Hindawi
Advances in Agriculture
Volume 2021, Article ID 8924087, 9 pages
https://doi.org/10.1155/2021/8924087

Review Article

Diversified Crop Rotation: An Approach for Sustainable Agriculture Production

Kabita Kumari Shah,[1] **Bindu Modi**,[2] **Hari Prasad Pandey**,[3] **Arjun Subedi**,[4] **Geeta Aryal**,[5] **Meena Pandey**,[6] **and Jiban Shrestha**[7]

[1]*Institute of Agriculture and Animal Science, Gokuleshwor College, Tribhuvan University, Gokuleshwor, Baitadi, Nepal*
[2]*Central Department of Chemistry, Tribhuvan University, Kathmandu, Nepal*
[3]*Ministry of Forests and Environment, Government of Nepal, Kathmandu, Nepal*
[4]*College of Agriculture, Life, and Physical Sciences, Southern Illinois University of Carbondale, Carbondale, IL 62901, USA*
[5]*Tri-Chandra Multiple Campus, Ghantaghar, Kathmandu, Nepal*
[6]*Paklihawa Campus, Institute of Agriculture and Animal Science, Tribhuvan University, Bhairahawa, Rupandehi, Nepal*
[7]*Nepal Agricultural Research Council, National Plant Breeding and Genetics Research Centre, Khumaltar, Lalitpur, Nepal*

Correspondence should be addressed to Kabita Kumari Shah; agri.kabita35@gmail.com and Jiban Shrestha; jibshrestha@gmail.com

Received 30 May 2021; Revised 4 July 2021; Accepted 6 July 2021; Published 22 July 2021

Academic Editor: Shah Fahad

Copyright © 2021 Kabita Kumari Shah et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Diversified crop rotation (DCR) improves the efficiency of farming systems all over the world. It has the potentiality to improve soil condition and boost system productivity. Improved soil attributes such as increased soil water uptake and storage, and a greater number of beneficial soil organisms, may improve yield tolerance to drought and other hard growing conditions in a variety of crop rotations. Crop rotations with a variety of crops benefit the farmers,reduce production risk and uncertainty, and enhance soil and ecological sustainability. Farmers may be able to diversify their sources of income by adopting diversified crop rotations. Furthermore, because of the distinct structure, function, and relationship of plant community with soil in DCR, it contributes to the long-term development of soil health by decreasing insect, weed, and disease incidence and increasing the physical and chemical structure of the soil. DCR is becoming more popular approach for maintaining sustainable crop production. This review provides the evidence of the significance of DCR, challenges to adapt it, and possible way out to overcome the challenges.

1. Introduction

With insufficient agricultural supplies, meeting the population's ever-increasing food demand is a tremendous challenge on a national and global scale [1, 2]. Due to increased food demand and lower crop yields as a result of population growth, the agricultural sector is critical in resolving the productivity crisis. In terms of agricultural efficiency, soil texture or fertility is critical to maintaining a healthy environment. In future, rising food demand and a scarcity of agricultural land will necessitate greater crop yield and soil productivity [3]. An increasing interest in efficient and innovative agricultural practices has sparked a pragmatic strategy for agricultural land management, especially in light of the concerns of soil erosion exacerbated by anthropogenic behavior and unsustainable farming practices. In recent years, experts have become increasingly concerned about soil depletion caused by intensive farming [4, 5]. Since the 1950s, almost 60% of soil depletion has been attributed to various degrees of soil ecological processes, with farming practices becoming one of the major contributors [6, 7]. Researchers will explore taking a significant position in the global resilience of agricultural purposes by transforming scientific information about soils into actual techniques that increase farmers' understanding of the viability of their farming activities [8]. One of the approaches of sustainable farm management is aimed at growing soil organic matter and reducing soil erosion by crop rotation. Crop rotation disrupts insect and pathogen reproduction and hence their life cycle. Plant nutrients are restored when certain plant species are included in crop rotation, requiring less chemical fertilizer. Crop rotation is a useful technique in the practice of sustainable agriculture [9]. In contrast to monocultures or double farmed rotations, diversified crop rotations (DCR) refer to a set or multiple rotations of three or more crops [10]. Carefully selecting a crop rotation scheme has the potential to reduce trade-offs between crop viability and environmental impacts, maintain long-term soil fertility, and disrupt the weed and disease cycle process through intrinsic nutrient recycling [11]. The benefits of DCR in food security and soil health maintenance are shown in Figure 1. Diverse cropping systems are also used as a promising option for more productive agriculture [12], and this diversified crop rotation method offers many benefits for soil quality by strengthening soil conditions and increasing system production around the world [13]. Doran and Zeiss said, "the soil to serve as a vital life cycle within the ecosystem and land-use limitations for sustaining plant and animal growth, controlling or increasing the quality of water or the environment, and nurturing plant and animal health," [14]. Soil health [15], or the ability of the land to sustain crop production despite soil depletion or environmental degradation, determines the quantity and consistency of soil-based organic meals [16]. Soil health is defined as a soil's ability to function and maintain ecosystem resources [15], or the soil's ability to boost crop development without deteriorating the soil or harming the environment. Soil health determines the quality and performance of soil-based agricultural products [17]. After the rotation, the expanding heterogeneity of the crop production system will sustain or improve soil performance by increasing crop residues and diverse root systems, as well as ramping up and expanding microbial activity [18]. The DCR boosts soil water conservation, wet-soil aggregate equilibrium (WAS), and soil enzymatic activities. Restoration of the physical and chemical quality of soil have been reported in a variety of studies [19–22].The DCR helps in soil erosion management and crop production enhancement [23] and significantly improves the soil properties and uses water and nutrients in the soil profile to sustain productivity [24]. Nonetheless, no single piece of literature covers the subject of DCR. Recognizing this, the purpose of this study is to summarize the concept of DCR, its importance, the problems of adapting DCR in various locations, and the reasoning behind adapting DCR for agricultural productivity and sustainability.

This study will give insights into the quality of soil in the agriculture system and provide a clear understanding of how DCR helps to improve soil health through the disruption of the disease cycle by enhancing the physical and chemical properties of soil systems while preserving soil quality and its foundation for the adoption of better agricultural practices. Moreover, the study accentuates the challenges, obstacles, and influences impacting the adaptation and implementation of the DCR in the agricultural production system. These thematic areas are described briefly in the following subheadings.

2. Factors Affecting Adoption of Diversified Crop Rotation

Different studies [25–29] showed that land fragmentation is also seen as the major factor that affects the adoption of diversified crop rotation attributed to inadequate allocation of resources, which is correlated with production costs; suboptimal use of factor inputs that minimize total returns to land due to extra travel time losses, wasted space across boundaries, insufficient surveillance, and reluctance to use predefined types of machinery; and hindering agricultural development and restructuring schemes to adjust adverse implications, among others. The incentive to improve the productivity of smallholders' farmland through area expansion is confined, and farmers are hesitant to diversify crops due to modest outputs from diverse specified crops, given the expanding population versus the subsequent fragmentation of land size and depletion of natural resources [30].

According to [31], farmers with more and smaller plots prefer employing fewer current technologies, monocropping, and decreasing the average distance between plots, while an increase in farm size improves the farmer's interest in picking diverse crops with rotation, lowering the overall cost of production per unit. The factors influencing the adoption of these technologies and practices (i.e., DCR), the diffusion of information (cultivation knowledge and adoption technique), and the impact of the interventions that facilitate them (improved production and benefit to farmers) have all been highlighted, although there are substantial gaps in knowledge (training and outreach programs). In low-income nations, there are numerous dramatic market swings in outputs, production variables, and awareness; as a result, the mechanisms of diffusion, adoption potential, and profitability are likely to be diverse across a wide range of technologies, which have been the primary barrier to agricultural practice acceptance [32, 33]. Risks and uncertainty are widespread in agriculture, as there is disconnection between decision-making and profit realization. Many factors influence DCR adoption, including crop insurance limits, experience adopting new technology, economic level, and decision-maker age, all of which must be taken into account while developing strategies and procedures.

3. Examples of Crop Rotation

Crop rotation increases yield and profit and allows for sustained production. Crop rotation with legumes not only increases the cropping intensity but also increases the total food availability and the net return from selling it. The use of a legume cover in crop rotation can provide a substantial amount of nitrogen (N) to a succeeding crop. The Nepalese agriculture system and the cropping pattern are highly dominated by geography. The common crop rotation prevalent in Nepal is given in Table 1.

4. Roles of Diversified Crop Rotations

4.1. Soil Health Improvement. Researchers and farmers have been the forerunners in developing and maintaining soil health methods. Agricultural producers and academicians play an important role in preventing inadvertent soil depletion by focusing on long-term sustainability. Soil health and quality are influenced by agricultural production methods such as diverse crop cultivation, crop rotation, and associated intercropping from a variety of spatial and temporal perspectives [35]. Diversified crop rotation is essential not only for crop production optimization, but also for enhancing soil health by increasing soil fertility, nutrient efficiency, and preventing the spread of soil-borne diseases [36, 37]. The broad topic themes involved in increasing soil health are explored further down.

4.2. Resistance to Diseases. In varied crop rotation, the ability to break the disease cycle in a soil profile is extremely beneficial. Pathogen buildup is aided by monoculture on the same farmland. In the absence of rotation, such infections can proliferate in the soil and outrun spreads, causing plant disease outbreaks to become more severe. The monoculture farming method could serve as a host plant for diseases to thrive. The pathogen cycle is disrupted by rotations that result in the growth of a plant belonging to a different family, as the pathogen cannot infect a plant belonging to a different family. As a result, the pathogen population in the soil rapidly declines. Consider the seven-year diverse crop rotation period, which includes three years of alfalfa, two years of chile pepper, and two years of cotton before returning to alfalfa. Alfalfa, chile, and cotton are three plants that correspond to a variety of crops. These three plants—alfalfa, chile, and cotton—belong to different crop families, so they can help break the disease cycle and boost productivity [38, 39]. By breaking the pest cycle, lowering weeds and illnesses, improving soil quality, and safeguarding the ecosystem, the DCR aids in pest management [40].

By shortening the life cycles of soil-borne pathogens aligned with a species plant or crop genotype, the DCR offers a good chance for the development of certain soil-functional microorganisms [41]. For example, different genotypes of chickpeas (cultivars) or rotating vegetative crops (such as pea and chickpea) can affect the microbial functionality of the soil as well as the performance of pulse crops and subsequent wheat crops [42]. Various plant species, in particular, can produce residues and root exudates that improve the diversity and efficiency of the soil's microbial population as well as soil C and N cycling [17, 36, 43]. The goal of DCR implementation is to increase the microbial population and soil heterogeneity [35]. Different microbes interact with different plant roots, promoting soil quality with a wider spectrum of soil microbiomes [44].

4.3. Improvement in Physical and Chemical Properties of Soil. Diversified crop rotation approaches as cover crops sown between both forms of cash crops integrate root exudates and biomass to maintain the physicochemical composition of soil erosion. Through the creation and secretion or emergence of rhizosphere, root and associated hyphal interaction or degradation stabilizing and destabilizing components, and the creation of resilient biopores, the root and remnants of these plant parts may impact numerous elements in preserving soil quality. The study in [45] reported small and inconsistent differences in soil watertable and bulk aggregates accompanying the use of crops like wheat or lupin in South Australia. Similarly, the work in [46] found that following canola and lupin cropping; the soil was more permeable and had decreased soil hardness. After harvesting diversified crop peas and barley and after their roots were accounted for the accumulation of soils and the production of macropore, the soil has solid and more permanent particles. It is worth noting that the non-AMF (arbuscular mycorrhizal fungi) hosts are both lupin and canola, which makes it difficult to interpret changes in cumulative stabilization supporting glomalin development by the matching AMF [47] regarding the recent history of other crops. Furthermore, certain nonmycorrhizal plant species, such as canola and mustard, may be unable to form symbiotic relationships with a specific rhizobacterial characteristic as more chemical fertilizer is required, thus altering the physiological soil structure and fertility in the near future [48].

4.4. Soil Quality Maintenance. It is self-evident that soil with perfect physical, chemical, and biological features improves soil quality in the farming system. For example, a wheat-pulse crop rotation can improve soil conditions and increase system productivity [49–51].

The authors of [52–55] found that a four-year wheat-fallow field pea (*Pisum sativum*) rotation provided enough cover to prevent soil deterioration by conserving the land's physical structure. According to certain recorded studies [56]; diversifying cropping systems with plus crop rotation is beneficial to increase soil water conservation and boost the supply of soil nitrogen. The study in [55] discovered that cover crops like rye and phacelia (*Phacelia tanacetifolia L.*) were successful in absorbing nitrogen and water, reducing nitrate leaching in irrigated broccoli (*Brassica oleracea* var. *italica*) by 70%, and reducing fertilizer consumption in the soil.

The diversified cropping system has a number of substantial advantages that have been documented around the world. Diversified cropping schemes, for example, improve water use efficiency and grain production by combining cereals with broadleaf crops [57]. According to two global studies conducted by [24, 56, 58], crop rotation diversification or better crop rotation has been linked to higher soil organic carbon (SOC) levels than monoculture [59, 60]. In general, the crop rotation system's different abundance, uniformity, and dispersion of crop residues contribute to higher soil enzyme activity than the crop rotation system [61].

High soil component quality has been shown to have a positive impact on crop productivity [62]. Farmers can improve management of weed, insect, and disease , reduce soil depletion, and promote SOC and nitrogen fixation in agricultural production processes by farming different crops in the same location (crop rotation). For example, in two current long-term rotational tests of consistent corn, consistent soybean, corn-soybean, and corn-soybean-wheat rotation, the most diversified rotation of corn-soybean-wheat rotation increased the organic carbon capacity of the soil by 7% compared to consistent soybean, and rotational and tilling interactions with soil organic carbon were 7% greater than standard farming [22]. The mutual retention or enhancement of these plants' output capacities can provide an extra benefit [32, 63]. By adopting a wider variety of crops, SOC sequestration, soil composition, and texture can be enhanced while production is enhanced, reducing soil and environmental damage [49, 56, 64].

5. Agronomic Impact of Crop Rotation

By replacing fallow periods with growing different crops that replenish soil nutrients, crop rotation has helped to increase productivity. Crop rotation also aids in the fight against erosion forces. The agronomic impact of crop rotation is given in Table 2.

6. Benefits of Diversified Crop Rotation

6.1. Economic Benefits of Diversified Crop Rotation. Long before the development of the current farming system, its economic and ecological value was recognized. The diverse crop rotation includes weed, disease, insect, and nematode management; soil erosion reduction; soil fertility maintenance and improved efficiency; ecosystem resource preservation; and lower threat and market risks [66–72].

6.2. Reduction of Production Risk. Crop diversification is one of the most cost-effective solutions to reduce income instability among farmers, especially among impoverished smallholders [73]. To prevent production risks or control limited resources when seeding or harvesting, farmers frequently employ this strategy by picking diversified crops preceded by crop rotation. The latest data of the economic net return from crop rotations in the Midwest United States shows that increasing land efficiency reduces outside investments while increasing crop yields [74]. Farmers can get significant concrete benefits from alfalfa-containing crop rotations while minimizing the risk of herbicide-resistant enormous ragweed pests, according to the results of the stochastic study [75]. DCR is linked to increased production of various agricultural inputs as well as a systemic economic transformation in which farm contracts account for a greater part of GDP [76]. Continued financial crises, quick demand fluctuations, and increased technological breakthroughs provide a clear incentive to diversify crops, lowering risk in the agricultural system.

6.3. Increase in Farmers' Income. Numerous researchers, including [77] in Zimbabwe, [78] in El Salvador and Honduras, and [79] in the Brazilian Amazon, have found a significant beneficial relationship between crop diversification rotations and total agricultural productivity for the full year. According to [77], increased production from a diverse crop rotation system results in higher revenue for farmers throughout the year. Similarly, [78] showed an average increase of 21% in farm income across all samples in the study, while [79] found a generally positive relationship between diversification and income in the Brazilian Amazon. Furthermore, the integration of different crops in the same area could raise farmers' income and stabilize them [80, 81].

6.4. Increase in Crop Productivity. In parts of the world where diverse cropping is a common element of agroecosystem management, productivity is usually far more robust and consistent throughout time [66, 82]. In comparison to standard double-crop rotations, the DCR field study in the Iowa region between 2003 and 2011 found that crop output has improved, agricultural inputs have dropped, and weeds have decreased. When compared to a single system, using a varied crop rotation strategy can have a synergistic effect, resulting in enhanced rewards [58]. In crop rotation, the availability of nutrients from the soil provides ample nourishment to all plants, ensuring that the yield produced is successful.

6.5. High Resilience at Locality. Multiyear crop rotations, which require fewer commercial fertilizers and additional agricultural inputs including fertilizer and crop nutrient recycling, banded fertilizer application, and chemical pest control inputs, can help reduce reliance on external inputs [83]. Adoption of DCR in a specific sequence, such as corn-soybean-wheat-oats, corn-soybean-wheat, corn-soybean-wheat, corn-soybean-oats, and cover crops, helps to maintain soil health by reducing the use of chemical fertilizers. Crimson clover, annual ryegrass, oats, cereal rye, and oil-seed radishes are examples of cover crops that can improve soil structure, improve soil organic matter, enhance water percolation, suppress weeds, reduce soil erosion, and fix residual nitrogen after grain harvest [84]. These positive cover crop effects can boost farm profitability by lowering expenses (e.g., by reducing the need for commercial fertilizers) or increasing production (by improving soil quality and fertility). In Michigan, for example, [85] found that using cover crops in a corn-soybean-wheat rotation reduced nitrate leaching while maintaining profitability. As a result, integrating varied crop rotation benefits farmers by reducing their reliance on external inputs, resulting in financial gains. Therefore, the implementation of diversified crop rotation enables farmers to reduce the resilience of external inputs, supporting them with economic benefits.

7. Barriers for DCR Adoption

7.1. Resources Limitation. Due to a lack of essential investments in machines, infrastructures, and expertise, as well as research proof, DCR measures are rarely applied [72, 86–90]. One of the most significant challenges to the adoption of this strategy is financial, as integrating extra crops into normal rotations may require farmers to make significant up-front investments, such as in new machinery, and impose an additional short-term cost. Furthermore, most farmers who rent farmland from others have short-term contracts that do not allow for long-term planning or incentives for soil or production development. Lack of experience, limited financing access for investment, and lack of technological support and knowledge by stakeholders and

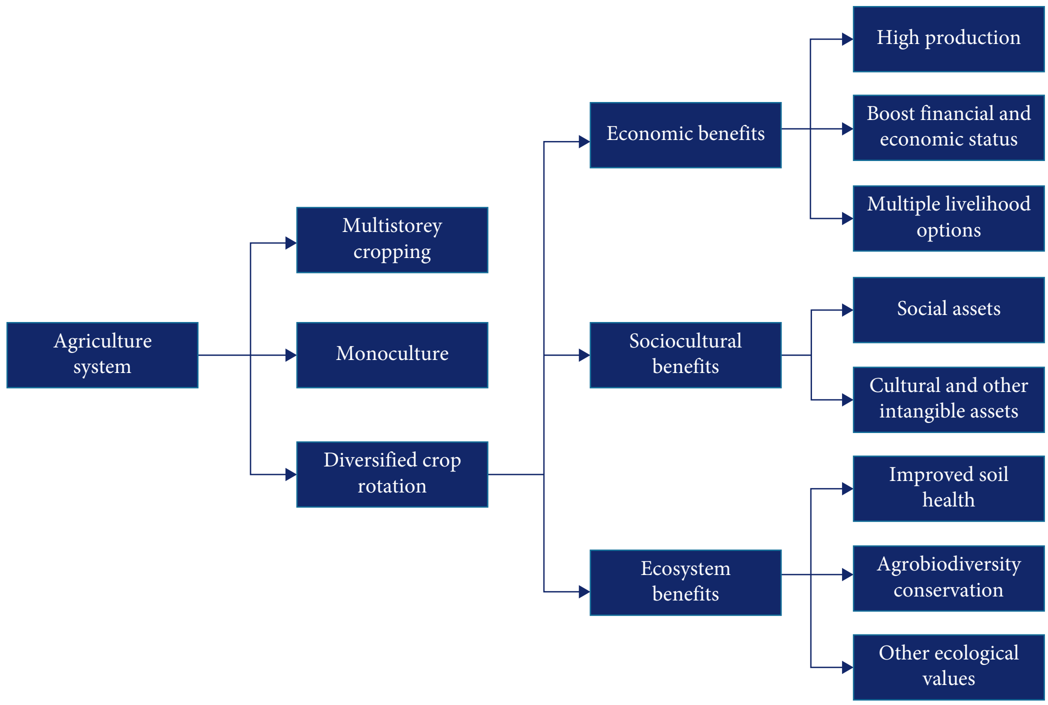

Figure 1: Conceptual framework of importance of DCR in food security and soil health maintenance.

Table 1: Major crop rotation in Nepal.

i. Terai (<1000 masl)	
Irrigated area	Rainfed area
Rice-wheat-rice	Rice-fallow-fallow
Rice-wheat-fallow	Rice-wheat-fallow
Rice-wheat-dhaincha	Rice-lentil-fallow
Rice-wheat-mung	Rice-rapeseed-fallow
Rice-potato-dhaincha	Rice/lentil
Rice-peasonpea (in bund)-wheat	Maize-chickpea + rapeseed
Rice-potato-maize	
Rice-potato-dhaincha	Rice/lentil
Rice-maize-rice	Rice-fallow-tobacco
Rice/lentil-rice	Jute-rapeseed-fallow
Rice-chickpea, linseed	Jute-wheat-fallow
Rice-wheat-maize	Maize-chickpea, lentil
ii. Mid hill (1000–2000 masl)	
Irrigated area	Rainfed area
Rice-barley	Maize-oat
Rice-maize	Maize + upland rice
Rice-wheat-fallow	Maize/millet-wheat
Rice-wheat-rice	Maize/millet-fallow
Rice-wheat-maize	Maize + soybean-rapeseed-fallow
Rice-black gram (in bund)-wheat	Maize-wheat
Rice-rapeseed-maize	Maize + upland rice-wheat
Rice-rapeseed-rice	
Rice-potato-maize	
iii. High hill	
Irrigated area	Rainfed area
Rice-barley	Maize-fallow
Rice-necked barley (uwa)	Maize-wheat
Potato + necked barley (uwa)-fallow (2-year cropping pattern)	Maize-wheat-finger millet (2-year cropping pattern)
Rice-fallow-finger millet-barley-wheat (2-year cropping pattern)	Potato-fallow, potato-buckwheat, maize-rapeseed, uwa-fallow, maize-buckwheat
Rice-wheat	Wheat-finger millet (2-year cropping pattern)
Buckwheat-necked barley (uwa)	Maize-necked barley (uwa)-finger millet (2-year cropping pattern)

(Source: [34]).

Table 2: Agronomic impacts of crop rotations.

Impacts	Effects	Examples
Primary impacts	Yield increases of cereal crops due to:	
	N fixation from pulses or pasture legumes	Subterranean clover ley has an impact on soil nitrogen, soil structure, and wheat yield
	Break crop effects	Due to the introduction of lupins (WA) and canola, take-all in cereals has decreased (Southern Australia)
	Better utilization of resources	Use of subsoil moisture by lucerne after a crop phase
Secondary effects	Effect of break crops or pasture phases on:	
	Weed populations	Rotation of herbicide groups, reduction in seed pools, plant competition
	Insect populations	Many pasture and crop species are unattractive to potential insect pests
	Disease incidence	Using cereals and legumes to reduce the incidence of blackleg in Canada
Other impacts	Water use efficiency	Wheat shown after a rice crop
	Nutrient use efficiency	Different extraction rates if N, P, and S by crops
	Allelopathy	Plant leftovers have a chemical influence on other plants, which is frequently negative.

(Source: [65]).

farmers have all been identified as important barriers to adopting diversified crop rotation [89, 91]. Furthermore, the scarcity of markets is widely acknowledged in the form of impediments to extending rotations of varied crops, with some farmers participating in biomass markets, albeit these markets are currently quite regulated [89]. Despite the potential benefits of conservation agriculture, such as diversified crop rotation for enhanced crop yields, soil health through minimizing soil erosion, water-use efficiency, and other factors, its adoption rate is low.

Access to information issues and a lack of understanding can stymie broader adoption [68]. Furthermore, due to inadequate budget allocation, the inadequacy of mobility, outmoded knowledge, understaffing, and low staff morale, the basic impediments to the application of new conservation methods are communication skills and technological diffusion [92]. Crop insurance and credit limits are other significant barriers to this approach's adoption, as lenders unfamiliar with the profitability potential of longer cycles with varied cropping systems are sometimes put off by complex rotations and are hesitant to issue loans in this sector. Farmers usually need assurance that new methods are feasible, can be effectively implemented in their locations, and can benefit their bottom line.

Similarly, the DCR adoption is hampered by a lack of reinforcement and institutional coordination that involves both public and private institutions, a lack of investment and apprehension about production risk, and a lack of strategy studies that address dissemination and implementation. Apart from these, climate issues, technological adaptation problems in DCR, model farmer development, exposure and exhibition, and demonstration limitations are the principal roadblocks to DCR adaptation on a larger and broader scale [89, 93]. Because the DCR concept is a relatively new system among farming communities, they may be hesitant to adopt it due to concerns about economic loss from the newly chosen rotation compared to their old rotation of fewer crops that they have been familiar with for a long time.

8. Conclusion

Diversified crop rotations are becoming more popular as a tool for maintaining sustainable crop production as people are becoming more concerned about the need to provide high-quality food with minimal environmental impact. DCR encourages beneficial soil microbes and their interactions, breaks the disease cycle, and reduces the number of weeds. DCR improves the physical and chemical properties of soil and increases land-use efficiency and crop productivity. It is a valuable practice for long-term profitability. Farmers require diversified crop rotations that are flexible and economic in order to respond to market demands. Policy and organizational supports are needed to adopt diversified crop rotation practices at the farmer's level. The scientific community should focus their current and future research strategies and efforts on developing better-diversified crop rotation practices that are adaptable to changing climatic conditions.

Data Availability

Data supporting the findings of the study are available upon request from the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

The authors would like to express their immense pleasure and profound acknowledgment to NARC Library, AFU Library, and PSU Library for providing information and data for this review.

References

[1] K. F. Davis, J. A. Gephart, K. A. Emery, A. M. Leach, J. N. Galloway, and P. 'D'Odorico, "Meeting future food demand with current agricultural resources," *Global Environmental Change*, vol. 39, pp. 125–132, 2016.

[2] D. Renard and D. Tilman, "National food production stabilized by crop diversity," *Nature*, vol. 571, no. 7764, pp. 257–260, 2019.

[3] M. M. Tahat, K. M. Alananbeh, Y. A. Othman, and D. I. Leskovar, "Soil health and sustainable agriculture," *Sustainability*, vol. 12, no. 12, p. 4859, 2020.

[4] Y. Khaledian, F. Kiani, S. Ebrahimi, E. C. Brevik, and J. Aitkenhead-Peterson, "Assessment and monitoring of soil degradation during land use change using multivariate analysis," *Land Degradation and Development*, vol. 28, no. 1, pp. 128–141, 2017.

[5] M. Mekonnen, S. D. Keesstra, L. Stroosnijder, J. E. M. Baartman, and J. Maroulis, "Soil conservation through sediment trapping: a review," *Land Degradation and Development*, vol. 26, no. 6, pp. 544–556, 2015.

[6] R. Lal, "Restoring soil quality to mitigate soil degradation," *Sustainability*, vol. 7, no. 5, pp. 5875–5895, 2015.

[7] V. V. Snakin, P. P. Krechetov, T. A. Kuzovnikova, I. O. Alyabina, A. F. Gurov, and A. V. Stepichev, "The system of assessment of soil degradation," *Soil Technology*, vol. 8, no. 4, pp. 331–343, 1996.

[8] J. W. Doran, "Soil health and global sustainability: translating science into practice," *Agriculture, Ecosystems & Environment*, vol. 88, no. 2, pp. 119–127, 2002.

[9] J. Shrestha, S. Subedi, K. P. Timsina et al., "Sustainable intensification in agriculture: an approach for making agriculture greener and productive," *Journal of Nepal Agricultural Research Council*, vol. 7, pp. 133–150, 2021.

[10] L. Wang, Y. Zhao, M. Al-Kaisi, J. Yang, Y. Chen, and P. Sui, "Effects of seven diversified crop rotations on selected soil health indicators and wheat productivity," *Agronomy*, vol. 10, no. 2, p. 235, 2020.

[11] C. P. Andam, M. J. Choudoir, A. Vinh Nguyen, H. Sol Park, and D. H. Buckley, "Contributions of ancestral inter-species recombination to the genetic diversity of extant Streptomyces lineages," *The ISME Journal*, vol. 10, no. 7, pp. 1731–1741, 2016.

[12] J. Hufnagel, M. Reckling, and F. Ewert, "Diverse approaches to crop diversification in agricultural research. A review," *Agronomy for Sustainable Development*, vol. 40, no. 2, p. 14, 2020.

[13] T. Wang, H. Jim, B. B. Kasu, J. Jacquet, and S. Kumar, "Soil conservation practice adoption in the northern great plains: economic versus stewardship motivations," *Journal of Agricultural and Resource Economics*, vol. 44, no. 2, Article ID 287989, 2019.

[14] J. W. Doran and M. R. Zeiss, "Soil health and sustainability: managing the biotic component of soil quality," *Applied Soil Ecology*, vol. 15, no. 1, pp. 3–11, 2000.

[15] H. M. van Es and D. L. Karlen, "Reanalysis validates soil health indicator sensitivity and correlation with long-term crop yields," *Soil Science Society of America Journal*, vol. 83, no. 3, pp. 721–732, 2019.

[16] D. F. Acton and L. J. Gregorich, *The Health of Our Soils: Toward Sustainable Agriculture in Canada*, Centre for Land and Biological Resources Research, Agriculture and Agri-Food Canada, Ottawa, Canada, 1995.

[17] M. A. Gregory and G. Pj, "Soil, food security and human health: a review," *European Journal of Soil Science*, vol. 66, no. 2, pp. 257–276, 2015.

[18] G. A. Studdert and H. E. Echeverría, "Crop rotations and nitrogen fertilization to manage soil organic carbon dynamics," *Soil Science Society of America Journal*, vol. 64, no. 4, pp. 1496–1503, 2000.

[19] W. A. Dick, "Influence of long-term tillage and crop rotation combinations on soil enzyme activities," *Soil Science Society of America Journal*, vol. 48, no. 3, pp. 569–574, 1984.

[20] M. R. Nunes, H. M. van Es, R. Schindelbeck, A. J. Ristow, and M. Ryan, "No-till and cropping system diversification improve soil health and crop yield," *Geoderma*, vol. 328, pp. 30–43, 2018.

[21] L. K. Tiemann, A. S. Grandy, E. E. Atkinson, E. Marin-Spiotta, and M. D. McDaniel, "Crop rotational diversity enhances belowground communities and functions in an agroecosystem," *Ecology Letters*, vol. 18, no. 8, pp. 761–771, 2015.

[22] S. M. Zuber, G. D. Behnke, E. D. Nafziger, and M. B. Villamil, "Carbon and nitrogen content of soil organic matter and microbial biomass under long-term crop rotation and tillage in Illinois, USA," *Agriculture*, vol. 8, no. 3, p. 37, 2018.

[23] A. Alhameid, M. Ibrahim, S. Kumar, P. Sexton, and T. E. Schumacher, "Soil organic carbon changes impacted by crop rotational diversity under no-till farming in South Dakota, USA," *Soil Science Society of America Journal*, vol. 81, no. 4, pp. 868–877, 2017.

[24] P. R. Miller, Y. Gan, B. G. Mcconkey, and C. L. McDonald, "Pulse crops for the northern great plains," *Agronomy Journal*, vol. 95, no. 4, pp. 980–986, 2003.

[25] G. T. Alemu, Z. Berhanie Ayele, and A. Abelieneh Berhanu, "Effects of land fragmentation on productivity in northwestern Ethiopia," *Advances in Agriculture*, vol. 2017, Article ID 4509605, 9 pages, 2017.

[26] T. D. Beuchelt, "Gender, social equity and innovations in smallholder farming systems: pitfalls and pathways," in *Technological and Institutional Innovations for Marginalized Smallholders in Agricultural Development*, F. W. Gatzweiler and J. von Braun, Eds., Springer International Publishing, Cham, Switzerland, pp. 181–198, 2016.

[27] M. S. Bowman and D. Zilberman, "Economic factors affecting diversified farming systems," *Ecology and Society*, vol. 18, no. 1, Article ID 180133, 2013.

[28] M. W. Lawless and P. C. Anderson, "Generational technological change: effects of innovation and local rivalry on performance," *Academy of Management Journal*, vol. 39, no. 5, pp. 1185–1217, 1996.

[29] A. V. Manjunatha, A. R. Anik, S. Speelman, and E. A. Nuppenau, "Impact of land fragmentation, farm size, land ownership and crop diversity on profit and efficiency of irrigated farms in India," *Land Use Policy*, vol. 31, pp. 397–405, 2013.

[30] T. S. Jayne, J. Chamberlin, and D. D. Headey, "Land pressures, the evolution of farming systems, and development strategies in Africa: a synthesis," *Food Policy*, vol. 48, pp. 1–17, 2014.

[31] S. Asmah, M. Syafiq, M. S. Yahya et al., "Effects of monoculture and polyculture farming in oil palm smallholdings on terrestrial arthropod diversity," *Journal of Asia-Pacific Entomology*, vol. 19, no. 2, pp. 415–421, 2016.

[32] D. G. Bullock, "Crop rotation," *Critical Reviews in Plant Sciences*, vol. 11, no. 4, pp. 309–326, 1992.

[33] G. Feder, R. E. Just, and D. Zilberman, "Adoption of agricultural innovations in developing countries: a survey,"

Economic Development and Cultural Change, vol. 33, no. 2, pp. 255–298, 1985.

[34] N. Gadal, J. Shrestha, M. N. Poudel, and B. Pokharel, “A review on production status and growing environments of rice in Nepal and in the world,” *Archives of Agriculture and Environmental Science*, vol. 4, no. 1, pp. 83–87, 2019.

[35] E. Vukicevich, T. Lowery, P. Bowen, J. R. Úrbez-Torres, and M. Hart, “Cover crops to increase soil microbial diversity and mitigate decline in perennial agriculture. a review,” *Agronomy for Sustainable Development*, vol. 36, no. 3, p. 48, 2016.

[36] G. M. Gurr, Z. Lu, X. Zheng et al., “Multi-country evidence that crop diversification promotes ecological intensification of agriculture,” *Nature Plants*, vol. 2, no. 3, p. 16014, 2016.

[37] G. Martin, J.-L. Durand, M. Duru et al., “'Role of ley pastures in tomorrow’s cropping systems. a review,” *Agronomy for Sustainable Development*, vol. 40, no. 3, p. 17, 2020.

[38] O. Idowu, R. Ghimire, R. P. Flynn, and A. Ganguli, *SOIL HEALTH-Importance, Assessment, and Management*, College of Agricultural, Consumer and Environmental Sciences, New Mexico State University, Las Cruces, NM, USA, 2020.

[39] M. Omer, O. Idowu, A. Ulery, D. VanLeeuwen, and S. Guldan, “Seasonal changes of soil quality indicators in selected arid cropping systems,” *Agriculture*, vol. 8, no. 8, p. 124, 2018.

[40] N. Z. Lupwayi, G. W. Clayton, and W. A. Rice, “Rhizobial inoculants for legume crops,” *Journal of Crop Improvement*, vol. 15, no. 2, pp. 289–321, 2006.

[41] T. Yang, K. H. M. Siddique, and K. Liu, “Cropping systems in agriculture and their impact on soil health-A review,” *Global Ecology and Conservation*, vol. 23, Article ID e01118, 2020.

[42] C. Yang, C. Hamel, Y. Gan, and V. Vujanovic, “Pyrosequencing reveals how pulses influence rhizobacterial communities with feedback on wheat growth in the semiarid Prairie,” *Plant and Soil*, vol. 367, no. 1–2, pp. 493–505, 2013.

[43] Z. Mayer, Z. Sasvári, V. Szentpéteri, B. Pethone Rethati, B. Vajna, and K. Posta, “Effect of long-term cropping systems on the diversity of the soil bacterial communities,” *Agronomy*, vol. 9, no. 12, p. 878, 2019.

[44] G. Berg, D. Rybakova, M. Grube, and M. Köberl, “The plant microbiome explored: implications for experimental botany,” *Journal of Experimental Botany*, vol. 67, no. 4, pp. 995–1002, 2016.

[45] T. Reeves, A. Ellington, and H. Brooke, “Effects of lupin-wheat rotations on soil fertility, crop disease and crop yields,” *Australian Journal of Experimental Agriculture*, vol. 24, no. 127, pp. 595–600, 1984.

[46] M. K. Alam, M. M. Islam, N. Salahin, and M. Hasanuzzaman, “Effect of tillage practices on soil properties and crop productivity in wheat-mungbean-rice cropping system under subtropical climatic conditions,” *The Scientific World Journal*, vol. 2014, Article ID 437283, 15 pages, 2014.

[47] S. F. Wright and R. L. Anderson, “Aggregate stability and glomalin in alternative crop rotations for the central Great Plains,” *Biology and Fertility of Soils*, vol. 31, no. 3–4, pp. 249–253, 2000.

[48] W. Ellouze, A. Esmaeili Taheri, L. D. Bainard et al., “Soil fungal resources in annual cropping systems and their potential for management,” *BioMed Research International*, vol. 2014, Article ID 531824, 15 pages, 2014.

[49] C. Campbell, “Carbon storage in soils of the North American great plains: effect of cropping frequency,” *Agronomy Journal*, vol. 97, p. 363, 2005.

[50] Y. T. Gan, P. R. Miller, B. G. Mcconkey, R. P. Zentner, F. C. Stevenson, and C. L. McDonald, “Influence of diverse cropping sequences on durum wheat yield and protein in the semiarid northern great plains,” *Agronomy Journal*, vol. 95, no. 2, p. 245, 2003.

[51] X. Yang, W. Gao, M. Zhang, Y. Chen, and P. Sui, “Reducing agricultural carbon footprint through diversified crop rotation systems in the North China Plain,” *Journal of Cleaner Production*, vol. 76, pp. 131–139, 2014.

[52] D. Tanaka, A. Bauer, and A. Black, “Annual legume cover crops in spring wheat-fallow systems,” *Journal of Production Agriculture*, vol. 10, pp. 251–255, 1997.

[53] J. K. ’O’Dea, C. A. Jones, C. A. Zabinski, P. R. Miller, and I. N. Keren, “Legume, cropping intensity, and N-fertilization effects on soil attributes and processes from an eight-year-old semiarid wheat system,” *Nutrient Cycling in Agroecosystems*, vol. 102, no. 2, pp. 179–194, 2015.

[54] H. Blanco-Canqui, J. D. Holman, A. J. Schlegel, J. Tatarko, and T. M. Shaver, “Replacing fallow with cover crops in a semiarid soil: effects on soil properties,” *Soil Science Society of America Journal*, vol. 77, no. 3, pp. 1026–1034, 2013.

[55] U. Wyland, L. E. Jackson, W. E. Chaney, K. Klonsky, S. T. Koike, and B. Kimple, “Winter cover crops in a vegetable cropping system: impacts on nitrate leaching, soil water, crop yield, pests and management costs,” *Agriculture, Ecosystems & Environment*, vol. 59, pp. 1–17, 1996.

[56] Y. Gan, C. Hamel, J. T. O’Donovan et al., “Diversifying crop rotations with pulses enhances system productivity,” *Scientific Reports*, vol. 5, no. 1, Article ID 14625, 2015.

[57] P. Miller, “Pulse crop adaptation in the northern great plains,” *Agronomy Journal*, vol. 94, Article ID 2610, 2002.

[58] J. Li, L. Huang, J. Zhang, J. A. Coulter, L. Li, and Y. Gan, “Diversifying crop rotation improves system robustness,” *Agronomy for Sustainable Development*, vol. 39, no. 4, p. 38, 2019.

[59] M. D. Mcdaniel, L. K. Tiemann, and A. S. Grandy, “Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? a meta-analysis,” *Ecological Applications*, vol. 24, no. 3, pp. 560–570, 2014.

[60] T. West and W. Post, “Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis,” *Soil Science Society of America Journal*, vol. 66, pp. 1930–1946, 2002.

[61] S. Klose and M. A. Tabatabai, “Urease activity of microbial biomass in soils as affected by cropping systems,” *Biology and Fertility of Soils*, vol. 31, no. 3–4, pp. 191–199, 2000.

[62] R. Lal, “Soil degradation as a reason for inadequate human nutrition,” *Food Security*, vol. 1, no. 1, pp. 45–57, 2009.

[63] M. V. Brady, K. Hedlund, R.-G. Cong et al., “Valuing supporting soil ecosystem services in agriculture: a natural capital approach,” *Agronomy Journal*, vol. 107, no. 5, pp. 1809–1821, 2015.

[64] B. M. Shrestha, B. G. McConkey, W. N. Smith et al., “Effects of crop rotation, crop type and tillage on soil organic carbon in a semiarid climate,” *Canadian Journal of Soil Science*, vol. 93, no. 1, pp. 137–146, 2013.

[65] E. Wolfe and P. Cregan, *Smart Rotations: Farming Systems for the Future*, Prince Field Crop Production, Accessed: May 29, 2021. [Online]. Available: https://researchoutput.csu.edu.au/en/publications/smart-rotations-farming-systems-for-the-future, pp. 294–320, 2003.

[66] M. A. Altieri, “Applying agroecology to enhance the productivity of peasant farming systems in Latin America,” *Environment, Development and Sustainability*, vol. 1, no. 3/4, pp. 197–217, 1999.

[67] L. E. Drinkwater, “Cropping systems research: reconsidering agricultural experimental approaches,” *HortTechnology*, vol. 12, pp. 355–361, 2002.

[68] S. A. Ejiaku, “Technology adoption: issues and challenges in information technology adion in emerging economies,” *Journal of International Technology and Information*, vol. 23, no. 2, p. 11, 2014.

[69] L. G. Heatherly, R. A. Wesley, and C. D. Elmore, “Cropping systems for clay soil: irrigated and nonirrigated soybean rotated with corn and sorghum,” *Journal of Production Agriculture*, vol. 5, no. 2, pp. 248–253, 1992.

[70] M. Liebman and E. Dyck, “Crop rotation and intercropping strategies for weed management,” *Ecological Applications*, vol. 3, no. 1, pp. 92–122, 1993.

[71] S. Temple, O. A. Somasco, M. Kirk, and D. Friedman, “Conventional, low-input and organic farming systems compared,” *California Agriculture*, vol. 48, no. 5, pp. 14–19, 1994.

[72] J. E. Ikerd, “A decision support system for sustainable farming,” *Northeastern Journal of Agricultural and Resource Economics*, vol. 20, no. 1, pp. 109–113, 1991.

[73] D. Feliciano, “A review on the contribution of crop diversification to Sustainable Development Goal 1 “No poverty”: in different world regions,” *Sustainable Development*, vol. 27, no. 4, pp. 795–808, 2019.

[74] B. Gebremedhin and G. Schwab, *The Economic Importance of Crop Rotation Systems: Evidence from the Literature*, https://www.researchgate.net/publication/2520217_The_Economic_Importance_of_Crop_Rotation_Systems_Evidence_from_the_Literature, 2001.

[75] J. J. Goplen, J. A. Coulter, C. C. Sheaffer et al., “Economic performance of crop rotations in the presence of herbicide-resistant giant ragweed,” *Agronomy Journal*, vol. 110, no. 1, pp. 260–268, 2018.

[76] F. Goletti, *Agricultural Diversification and Rural Industrialization as a Strategy for Rural Income Growth and Poverty Reduction in Indochina and Myanmar*, International Food Policy Research Institute (IFPRI), Accessed: May 29, 2021. [Online]. Available: https://ideas.repec.org/p/fpr/mtiddp/30.html, 1999.

[77] C. Makate, R. Wang, M. Makate, and N. Mango, “Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change,” *SpringerPlus*, vol. 5, no. 1, p. 1135, 2016.

[78] B. Bravo-Ureta, H. Cocchi, and D. Solis, *Output Diversification Among Small-Scale Hillside Farmers in El Salvador*, Research Papers in Economics (RePEc), Inter-American Development Bank, Washington, DC, USA, 2006.

[79] S. G. Perz, “Are agricultural production and forest conservation compatible? Agricultural diversity, agricultural incomes and primary forest cover among small farm colonists in the Amazon,” *World Development*, vol. 32, no. 6, pp. 957–977, 2004.

[80] J. Hansen, J. Hellin, T. Rosenstock et al., “Climate risk management and rural poverty reduction,” *Agricultural Systems*, vol. 172, pp. 28–46, 2019.

[81] R. A. Jat, R. A. Dungrani, M. K. Arvadia, and K. L. Sahrawat, “Diversification of rice (Oryza sativaL.)-based cropping systems for higher productivity, resource-use efficiency and economic returns in south Gujarat, India,” *Archives of Agronomy and Soil Science*, vol. 58, no. 6, pp. 561–572, 2012.

[82] S. R. Gliessman and A. M. Amador, “Ecological aspects of production in traditional agroecosystems in the humid lowland tropics of Mexico,” in *Proceedings of the International Symposium on Tropical Ecology*, pp. 601–608, Kuala Lumpur, Malaysia, Apr 1979.

[83] C. Kelly, “Lower external input farming methods as a more sustainable-olution for small-scale farmers,” Thesis, University of Stellenbosch, Stellenbosch, South Africa, 2008.

[84] M. E. Jones, R. R. Harwood, N. C. Dehne, J. Smeenk, and E. Parker, “Enhancing soil nitrogen mineralization and corn yield with overseeded cover crops,” *Journal of Soil and Water Conservation*, vol. 53, no. 3, pp. 245–249, 1998.

[85] S. Snapp, S. Switton, R. Labarta et al., *REVIEW and INTERPRETATION Evaluating Cover Crops for Benefits, Costs and Performance within Cropping System Niches*, vol. 97, pp. 322–332, 2015.

[86] F. W. Geels, “The multi-level perspective on sustainability transitions: responses to seven criticisms,” *Environmental Innovation and Societal Transitions*, vol. 1, no. 1, pp. 24–40, 2011.

[87] J.-M. Meynard, F. Charrier, M. H. Fares et al., “Socio-technical lock-in hinders crop diversification in France,” *Agronomy for Sustainable Development*, vol. 38, no. 5, p. 54, 2018.

[88] L. Ponisio and P. Ehrlich, “Diversification, yield and a new agricultural revolution: problems and prospects,” *Sustainability*, vol. 8, no. 11, p. 1118, 2016.

[89] G. E. Roesch-McNally, J. G. Arbuckle, and J. C. Tyndall, “Barriers to implementing climate resilient agricultural strategies: the case of crop diversification in the U.S. Corn Belt,” *Global Environmental Change*, vol. 48, pp. 206–215, 2018.

[90] F. Tian, L. Zhou, Z. Zhang et al., “Paucity of nanolayering in resin-dentin interfaces of MDP-based adhesives,” *Journal of Dental Research*, vol. 95, no. 4, pp. 380–387, 2016.

[91] T. B. Karki and J. Shrestha, “Conservation agriculture: significance, challenges and opportunities in Nepal,” *Advances in Plants & Agriculture Research*, vol. 1, no. 5, 2014.

[92] R. C. Atwell, L. A. Schulte, and L. M. Westphal, “Linking resilience theory and diffusion of innovations theory to understand the potential for perennials in the U.S. Corn belt,” *Ecology and Society*, vol. 14, no. 1, p. art30, 2009.

[93] M. Ijaz, A. Nawaz, S. Ul-Allah et al., “Crop diversification and food security,” in *Agronomic Crops*, M. Hasanuzzaman, Ed., pp. 607–621, Volume 1: Production Technologies, Springer, Singapore, 2012.