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Review Paper

Seasonal Crop Diversity in Afghanistan: Implications for Agricultural Sustainability and Food Security

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***Abstract*— This study investigates the role of seasonal crop diversity classified into Kharif, Rabi, and Zaid seasons in enhancing agricultural sustainability and food security in Afghanistan. Given the country's vulnerability to climate variability and political instability, optimizing seasonal cropping strategies is critical for improving resilience and productivity in farming systems. A qualitative literature review was conducted, synthesizing findings from peer-reviewed publications, extension materials, and policy documents to examine the ecological, agronomic, and socioeconomic dimensions of seasonal cropping. The analysis focuses on agroecological compatibility, crop rotation benefits, and the integration of legumes and climate-smart practices. Results indicate that aligning cropping patterns with seasonal climatic conditions significantly improves resource use efficiency, particularly in terms of water and nitrogen management. The inclusion of legumes such as alfalfa enhances nitrogen fixation, reduces dependence on synthetic fertilizers, and contributes to soil fertility and crop productivity. Improved irrigation practices and residue management further support environmental sustainability and economic feasibility. The findings underscore the importance of integrating traditional agricultural knowledge with modern technologies to address food insecurity and adapt to climate change. The study concludes that a holistic approach incorporating seasonal crop planning, legume integration, and climate-resilient practices is essential to strengthen Afghanistan's agricultural systems and ensure long-term food security.**

Keywords*— Seasonal Crop Diversity, Agricultural Sustainability, Food Security, Climate-Smart Agriculture, Legume Integration

I. Introduction

Agricultural sustainability and food security remain critical global challenges, particularly in developing nations such as Afghanistan, where mixed crop-livestock systems form the backbone of rural livelihoods. These integrated systems support nearly half of the global food supply, relying on synergistic interactions between crops and livestock to recycle nutrients, generate income, and ensure resilience [23, 61]. However, escalating pressures from climate change, soil nutrient depletion, and population growth have increasingly undermined their effectiveness, especially in fragile agroecological zones [78].

Existing literature emphasizes the role of N cycling, integrated weed management, and optimized irrigation in enhancing crop yields and soil fertility across diverse contexts, including Afghanistan [4, 33, 83]. Despite these technical advances, Afghan smallholder farmers continue to face compounded barriers such as inadequate food safety regulations, limited access to markets, and climate-induced vulnerabilities [52, 60]. While some studies have proposed climate-smart agriculture, crop diversification, and the incorporation of legumes to improve soil health and reduce input dependency there remains a lack of context-specific research on seasonal crop planning in relation to sustainability outcomes [36, 57]. The purpose of this study is to explore the role of seasonal crop diversity specifically the categorization of crops into Kharif, Rabi, and Zaid seasons in improving agricultural sustainability and food security in Afghanistan. By synthesizing existing research on crop-livestock integration, N management, and the ecological benefits of legumes, this study seeks to inform adaptive strategies that address the multifaceted challenges facing Afghanistan agriculture. We hypothesize that the strategic integration of seasonal crop diversification, climate-smart practices, and legume-based systems can significantly enhance farm productivity, soil nutrient balance, and economic resilience in Afghanistan's mixed farming systems. This review contributes to the literature by filling a key gap: while global studies acknowledge the theoretical benefits of seasonal cropping and legume integration, few have examined how these practices operate under Afghanistan's unique political, climatic, and socio-economic conditions. Through a qualitative synthesis of peer-reviewed studies and regional data, this study aims to bridge this knowledge gap and offer actionable insights for sustainable agricultural development.

II. Research Methods

This study employed a qualitative research design, specifically a literature review methodology, to investigate the role of seasonal crop diversity categorized into Kharif, Rabi, and Zaid crops in advancing agricultural sustainability and food security in Afghanistan. The primary objective was to synthesize and critically evaluate existing research and empirical evidence relevant to seasonal cropping systems within the Afghanistan context and comparable agroecological settings. Data were collected through an extensive and targeted review of secondary sources, including peer-reviewed journal articles, agricultural extension reports, academic dissertations, government publications, and authoritative reference texts. The core reference document was titled "Seasonal Crop Diversity in Afghanistan: Implications for Agricultural Sustainability and Food Security", which provided detailed classifications of seasonal crops, farming practices, and their alignment with climatic patterns. Supplementary literature was retrieved from reputable academic databases such as Google Scholar, ScienceDirect, and AGRIS, using keyword combinations such as "seasonal food crops," "Kharif and Rabi agriculture," "crop diversity," and "agricultural sustainability." The inclusion criteria focused on sources directly related to seasonal cropping patterns, crop productivity, agroecological adaptation, and their implications for food security. Data were analyzed using thematic content analysis, allowing for the categorization of findings into key themes such as crop seasonality, soil fertility, economic feasibility, and climate resilience. This structured synthesis enabled a comparative analysis of seasonal cropping practices and their contributions to sustainable agriculture, with particular emphasis on South Asia and Afghanistan. Given that the study was based solely on secondary data and did not involve direct human participation, no ethical approval or informed consent was required. Nonetheless, academic integrity was upheld through rigorous citation and acknowledgment of all sources utilized. A notable limitation of this study is its reliance on existing literature, which may not fully capture emerging trends or region-specific farming innovations currently in practice. Future empirical research involving fieldwork and primary data collection is recommended to validate and expand upon the findings of this review.

III. Results And Discussion

A. *The role of nitrogen cycling in integrated farming systems*

Integrated farming systems, which combine crops and livestock, play an important role in Nutrient cycling and sustainable agriculture, especially in developing countries. These systems contribute significantly to nutrient flows, with up to 76% of nutrient cycling through integrated crop and livestock practices [17]. Nitrogen cycling is particularly important, with an estimated 60-70% of N in plant biomass being recycled and resorbed [22]. However, challenges remain, including nutrient depletion in arable land and insufficient manure to maintain soil fertility [61]. Improved management practices, such as collecting liquid manure, can reduce nutrient losses and improve system performance [17]. Despite these benefits, integrated farming systems still face obstacles, such as pest infestations after grass/alfalfa tillage [44]. As population pressures increase in semi-arid regions, the shift to more intensive, higher-input production patterns presents both opportunities and challenges for achieving long-term production growth [61].

1) Role of Legumes in Nitrogen Fixation: Legumes play an important role in N fixation and sustainable agriculture in Afghanistan and around the world. Studies have found that the presence of multiple strains of rhizobia in Afghanistan soils significantly promoted the growth and N fixation of alfalfa [19]. Inoculation of legumes with rhizobia and the addition of a starting dose of N increased forage yield and nodule formation in a variety of forage crops such as clover, and alfalfa [2]. Forage legumes contribute positively to livestock nutrition, soil fertility, biodiversity, and carbon sequestration, while also helping to mitigate the effects of climate change [43]. Studies have shown that forage legumes can fix up to 90% of N requirements, with some species (such as alfalfa) fixing up to 770 kg of N per hectare per year [11]. These findings highlight the importance of legumes in sustainable agricultural systems, especially in N-limited environments such as Afghanistan. Legumes' significant contribution to N fixation reduces reliance on synthetic fertilizers. Alfalfa exhibits the highest N fixation capacity, making it an ideal choice for arid regions such as Afghanistan [11 ,2] (see Fig 1).

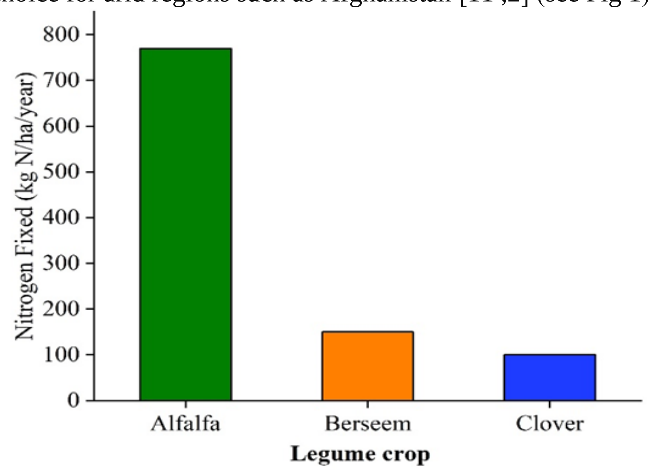

Fig. 1. Nitrogen fixation rates of leguminous forages

2) Nitrogen input-output dynamics in crop-livestock systems: Nitrogen cycling in crop-livestock systems is a complex process involving multiple components and pathways [22]. The global N surplus in these systems has increased significantly over the past century, raising environmental concerns [9]. In China, various livestock systems contribute differently to the nitrogen budget, with landless industrial systems accounting for the majority of mineral fertilizer use and feed imports [29]. Livestock systems in Africa face unique challenges with regard to N budgets due to data limitations and uncertainties regarding factors such as livestock density, excretion rates, and manure management [64]. Improving N use efficiency and reducing losses will require a combination of strategies, including better integration of animal manure into crop production, matching N supply to livestock requirements, and possible dietary adjustments [9, 29]. Future research should focus on collecting spatial livestock data and assessing N flows beyond crop fields to include livestock and crop-livestock interactions [64] (Fig. 2).

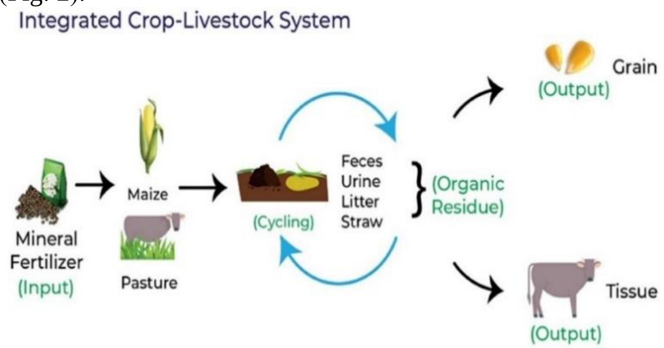

Fig. 2. A representation of the inputs and outputs of nitrogen and organic residues generated in the integrated systems [55].

3) Comparison of Maize–Vetch and Wheat–Alfalfa in Soil Nitrogen Enrichment :Legume crops significantly improve soil properties and enhance the yields of subsequent crops such as corn and wheat [53]. Alfalfa residues, in particular, have shown beneficial effects by increasing wheat yield by up to 1.7 tons per hectare compared to control treatments, while consistently providing N release that aligns with crop demand [32]. Incorporating vetch during the flowering stage within rotation systems maximizes N uptake and yields for subsequent crops [15]. In the North China Plain, intercropping systems of alfalfa-silage Maize demonstrated productivity and profitability comparable to traditional wheat-maize rotations, while also reducing environmental impacts due to lower irrigation and N fertilizer requirements [82]. These studies underscore the potential of legume-based cropping systems, particularly those involving alfalfa and vetch, to enhance soil fertility, crop yields, and sustainability across various agricultural contexts. Alfalfa-based systems outperform vetch in terms of yield and N efficiency, providing sustainable alternatives to traditional rotation practices [32, 82] (Table I).

TABLE I. COMPARISON OF MAIZE-VETCH AND WHEAT-ALFALFA SYSTEMS

System	***Yield (t/h)***	***Nitrogen (kg/h)***	***Environmental***
Maize-Vetch	1.2	40	Moderate
Wheat-Alfalfa	1.7	60	Low

4) Nitrogen loss pathways *and their environmental impacts:* Nitrogen losses in agricultural systems pose significant risks to the environment and health. These losses occur through multiple pathways, including ammonia emissions, nitrate leaching, and nitrous oxide emissions [10]. Ammonia can cause acid rain, while nitrate leaching can cause eutrophication of water bodies and contaminate drinking water sources [10]. Nitrous oxide is a potent greenhouse gas that contributes to ozone depletion and climate change [10, 59]. In Afghanistan, climate change has exacerbated air pollution, leading to increased respiratory diseases and mortality [37]. As the N fixation by legume crops are most important to control environmental pollution while, Agricultural non-point source pollution, mainly due to nitrogen fertilizer application, causing environmental degradation [29]. Factors that affect N losses include precipitation, soil properties, and land use practices [29]. To mitigate these impacts, soil and plant systems must be carefully managed, best practices implemented, and new technologies developed to achieve sustainable agriculture and environmental protection [10].

B. Economic feasibility

1) Input costs and resource requirements: This section synthesizes findings from studies on agricultural systems in Afghanistan and China, with attention to costs, yields, and returns. In China, alfalfa-maize intercropping achieved comparable productivity and profitability to wheat-maize systems, with environmental benefits such as reduced nitrogen leaching and irrigation use. Xu and his group reported net returns of approximately $950–1,050/ha for alfalfa-maize systems [82]. In Afghanistan, Maletta analyzed wheat production and found average net returns ranging between $420–530/ha, accounting for both grain and residue values [49]. Hashimi and his group reported that rice-wheat systems in Khost, while yielding slightly less than conventional methods, reduced input costs by 15–20% and improved soil organic matter through organic fertilizer use [20]. An urban agriculture study in Kabul found that vegetable farming provided the highest net returns, averaging $1,300/ha, followed by cereal crops at around $600/ha, while grape cultivation yielded the lowest returns at under $400/ha [66]. These findings emphasize the importance of evaluating cropping systems not just for yield, but also for input efficiency, environmental performance, and net profitability[34]. These studies highlight those multiple factors must be considered when evaluating agricultural systems in these regions, including environmental impacts, soil quality, and economic viability. Vegetable cultivation brought the highest returns, while the alfalfa-corn system achieved a good balance between profitability and environmental benefits [66, 82] (see Fig 3).

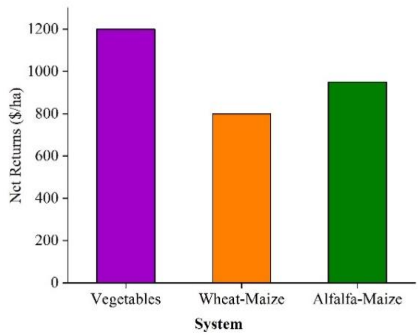

Fig. 3. Profitability of cropping systems in Afghanistan

2) Forage biomass production and livestock productivity: Forage productivity is vital for livestock-based systems. In dry temperate rangelands, seasonal rainfall patterns dictate biomass production, peaking in July and August [26]. Improved management such as optimal tillage, sowing timing, and nitrogen application has shown to increase forage yield by up to 25% and boost crude protein content by 10–15% [42]. Intercropping cereals with legumes (e.g., maize with cowpea or vetch) improved biomass quantity and quality, with forage yields increasing by 1.2–1.7 tons/ha, depending on the system. These practices can significantly reduce feed costs and enhance livestock productivity, particularly in resource-constrained environments.

3) Net returns and system profitability: Studies consistently show that alfalfa-based intercropping systems outperform or match conventional rotations in profitability. Xu and his group reported net returns of $980/ha for alfalfa-maize intercropping, compared to $890/ha for wheat-maize systems, with reduced nitrogen inputs [82]. In Afghanistan, vegetable farming remains the most profitable urban farming activity with returns exceeding $1,200/ha, while cereal cropping yielded around $600–700/ha, and grape cultivation provided under $450/ha [67]. Singer and his group found that incorporating alfalfa in rotation increased returns by 15–20% over continuous maize systems [74]. In Pakistan, Ahmad and his group showed that combining farm compost with urea in high-density maize cropping increased net income to $1,100/ha, demonstrating the benefit of integrated nutrient strategies [1]. These findings support the conclusion that diversified cropping systems especially those incorporating legumes offer higher economic Food Agricultural Sciences and Technology (FAST) returns while maintaining environmental sustainability.

4) Economic resilience in diverse agro-climatic zones: Climate change poses significant challenges to Afghanistan's agricultural sector and rural livelihoods in diverse agro-climatic zones. In the eastern region, climate change has caused internal displacement, changes in cropping patterns, and migration as a coping strategy [69]. Farmers in the central region have adapted by adjusting cropping patterns and seeking expert advice, and education and technical information have had a positive impact on willingness to purchase crop insurance [70]. The Pamir Mountains demonstrate how ethnic and cultural diversity can enhance resilience and food security in the face of environmental change [35]. Meanwhile, a study of winter wheat in four agro-climatic zones showed that soil pH significantly affected yield and quality, and the application of N and phosphorus fertilizers increased yield and protein content. Site-specific fertilizer recommendations based on economic returns can benefit farmers in different regions [62]. These studies highlight the importance of developing tailored strategies to enhance economic resilience in each agro-climatic zone of Afghanistan, such as implementing crop insurance in the central region to improve adaptation to climate change [62] (Table II).

TABLE II. ECONOMIC RESILIENCE STRATEGIES IN VARIOUS AGROCLIMATIC ZONES OF AFGHANISTAN

Zone	***Adaptation strategy***	***Key crops***
Eastern	Crop diversification, migration	Wheat, Maize
Central	Crop insurance, expert consultations	Barley, Alfalfa
Pamir Mountains	Traditional practices, food sovereignty	Legumes, Potatoes

C. Food safety impact

Afghanistan faces major challenges in food safety, largely due to an inadequate regulatory system and fragmented institutional responsibilities [52]. Although the poultry sector is growing, it continues to struggle with contamination from foodborne pathogens and chemical residues in meat and eggs [16]. Traditional food production and storage practices especially those involving fruits also contribute to the risk of aflatoxin contamination, posing significant public health risks [54]. The overall food safety situation has been further undermined by conflict, economic instability, and the COVID-19 pandemic, which have reduced food availability and limited access to safe and nutritious food [28]. To address these concerns, researchers and policy experts have proposed several solutions: establishing a unified national food safety authority, improving coordination among health and veterinary sectors, raising awareness of safe food handling practices, and advancing international cooperation to reduce food insecurity [16, 28, 52, 54].

1) Nitrate accumulation and animal health risks: Nitrate accumulation in feed and groundwater represents a significant food safety concern, with both human and livestock health implications. In Afghanistan, urban groundwater frequently exceeds safe nitrate levels, posing a non-carcinogenic risk to humans [72]. Similar findings in Pakistan's Khyber region reveal high nitrate concentrations that threaten child health [7]. Drought conditions worsen the problem by promoting nitrate buildup in forage crops. When consumed by livestock, these nitrates are converted in the rumen into toxic nitrites, which impair oxygen transport in the blood a condition known as methemoglobinemia [21, 48]. Young and pregnant animals are especially vulnerable. Agricultural runoff and untreated urban sewage are major contributors to this contamination [7, 72], emphasizing the need for better fertilizer application practices and groundwater monitoring (Table .III).

TABLE III. NITRATE POLLUTION RISK IN AFGHANISTAN

Source	Nitrate level (mg/L)	Health risk
Groundwater (Urban)	45–90	Non-carcinogenic (high)
Forage (Drought)	1,500–2,000	Livestock poisoning

2) Manure management and microbial contamination: While nitrate contamination stems largely from fertilizer overuse and sewage runoff, poor manure management represents another serious threat to food and water safety in Afghanistan Manure often carries microbial pathogens, including E. coli, which can contaminate crops and water sources. For example, vegetables irrigated with untreated wastewater in Kabul were found to contain heavy metals and fecal pathogens at levels exceeding international safety standards [66]. Modeling in the Kabul River Basin identified untreated human and livestock waste as primary sources of E. coli contamination [27]. Additionally, improper land application of manure can lead to groundwater contamination via leaching, especially under intermittent wet-dry irrigation cycles [6]. Pathogens transmitted via manure including bacteria, protozoa, and viruses pose health risks to both humans and animals. Recommended mitigation strategies include composting, applying manure in controlled doses, and using vegetative filter strips to reduce runoff [58]. Beyond contamination risks during cultivation, food safety in Afghanistan is also compromised by poor post-harvest handling and storage particularly for cereals and legumes in rural areas. Inadequate storage methods can lead to losses from pests, spoilage, and fungal contamination. Sealed storage technologies such as PICS bags have shown promise in reducing post-harvest wheat losses by 70–80%, compared to 30–40% loss rates using conventional polypropylene sacks [3]. These hermetic methods not only preserve grain quality and seed viability but also reduce exposure to moisture and mold. Studies in Uganda and elsewhere have confirmed that storage is one of the most critical points for food safety risks, particularly in climates affected by extreme temperature and humidity fluctuations [77, 80]. In Afghanistan, scaling up cost-effective storage solutions could have a significant impact on food security and farmer income (Table.IV).

TABLE IV. POST-HARVEST LOSS REDUCTION METHODS

Method	Loss reduction (%)	Cost efficiency
Hermetic (PICS bags)	70- 80	High
Traditional Sacks	30-40	Low

3) Local practices and food safety awareness: Wheat remains Afghanistan's dietary cornerstone, accounting for 60–75% of total caloric intake [76]). However, safety concerns remain significant. In past incidents, wheat flour contaminated with pyrrolizidine alkaloids led to outbreaks of hepatic veno-occlusive disease [30], underscoring the need for stronger quality control. In response, private seed companies have begun offering certified wheat varieties with higher yields, disease resistance, and early maturity [41]. Adoption of these varieties, combined with proper fertilizer use, has shown to significantly improve productivity. In parallel, non-governmental organizations have implemented wheat seed improvement projects to support rural livelihoods [14]. Nonetheless, food safety awareness remains low in many farming communities. Outreach and training programs aimed at promoting hygienic food handling, pesticide safety, and improved storage are essential for safeguarding both public health and agricultural resilience.

D. Comprehensive and comparative insights

This synthesis examines the challenges facing development in Afghanistan. The country faces significant health challenges, including a prevalence of hepatitis C virus ranging from 0.7% in the general population to 32.6% among injecting drug users [13]. Agricultural development is critical as the sector provides livelihoods for nearly 80% of Afghans. The Ministry of Agriculture's extension services work with non-governmental organizations to improve agricultural production and implement extension programs [39]. In addition, Afghanistan has undergone a disarmament, demobilization, and reintegration process, and NGOs have played an important role in post-conflict reconstruction [38]. These studies highlight the multiple challenges facing Afghanistan, including public health issues, the need for agricultural rehabilitation, and the complexity of post-conflict recovery, and emphasize the importance of both government and non-governmental institutions in addressing these issues.

1) Summary of agricultural performance: Recent studies have highlighted the challenges and opportunities facing Afghanistan's agricultural sector, particularly in crop production. Improved crop varieties have shown significant yield advantages over local varieties, with yields of wheat, rice, mung beans, and potatoes increasing by 57-70% [63]. However, Afghanistan still faces food security and malnutrition issues, with rice production meeting only 50% of domestic demand [31]. Wheat, a staple food, has a large yield gap due to factors such as low adoption of improved varieties and recommended agricultural management practices [79]. To achieve food self-sufficiency, a multi-pronged approach combining technology adoption, research projects, and community empowerment is needed [73]. Improving the technical efficiency of wheat production, which currently stands at 67%, could significantly narrow the yield gap and reduce dependence on imports [79]. These efforts are critical to improving food security and strengthening the Afghan economy. The adoption of improved seeds and fertilizers could reduce the yield gap to 1.2 tons per hectare [79] (Table V).

TABLE V. YIELD GAPS IN WHEAT PRODUCTION IN AFGHANISTAN

Factor	Yield gap (t/ha)	Solution
Low seed quality	0.8–1.2	Certified seeds
Poor fertilization	0.5–0.7	Balanced NPK application

2) Economic trade-Offs and risk analysis: The economic and environmental trade-offs of sustainable agricultural systems have been widely studied. Cover crop-based systems can achieve high profitability and low erosion risk, but may result in increased N losses [47]. Organic systems offer lower profit variability, attracting risk-averse farmers, but may result in increased phosphorus losses [47]. Economic insights are critical for managing N in agricultural systems and help balance production, risk, and environmental impacts [57]. Winter legumes can replace N in corn production, and alfalfa with moderate nitrogen fertilization can maximize expected net income under various risk attitudes [45]. However, legume cover crops not only increase the average corn yield, but also increase the variance of yield, which may increase farmers' economic risk [56]. Risk-averse farmers may prefer to use alfalfa without additional N fertilizer, while risk-neutral farmers may choose alfalfa with moderate N fertilization [56].

3) Comparison of food safety risks: This summary compares different cropping systems and their impacts on productivity, economic, and environmental factors. In China, alfalfa-maize intercropping showed comparable productivity and profitability to wheat-maize systems, while having lower environmental impacts [82]. In US, alfalfa cover crops with N fertilizers were found to have efficiency risks for no-till maize production [46]. In Afghanistan, rice-wheat systems with organic fertilizers improved soil quality and increased net income, although yields were slightly lower compared to conventional agriculture [20]. The study also highlighted the potential for soil carbon sequestration in these systems. However, Afghanistan's current food safety regulatory system faces challenges with overlapping institutional responsibilities [52]. These findings suggest that the integration of legumes and organic fertilizers could provide economic and environmental benefits to cropping systems, while improved regulatory structures may be necessary to ensure food safety.

4) Adoption potential and farmer constraints: Diversification of maize-based cropping systems to pulses offers the potential for sustainable intensification and improved soil fertility in smallholder farms in Africa [8, 51, 75]. Several pulses, including kapok, cowpea, groundnut and heliotrope, have shown potential in improving maize yields and nitrogen fixation [8, 51]. However, adoption is constrained by land scarcity, seed availability, labour shortages and farmers' preference for pulses as edible food [8, 51]. Soil phosphorus deficiency and acidity also limit the productivity of pulses [51]. Market conditions, farm resources and household composition influence farmers' technology choices [75]. In Afghanistan, wheat is the main crop, but production faces challenges due to conflict-affected irrigation infrastructure and volatile climate [60]. Addressing these constraints through improved seed access, soil improvement, and market development could enhance the adoption of pulses and the sustainability of agriculture [51, 60].

IV. CONCLUSION

This study underscores the strategic importance of seasonal crop diversification specifically, the Kharif, Rabi, and Zaid cropping patterns in promoting agricultural sustainability and food security in Afghanistan. Integrating leguminous crops into these seasonal systems, particularly within mixed crop-livestock frameworks, has been shown to enhance N cycling, reduce fertilizer dependency, and strengthen ecosystem resilience. Among these, Kharif–Rabi–Zaid rotations that include high-value legumes like alfalfa and chickpea demonstrate strong potential for balancing profitability with ecological sustainability, especially in semi-arid zones. Climate-smart practices such as crop rotation, optimized irrigation scheduling, and residue management further improve soil health and mitigate risks posed by increasing climate variability. However, the adoption of these practices remains constrained by region-specific adaptation challenges, including water scarcity, limited extension services, and insufficient access to inputs and credit. A notable limitation of this study is its reliance on secondary data, which may not fully reflect evolving local practices or on-ground innovations. Future research should involve field-based empirical validation of Kharif–Rabi–Zaid cropping models under different agro-climatic conditions to assess agronomic performance, economic viability, and farmer adaptability. Additional studies should also explore context specific policy incentives, value chain development, and capacity building initiatives to support scalable implementation. Addressing these gaps will be critical for developing resilient, inclusive, and sustainable agricultural systems across Afghanistan.

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