a higher N cycling potential (e.g., N mineralisation), such as red clover and alfalfa, resulted in higher yields with reduced N fertiliser inputs. Sincik [42] reported that potatoes following legume cover crops produced 36% to 38% higher tuber yields compared to those following winter wheat, even when no additional N was applied.

Furthermore, Jahanzad [68] found that potatoes following leguminous cover crops such as winter pea or forage radish exhibited comparable or higher yields (10–25%) at reduced N fertilisation rates (75 or 150 kg N ha^{-1}), as compared to potatoes grown without cover crops that required 225 kg N ha^{-1} for optimal yields (26.5 Mg ha^{-1}). Additionally, Sabet [69] observed that potatoes following rapeseed and rye cover crops yielded higher tuber outputs than those following hairy vetch and fallow. Conversely, Neeteson [12] found that oats as a preceding cover crop led to lower potato yields. Dabney [70] further emphasised the benefits of cover crops in water-limited conditions, showing a 12% to 30% increase in both total and marketable potato yields when grown after sorghum–sudangrass, with the most significant improvements seen in the production of large tubers. Similar results were reported by [71] in south-central Colorado, where the inclusion of sorghum–sudangrass, with and without hay cover crops, resulted in higher marketable and tuber yields for potatoes.

Mosquera [72], in the Andean region, conducted a four-year study (2011–2014) that emphasises the advantages of cover crops, including oat + vetch, barley, faba bean, and mixed legume grass pastures. They discovered that the production of potatoes was 18% higher than the yield obtained when residues were removed, underscoring the significance of living crop residues in the field. They also discovered that the implementation of conservation agriculture, particularly the integration of cover crops such as oat + vetch, barley, faba bean, and mixed legume grass pastures, can increase crop yields by up to 25% and increase profitability by approximately 24%, all while maintaining or enhancing yield sustainability. Their methodology was based on residue conservation and reduced tillage. A study by Jahanzad [68] found that forage radish and winter pea cover crops increased potato yields by 10–25% compared to plots without cover crops, while also reducing the need for nitrogen fertiliser application and enhancing tuber mineral concentration.

Table 1. Summary of cover cropping on different climatic conditions and their management goals on potatoes.

Cover Crops	Climate Region	Soil Type	Management Goals	References
Winter rye	Humid	Sandy soil	Reduce pest diseases, increase soil organic matter, and marketable yield.	[69]
Dolichos	Dry sub-humid	Humic Nitisol	Increase NUE, ground cover, soil moisture content, and potato yield.	[37]
Vetch	Continental monsoon	Loam	Reduce black scurf, common scab, and silver scurf, increase tuber yield, and water use efficiency.	[71]
Rapeseed	Wet temperate	Loam	Reduce black scurf and increase yield.	[72]
Pearl millet + sorghum sudangrass + red clover	Dry temperate	sandy loam	Reduce root-lesion nematodes and increase marketable yield.	[73]

Table 1. *Cont.*

Cover Crops	Climate Region	Soil Type	Management Goals	References
Hairy vetch + clover + rapeseed + ryegrass	–	–	Increase total marketable yield by increasing N available for crops.	[74]
Barley, canola, and rapeseed	–	sandy loam	Suppressed weeds and increased yield.	[26]
Indian mustard	–	Bangor silt loam	Reduced powdery scab (caused by *Spongospora subterranea*) and common scab (*Streptomyces scabies*) in potato cropping systems.	[75]
Rye + forage + radish and winter pea	–	sandy loam	Enhancing potato tuber yield.	[68]

5. Cover Cropping on Economic Viability, and Climate Change Mitigation

The carbon footprint (CF) is a key metric used to measure greenhouse gas (GHG) emissions and is widely regarded as one of the most important indicators of environmental impact [76]. Changes in cropping systems and farm management practices can influence both agricultural inputs and outputs, thereby affecting the overall CF [77]. For example, Wang [78] reported that using February orchid as a cover crop lowered the carbon footprint of cotton production systems by reducing the need for nitrogen fertiliser. Cover cropping systems may decrease plant–soil GHG emissions by altering carbon and N cycling processes (Table 2). A study by Ma [76] identified the February orchid and hairy vetch mixture as the most environmentally friendly cropping system, exhibiting the lowest carbon footprint and reducing GHG emissions by 30%. This combination also improved nitrogen use efficiency (NUE) by 23%, with hairy vetch alone increasing NUE by 43% and February orchid alone by 16%. In addition, a study by Pendey [79] on the estimating economic benefits of cover cropping on carbon and nitrogen storage on organic farms found that Sunn hemp + cowpea + sudangrass increased the economic return, decreased carbon dioxide by 709, and increased the net surplus by 280 kg N/ha. In a study on potato production, Mosquera [71] found that oat–vetch cover cropping increased economic return by 24%. In addition, Roth [80] found that cereal rye + daikon radish cover crops increased N recovery by 57% and decreased N leaching by 34%, while increasing economic returns by 61%. Integrating inorganic fertilisers with cover crops provides a more balanced nutrient supply and helps reduce nitrous oxide (N_2O) emissions, offering a clear advantage over the sole dependence on chemical fertilisers [81]. Research by Mohanty [82] and Malyan [83] further highlights that combining organic manure with lower doses of urea significantly reduces N_2O emissions compared to applying the full recommended nitrogen fertiliser rate. In addition, a study by Mahama [84] found that the use of cover crops such as pigeon pea, sunn hemp, and cowpea led to a reduction in nitrous oxide emissions, particularly as nitrogen fertiliser application rates were lowered.

Table 2. Summary of cover cropping on climate change and economic viability.

Crop of Interest	Legume/Non Legume Crop	Nitrogen Recovery (%)	Net Surplus (kg/ha)	N Leaching Recovery	CO_2 Reduced (%)	Cost Production	Economic Return	References
Maize	Orchid and hairy vetch mixture	+23	197	–	−30%	–	–	[76]
	Hairy vetch only	+43	112					

Table 2. *Cont.*

Crop of Interest	Legume/Non Legume Crop	Nitrogen Recovery (%)	Net Surplus (kg/ha)	N Leaching Recovery	CO_2 Reduced (%)	Cost Production	Economic Return	References
	February orchid only	+16	182					
	Common vetch	+74%						
	Alfalfa	+103%						
–	Sunn hemp + cowpea + sudangrass	-	280%		−709%	$320–$4364	–	[85]
Maize	cereal rye + daikon radish	57%	_	34%	_	_	61%	[80]
potato	oat–vetch	_	_		_	US$0.03 and US$0.06	+24%	[71]
Rice	Winged bean	15–33%	_	_	_	_	_	[86]
	Bush bean	20–29%	_	_	_	_	_	

6. Limitations of Using Cover Crops on Potatoes

While cover crops offer numerous agronomic and environmental benefits, their integration into potato-based systems presents several challenges. When not properly managed, cover crops may compete with potatoes for essential resources such as water, nutrients, and sunlight, potentially leading to reduced yields [87,88]. Moreover, they can lower soil temperatures, which may delay potato development if the cover crops are not terminated in a timely manner. Effective termination is therefore critical, as slow residue decomposition or poor residue management can interfere with potato planting and hinder early crop growth. In regions with short growing seasons, there may be insufficient time to establish a robust cover crop between harvest and the next planting. This temporal limitation reduces the potential for biomass accumulation and nutrient recycling. Additionally, cover crops can serve as alternate hosts for pests and diseases that threaten the subsequent potato crop. For instance, some species harbour nematodes or fungal pathogens, thereby increasing the risk of infestations [89,90]. These biological risks can diminish the intended benefits of cover cropping.

Labour demands associated with cover crop practices, such as planting, termination, and occasional irrigation can further increase production costs [91]. Despite the well-documented advantages of cover crops in improving soil health, enhancing nitrogen use efficiency, and promoting yield stability, adoption remains limited. Many farmers are hesitant due to high initial costs and a lack of technical knowledge. Economic profitability is often a primary factor influencing adoption decisions, as noted by Cary and Wilkinson [92]. However, national survey data from SARE/CTIC [93] challenge the assumption that profitability is a dominant barrier. Only 16% of farmers cited the lack of clear economic benefits as a significant concern, while 40% did not view it as a challenge at all. Similarly, O'Connell [94] found that economic constraints were not perceived as major deterrents to adoption. Interestingly, a survey of 894 farmers in the western United States revealed that larger farm sizes were positively associated with cover crop use. Conversely, higher household incomes were unexpectedly linked to lower adoption rates. When asked about changes in profitability following the adoption of cover crops, only 5.7% of farmers reported a decline, while 33% experienced an increase. The remaining respondents either observed no change or lacked sufficient data to assess the impact due to the short duration of adoption [93]. Access to agricultural information and the perception that benefits outweigh barriers significantly influence farmers' willingness to adopt cover crops [95]. Nonetheless, the inconsistent effects of cover crops on subsequent crop yields remain a notable constraint. Although diverse mixtures can provide significant environmental services, their impact on crop productivity is variable. In some cases, crop rotations involving cover crops result in short-term economic losses but yield long-term agronomic and financial gains. In other instances, while nitrogen leaching is reduced, the yields of specific subsequent crops may suffer, even as others respond positively.

A study by Una [49] conducted in western Washington illustrates the environmental limitations associated with cover cropping. Although interest among farmers is high, the narrow window between potato harvest (typically September to October) and the onset of winter with its cold, saturated soils, limits the successful establishment of cover crop biomass, thereby reducing effectiveness. Furthermore, the need to rotate with specific high-value crops can restrict the choice of compatible cover species. For example, in eastern Washington, mustard cover crops are preferred in potato systems due to their biofumigant properties, which suppress soilborne pathogens [96] and parasitic nematodes [54]. This highlights the importance of selecting cover crops that align with both environmental constraints and cropping system goals. In contrast, the use of flowering brassica cover crops in western Washington is discouraged due to the risk of cross-pollination with nearby *brassica* seed production and the potential spread of seedborne diseases such as black leg (*Leptosphaeria maculans* and *L. biglobosa*) [97]. Additionally, while some cover crops may help suppress soilborne pathogens, they can unintentionally increase populations of soil-dwelling pests such as wireworms (*Agriotes* spp.), further complicating adoption decisions [98]. A better understanding of the potential risks associated with cover crops, along with appropriate management strategies, can help farmers make more informed decisions about their costs, benefits, and how to effectively integrate them into their farming systems. Although some cover crops may be less effective at controlling weeds and pests or breaking up compacted soil layers, choosing the right species can lead to significant advantages. For example, cover crops such as radish, oilseed rape, mustard, and sorghum–sudangrass have been shown to reduce root-knot nematodes in potato production systems [99]. By carefully selecting suitable cover crops, farmers can enhance soil health, manage pests effectively, and reduce the risk of competition with potato crops.

7. Review Methodology

This study gathered the scientific literature using two databases: Web of Science (WOS) and Scopus, by searching with specific keywords. The search focused on studies published in English between 2003 and 2024 (Figure 1). The articles found were saved, checked for duplicates, and a final list of 810 articles was created. These articles were screened by their titles and abstracts, then fully reviewed to ensure they were relevant. The studies included in the analysis were those exploring sustainable practices like cover cropping, green manuring, N management, and their effects on soil health in potato farming. The bibliometric analysis was performed using RStudio (v4.2.3) and Biblioshiny (v4.0) [99,100], covering a 21-year period (2003–2024) to capture the latest advancements in sustainable potato farming worldwide. Peer-reviewed sources, such as journal articles, book chapters, conference papers, and review articles, were prioritised. The search terms used were as follows: "Potato production" OR "potato yield" AND "cover crops" AND "green manure." This method was chosen to highlight recent developments, identify key researchers, and analyse global trends in sustainable potato farming.

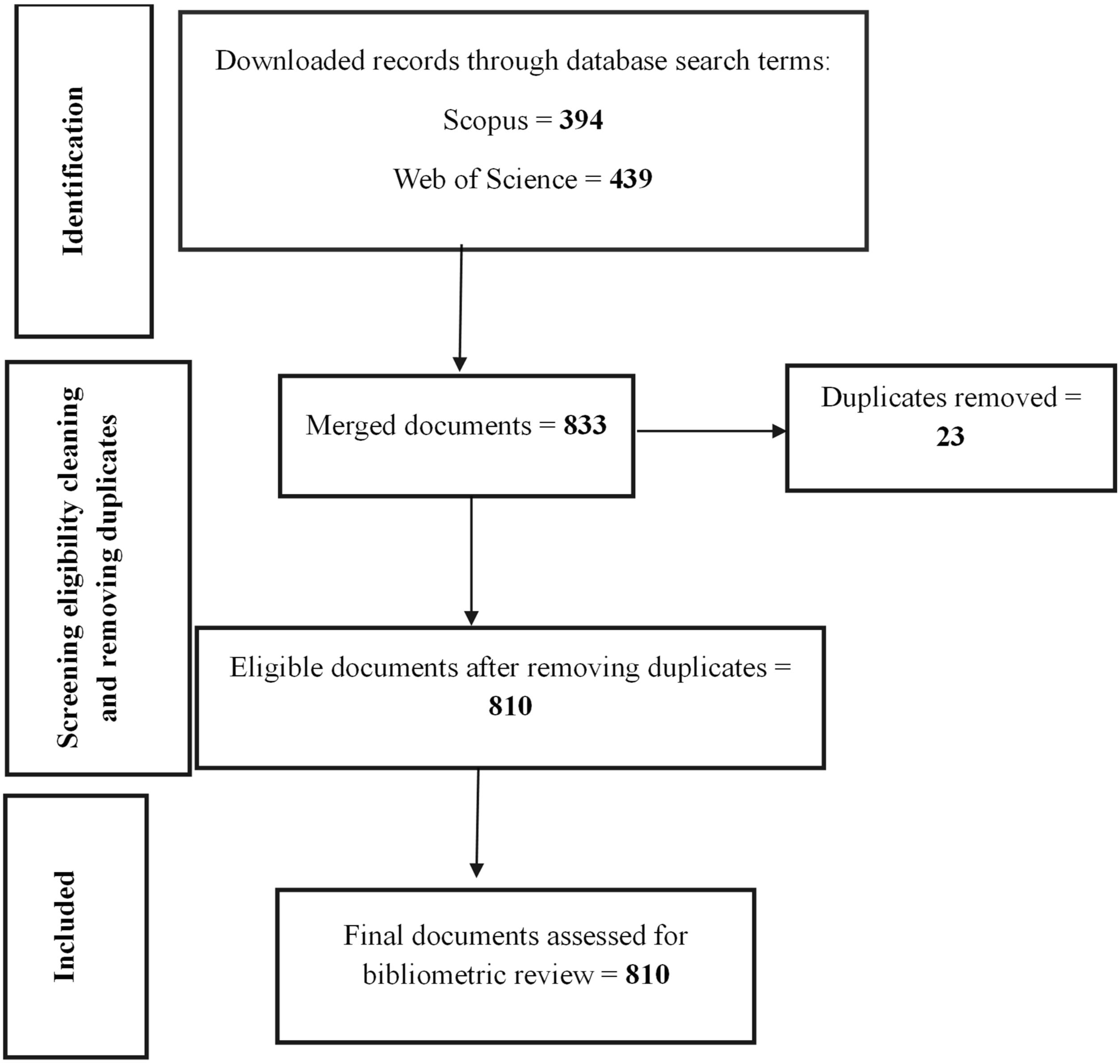

Figure 1. The PRISMA diagram for document selection criteria.

8. Results

8.1. Historical and Current Trend of Scientific Contribution per Document

This study presents a bibliometric analysis of 810 publications on potato production practices, with an annual growth rate of 11.32% (Figure 2). Data were sourced from the Web of Science and Scopus, including articles, book chapters, reviews, and conference papers. The results show a consistent upward trend in publications over time, with an exponential model (R^2 = 0.87) indicating growing interest. From 2003 to 2010, research activity was relatively low and fluctuating, followed by a steady increase between 2011 and 2016. A significant surge occurred between 2017 and 2024, peaking in 2021 and 2023. This growth likely reflects heightened global attention to sustainable agriculture, driven by environmental concerns and the need for climate-resilient farming systems. The findings underscore the scientific community's growing commitment to improving sustainable potato production, highlighting the evolving research landscape and the urgent need to address environmental challenges linked to food production and agricultural sustainability.

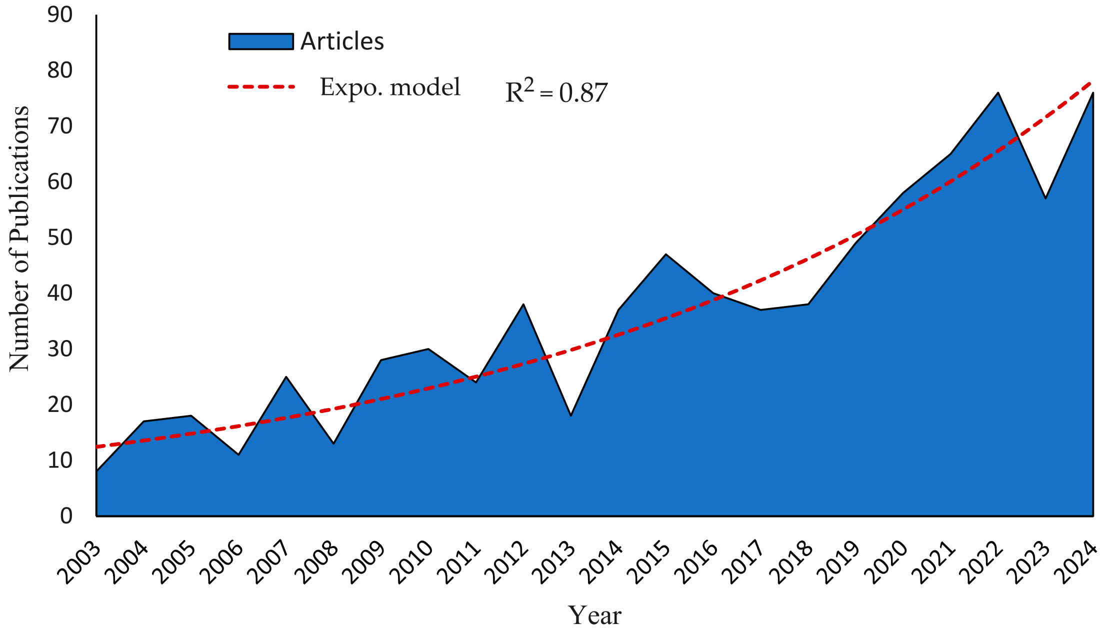

Figure 2. Annual scientific production of potato studies from 2003 to 2024; the R^2 indicates a strong correlation between the year and the number of publications.

8.2. Top Countries Contributing the Most Cited Scientific Research on Potato

Table 3 presents the leading countries in potato-related research based on single country publications (SCPs), total citations (TCs), average document citations (ADCs), and multiple country publications (MCPs). The United States tops the list with 180 SCPs (23.6%), followed by China with 71 SCPs (10.7%), reflecting their major contributions to sustainable practices like cover cropping, green manuring, and nutrient management. Developed countries such as the U.S., China, and the Netherlands show strong collaboration, as indicated by high MCPs and Figure 3. In contrast, developing countries like Kenya, Japan, and South Africa contribute modestly, with nine, nine, and ten SCPs, respectively. Citation metrics highlight research impact, with the U.S. leading in total citations (TC = 8311; ADC = 43.5), followed by China (TC = 1626), Canada (TC = 1364), and Brazil (TC = 797). These findings emphasise the dominant role of developed countries in advancing potato research and sustainable agricultural innovations.

Table 3. The most cited scientific research contributions per country, Scopus summary information, and WOS on potato application.

Country	TCP%	TC	AAC	SCP	MCP
USA	23.6	8311	43.50	180	11
China	10.7	1626	18.70	71	16
Canada	8.8	1364	19.20	66	5
Netherlands	3.6	1188	41.00	19	10
Brazil	1.7	1116	79.70	13	1
Italy	2.7	947	43.00	19	3
United Kingdom	2.5	943	47.10	17	3
France	1.6	818	62.90	12	1
Japan	1.2	593	59.30	9	1
South Africa	2	487	30.40	10	6
Germany	1.7	386	27.60	13	1
India	4.1	380	11.50	30	3
Kenya	1.9	323	21.50	9	6

Note: Total scientific production (**TCP**); Total citations (**TC**); Average article citations (**AAC**); single country publications (**SCP**); multiple country publications (**MCP**).

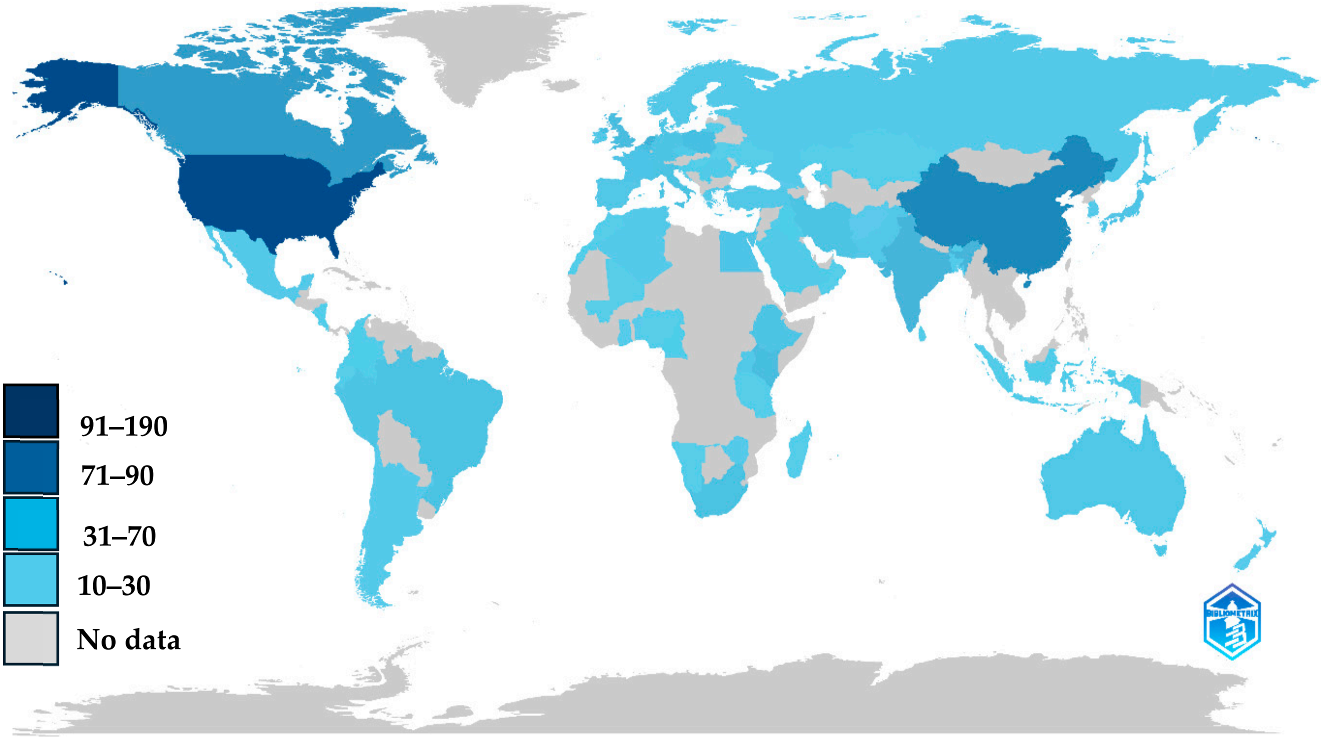

Figure 3. Spatial distribution map where potatoes were produced from 2003 to 2021.

8.3. Summary of Top Global Most Cited Published Documents

The top 10 highly cited studies on cover crops used in potato production provide valuable insights into various aspects of sustainable farming (Table 4). For instance, Jones [87] made crop modelling systems more flexible, allowing scientists to update them easily for different crops and environments. This flexibility facilitates better collaboration among experts from different fields, ultimately improving farming practices. Janvier [88] stressed the importance of soil health, noting that healthy soil supports better crop production and helps combat diseases more effectively than relying solely on chemical treatments. Furthermore, Kader [89] reviewed how mulching materials affect soil properties, water retention, and crop productivity. Their study showed that mulches can help improve water use efficiency. Similarly, Toth [90] investigated how the pathogen Dickeya spp. affects potatoes, emphasising the need for better disease management practices to protect crops. In addition, Welbaum [91] explored the role of soil microorganisms, demonstrating that managing these microbes can improve soil health and reduce the need for intensive farming techniques.

Moreover, Haverkort [92] developed a new breeding method to create disease resistant potato varieties, aiming to combat late blight, a major threat to potato crops. Meanwhile, Tahat [93] explored how farming practices, such as organic farming and different tillage methods, impact soil health and microbial diversity, which ultimately affects crop sustainability. Equally important, Castillo and Vovlas [94] studied the damage caused by *Pratylenchus* root lesion nematodes, which are harmful to many crops, including potatoes, and discussed management strategies. Lastly, Daryanto [95] examined the benefits of cover crops, which improve soil health, reduce erosion, and enhance crop productivity, while also considering trade-offs like pest management and greenhouse gas emissions. These studies collectively demonstrate that using cover crops and other sustainable practices can improve soil health, increase crop yields, and reduce environmental impacts, contributing to more resilient and sustainable agriculture.

Table 4. Top 10 globally cited published documents on sustainable potato studies from 2003 to 2024.

Rank	Author	DOI	TC	TC/Y
1	[87]	10.1016/S1161-0301(02)00107-7	3240	147.27
2	[49]	10.1016/S0065-2113(05)88004-6	972	48.60
3	[88]	10.1016/j.soilbio.2006.07.001	475	26.39
4	[89]	10.1016/j.still.2017.01.001	462	57.75
5	[90]	10.1111/j.1365-3059.2011.02427.x	323	23.07
6	[91]	10.1080/07352680490433295	297	14.14
7	[92]	10.1007/s11540-009-9136-3	281	17.56
8	[93]	10.3390/SU12124859	269	53.80
9	[94]	10.1163/ej.9789004155640.i-523	256	14.22
10	[95]	10.1016/j.earscirev.2018.06.013	244	34.86

TC = total citation; **TC** per year.

8.4. Authors' Key Words and Co-Occurrence Network

The analysis of selected authors and keyword clusters in potato studies, based on Zipf's law, is presented in clusters and nodes (Figure 4). This analysis identifies global research hotspots in areas such as cover cropping, compost, soil health, and N management by focusing on high-frequency keywords. It illustrates the connections between keywords in the literature, highlights the knowledge structure of the field, and can guide agricultural decisions by identifying emerging trends and areas for further research. Additionally, the lines between nodes indicate the strength and relationship of the clusters. Large nodes, such as *Phytophthora infestans* (potato blight) and yield, suggest that these terms are frequently used in the literature on potatoes (*Solanum tuberosum* L.). Sustainable agricultural practices like cover crops, disease-resistant cultivars, crop rotation, green manure, and compost are also common keywords.

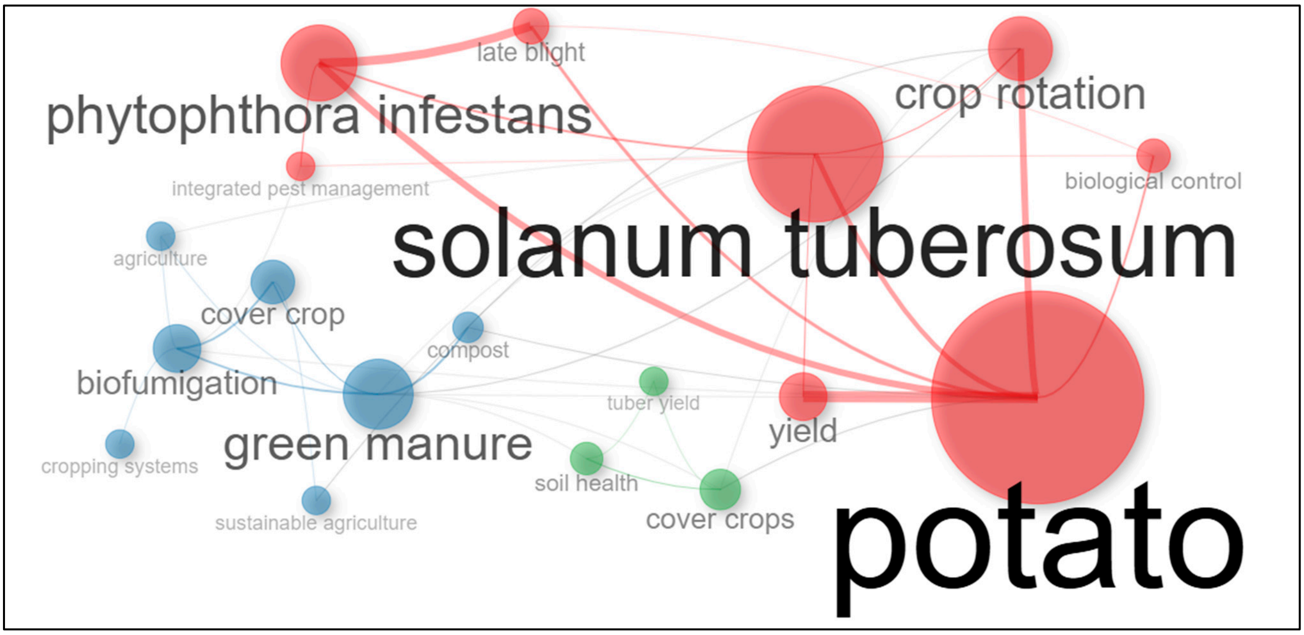

Figure 4. Author's keywords co-occurrence network on land restoration and biodiversity in food systems of Africa: various colours indicate word clusters; label size indicates how frequently each keyword occurs. The same cluster of keywords is frequently listed together.

The word cloud shows the most common keywords used in studies on potato production research (Figure 5). Larger words represent terms that appear more frequently, highlighting key areas of focus in the field. Keywords such as "*Solanum tuberosum*," "potato," "nitrogen," "soil," and "growth and management" suggest that these topics are central to current research. Other important terms like "resistance," "crop yield," "agriculture," and "crop rotation" focus on increasing potato production, improving resistance to pests and diseases, and using sustainable farming practices. Terms related to fertilisers, soil health, and specific pathogens like *Phytophthora infestans* point to challenges in enhancing potato production and managing diseases. Overall, this keyword analysis provides valuable insights into current trends and key research areas in the potato production industry.

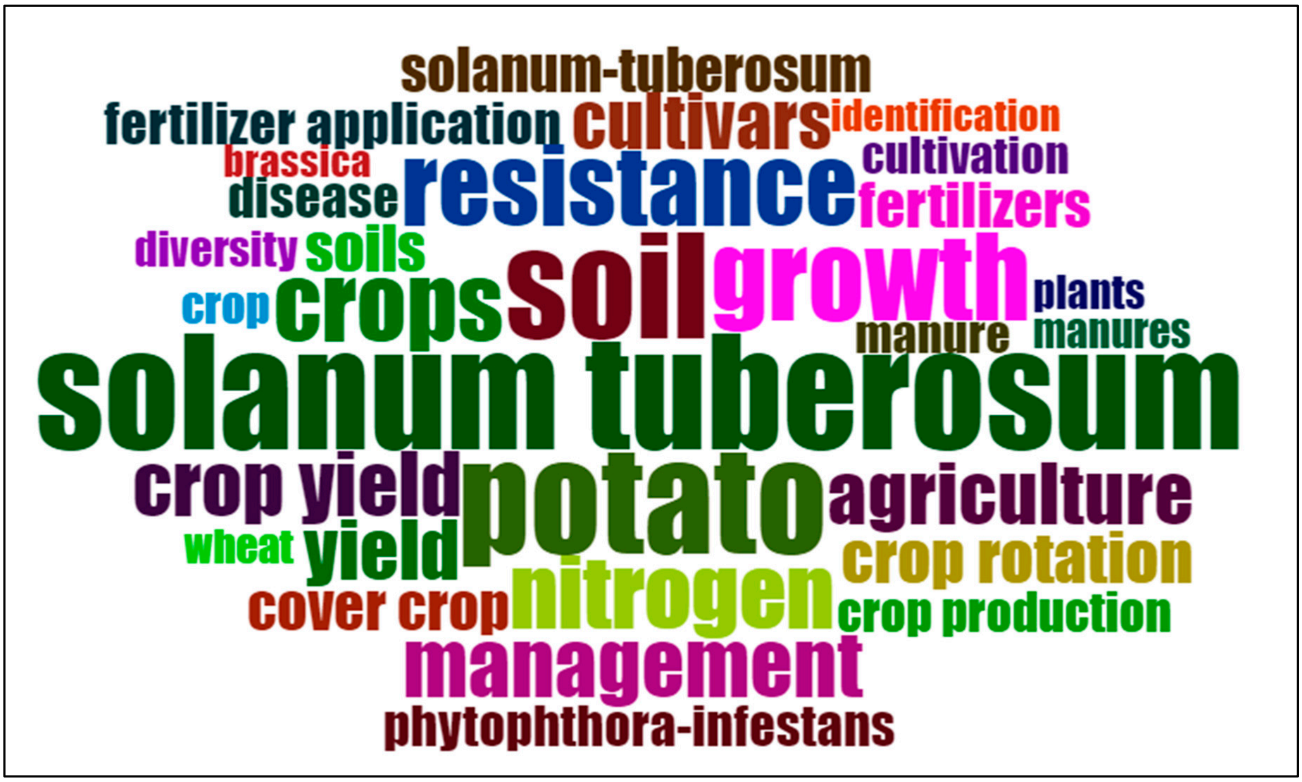

Figure 5. A word cloud of the most frequently used research keywords.

Hot Topics

The cumulative occurrence of key terms related to potato research from 2003 to 2024 is shown in Figure 6. The steady increase in the term "potato (*Solanum tuberosum* L.)" highlights its central role in research and the extensive attention it has received over this period. Keywords such as "crop yield" and "resistance" have grown significantly, indicating a stronger focus on improving potato productivity and resilience. This growth likely reflects the need for higher-yielding varieties and the challenges posed by pests and diseases. Additionally, terms like "soil," "nitrogen," and "management" have steadily increased, pointing to a growing interest in sustainable potato farming practices and nutrient management. This trend reflects a wider focus on sustainable methods to improve potato cultivation. As new research areas emerge such as N management, cover cropping, and resistance cultivars, these topics are gaining more attention, alongside established areas like improving potato yield. Properly managed cover crops, for example, can improve water retention, enhance nutrient cycling, suppress weeds, reduce erosion, and boost biodiversity, which ultimately helps reduce water loss and improve soil health [26].

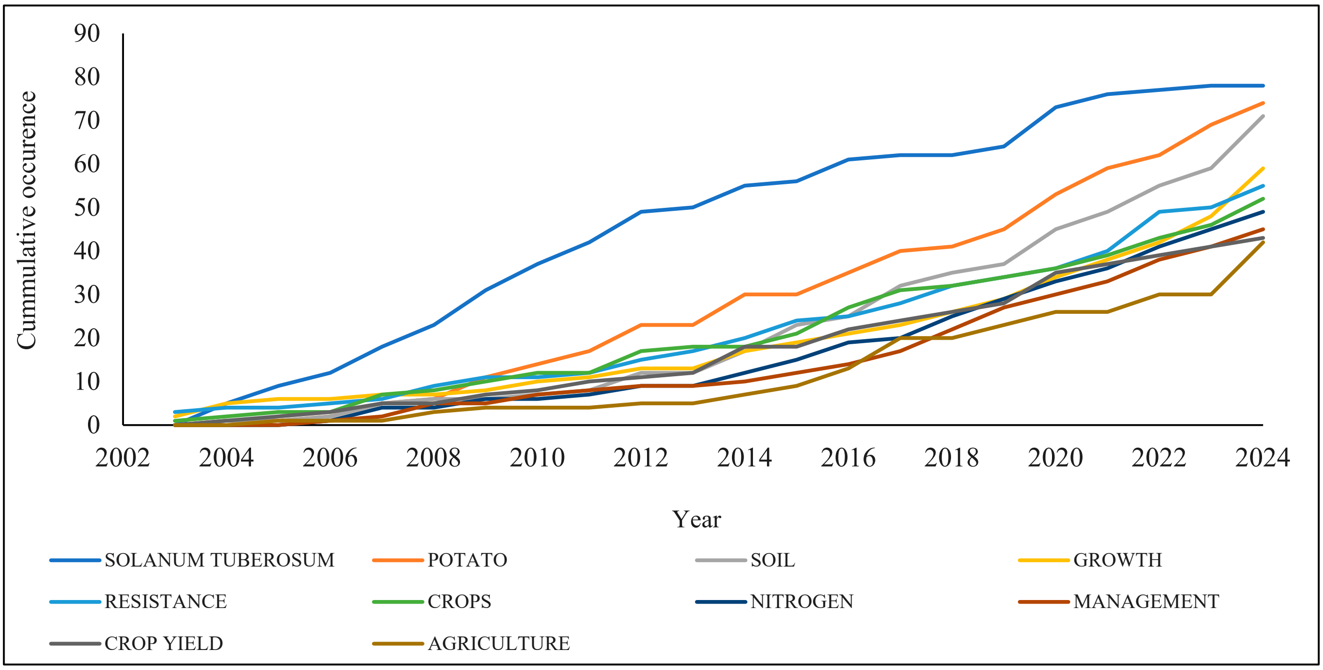

Figure 6. Evolving trends in authors' keywords studies between the periods of 2003–2024.

9. Discussion

Effective resource use is crucial for sustainable agricultural production, especially in potato farming, which requires a lot of water and nutrients for optimal growth. This review looks at different nutrient management strategies, focusing on resource efficiency and soil health in potato farming, while also examining key trends in potato-related research. The findings show that research on potatoes peaked in 2021 and 2023, with an average citation rate of 28.69%. Developed countries like China and the USA lead in research contributions, with high levels of international collaboration and citations. This is consistent with their major role in global potato production, with China being one of the top producers worldwide [49]. Despite this, the annual growth rate in research output, recorded at 11.32% since 2003, shows limited progress across all contributing countries. This highlights the need for developing countries like South Africa to increase their research efforts. More contributions from these regions could provide innovative solutions to the complex challenges in potato production, offering different perspectives [86,96]. However, an analysis of global research output reveals a lack of research from developing countries, including South Africa, on sustainable potato farming practices. This gap is partly due to the low adoption of sustainable practices like cover cropping, which could help mitigate climate change and protect the environment. Despite its benefits, cover cropping is not widely used, even in countries where it is technically and politically feasible [19].

The National Potato Council [100] identified cover crops as a key strategy for maintaining and protecting soil and water resources. However, farmers often hesitate to adopt these practices due to concerns about potential risks like yield loss and financial challenges [101]. In particular, commercial farms have discontinued cover cropping due to high costs, limited adoption potential, and management difficulties [21]. Addressing these barriers and raising awareness of the benefits of cover crops for agroecosystems could encourage their use in potato farming. By improving understanding and overcoming farmers' hesitations, adoption of cover crops could be increased, especially in potato cultivation. Additionally, the analysis reveals a lack of international collaborations to strengthen research partnerships in sustainable potato farming practices. Such collaborations are essential to address food security issues and improve crop resilience. This emphasises the need for enhanced global cooperation to advance research and promote sustainable practices in potato farming. The results also underscore the importance of N management, crop rotation, and intercropping in promoting soil health, enhancing sustainability, and improving the resilience and yield of potato crops.

Similarly, Nyawade [32] shows that incorporating legume cover crops into potato cropping systems, especially through crop rotation, can significantly reduce soil and nutrient losses caused by erosion. A study by [51] highlights that sustainable practices such as using cover crops not only improve crop health and soil quality but also enhance long-term productivity and sustainability in potato cropping systems. Furthermore, a study by Saliu [17] emphasised the importance of using the right amount of N for sustainable potato production in different regions. Similarly, Jalaini and Karimi [31] discovered that using 75% of the recommended N fertiliser with subsurface irrigation resulted in higher marketable yields and better water use efficiency in potato farming systems. However, irrigated potato farming can lead to environmental problems, such as nitrate contamination of groundwater from excessive fertiliser use and over-irrigation. To address these issues, strategies that reduce nutrient losses and improve soil moisture conservation are crucial for ensuring sustainable potato production while protecting water resources.

10. Conclusions

The global demand for potatoes highlights the urgent need for sustainable production practices, particularly in the face of challenges such as soil degradation, water scarcity, and climate change. Integrating cover cropping systems, especially those with legumes, into potato farming has been shown to significantly enhance soil health, improve N use efficiency, and boost yields. The benefits of cover cropping include increased N availability, better resource use efficiency, and reduced dependency on synthetic fertilisers, all of which contribute to sustainable agricultural practices without substantial additional costs. Despite these advantages, the adoption of cover cropping remains limited due to concerns over potential yield losses, increased labour, and the initial financial investment required for implementation. To overcome these barriers, it is essential to prioritise educational initiatives that demonstrate the long-term benefits of cover cropping, such as improved soil structure, enhanced pest management, and greater resilience to climate variability. Additionally, financial incentives, such as subsidies or cost-sharing programs, can alleviate the initial financial burden on farmers. Governments and agricultural organisations should develop and disseminate best practice guidelines, alongside practical training programs, to encourage effective cover cropping techniques. Collaborative research efforts between developed and developing countries can also foster the exchange of knowledge and innovations, leading to the creation of region-specific cover cropping practices tailored to diverse climatic and soil conditions. Policymakers must integrate sustainability metrics into agricultural policies, promoting conservation agriculture strategies that prioritise soil health, efficient water use, and crop rotation. By advancing these strategies, the adoption of sustainable practices in potato farming can be accelerated, enhancing soil health, crop resilience, and food production in the face of climate change. Through education, financial support, research collaboration, and supportive policies, the path to sustainable potato farming will become clearer, ensuring long-term agricultural productivity and environmental stewardship.

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