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Pakistan: A Cost-Benefit Analysis of Crop Rotation Practice in the Rainfed Areas

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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1. Introduction

Climate change is one of the most pressing challenges confronting our global system today (Arora, 2019). The scientific community has clearly established that global temperatures are rising and the consequences of climate change may swiftly transition from an environmental risk to an economic threat (Throp, 2023). Agriculture sector is particularly vulnerable to changes in weather and climatic condition (Parker et al., 2019; Syed et al., 2022; OECD, 2022; Arora, 2019). Over 60% of the yield variability is chalked upto to climate change; significantly affecting food production and farmer income (Reidsma et al., 2009; Osborne and Wheeler 2013; Ray et al., 2015; Matiu et al., 2017). Changes in climate affect the onset and duration of crop growing cycle (Fiwa et al., 2014; Zhao et al., 2015; Lemma et al., 2016), and the extent and duration of heat and water stress impact agriculture production (Lobell et al., 2015; Saadi et al., 2015; Schauberger et al., 2017). Moreover, it may trigger pest and disease outbreaks causing significant production losses (Chakraborty and Newton, 2011).

Small-scale farmers in rain-fed areas of Pakistan face the severe susceptibility to the challenges brought about by climate change (Saqib et al., 2019). This vulnerability stems from their heavy dependence on traditional farming methods and their limited ability to adapt, exacerbated by their limited access to advanced technologies and high levels of poverty. Worldwide, crop yields from rainfed farming are approximately 50 percent less than those achieved through irrigated methods (Jaramillo et al., 2020). In the absence of adaptation measures to cope with climate change, a potential decline of around 50 percent in rain-fed agricultural yields could potentially occur within the next 30-35 years (Dube et al., 2016). Promoting climate smart agricultural practices appears to be a dependable strategy for addressing risks posed by climate change (Ng'ang'a et al., 2020).

Climate Smart Agriculture (CSA) has been proposed as "an approach for transforming and reorienting agricultural development under the new realities of climate" (Lipper et al., 2014). Examples of CSA practices include the use of drought-tolerant, high yielding, or early maturing varieties, minimum tillage, cover crops, intercropping, crop rotation, soil management using organic fertilizers such as compost and manure. One of the proposed methods for enhancing food production in an ecologically sustainable manner is crop rotation (Lin, 2011; Gaudin et al., 2015), as changing cropping patterns continuously increase soil fertility and microbial community stability (Song et al., 2018). Crop rotation is a beneficial management practice in which legumes are planted to enhance yield of successive cereal crops especially wheat (Zhao et al., 2015; Ilyas et al., 2018; Galantini et al., 2000).

Scientific research underlines that incorporating legume plants into crop rotation substantially boosts biological nitrogen fixation (BNF) (MacMillan et al., 2022; ; Evans et al., 2001), enhances plant yield (Shafi et al. 2006; Yaqub et al. 2010), breaks pests cycles (MacWilliam et al., 2014; Peralta et al., 2018; Diaz-Ambrona and Minguez, 2001; Pala et al., 2007), boost soil water conservation (Gan et al., 2015), and improve nitrogen recycling through their residual effect on the soil (Cazzato et al., 2012 ; Danga et al., 2009). Legumes because of their ability to improve soil properties (Becker and Johnson, 1999) are often referred to as the 'soil-building' crop (Zeng et al., 2016). Nitrogen stands out as a crucial nutrient for plants (Makino, 2011), and effective nitrogen management is a vital practice for maximizing wheat production, particularly in soils with limited nitrogen availability (Bakht et al., 2009). It is widely acknowledged that residual retention of legume plants adds organic nitrogen, leading to increase in soil organic matter and improvement of soil structure and microbial activity (Chu et al., 2004; Rahman et al., 2014; Rochester and Peoples, 2005; McDaniel & Grandy, 2016; Poeplau & Don, 2015; Campbell & Zentner,1993;), and greater crop productivity (Kumar and Goh, 2000). Inclusion of legumes in the soil results in elevated concentrations of nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) and high wheat yields (Li et al., 2011). Kumar and Goh (2002) found that wheat grain yields were notably higher in rotations involving leguminous crops when compared to rotations with non-leguminous crops. The process of nitrogen fixation by leguminous crops offers a cost-effective alternative to nitrogen fertilizers and particularly important in developing countries where many farmers have limited access to inorganic fertilizers, because of their limited availability, high cost, and low return on investment (Njunie et al., 2004). Commonly, legumes such as mung bean, bush bean, long bean, soybean, sesbania are used in rotation with other crops (Rahman et al., 2014; Khan et al., 2010). The primary reason for choosing legumes as a rotational crop during fallow periods is their ability to withstand moderate water stress conditions (Abhiram and Eeswaran, 2022).

2. Types of Legumes

Soybeans are grown in diverse climatic conditions worldwide and serve as a significant and affordable source of both high-quality protein and oil (Graham and Vance, 2003). Soybean cultivation is cost-effective method for enhancing soil fertility through nitrogen fixation (Chianu et al., 2009; Kasasa et al., 2000; Tran, 2004; Agomoh et al., 2021). The mutual association between soybean and rhizobium bacteria lowers production expenses because of the lesser use of N fertilizers for cereal crops following soybean cultivation, rendering soybean an excellent choice for rotation with nitrogen-intensive crops (Varvel and Peterson, 1992). Growing wheat followed by soybean cultivation is expected to be more profitable than growing either corn or soybeans (Schnitkey et al., 2022). Yang et al., (2014) found that crop rotation of soybean green manure with wheat led to increases in yield of wheat crop when compared to fallow-wheat rotation. These benefits became more pronounced over time with a 21 percent higher yield in the second year and 12 percent higher yield in the third year in comparison to the highest wheat yield in fallow-wheat rotation. Furthermore, employing soybean in crop rotation with wheat led to a decline in the usage of nitrogen fertilizers.

Mung bean is a rapidly sprouting plant with a brief life cycle, which consumes relatively less water when compared to numerous other agricultural crops grown in fields. Mung bean cultivation is known to increase nitrogen availability in soil (Alvey et al. 2001; Rahman et al. 2014), enhance micronutrient availability and total organic carbon in soil (Surekha et al., 2003; Shafi et al., 2006), reduce pest infestation (Nadeem et al., 2019; Peiris et al., 2016), consequently improving the soil structure (Hayat and Ali 2004). Wheat cultivated after mung bean and proper fertilization exhibits superior growth compared to wheat following a period of fallow (Sharma, Prasad, and Singh 1996; Hayat and Ali 2004; Rahman et al. 2014). Ilyas et al., (2018) found positive effects of rotation of wheat and mung bean on physiochemical and biochemical parameters of soil in terms of increase in soil organic matter, water content, nitrogen, nitrate nitrogen, phosphorus and sugar content when compared to the fallow treatment. 17.8 percent increase in wheat yield was reported which was cultivated after mung bean and fertilized with NPK in comparison to wheat cultivated on fallow land. Bakht et al., (2009) reported that rotation of mung-bean with wheat increased the yield of wheat by 2.09 times. Ahmad et al. (2001) reported that incorporating mung bean and black gram into the rotation led to an increase in wheat yields ranging from 600 to 1100 kg per hectare compared to yields obtained from a cereal-cereal rotation. Shah et al., (2003) reported that grain yields were higher after retaining the residues of mung-bean.

Sesbania (commonly known as Jantar in Pakistan) is a versatile green manure crop primarily cultivated during the summer season. Green manuring involves cultivating crops, particularly legumes, and incorporating them into the soil when they are fresh and decomposed at the reproductive phase of their growth cycle, for the purpose of soil improvement by protecting it against erosion and enhancing the overall quality (Khan et al., 2010; Fageria, 2007; Sajjad et al., 2019). Green manure acts as an organic fertilizer (Yang, 2014), and aids in preservation of soil moisture (Sajjad et al., 2018), and is regarded as a feasible substitute to summer fallowing in agricultural systems (Mooleki et al., 2016). Sesbania incorporation in soil adds 60–80 kg per hectare nitrogen (Qazi et al., 2023). They report enhanced yield of wheat and rice grain after applying sesbania with the recommended dose of fertilizer along with increased profits. Incorporation of green manure in the form of green gram and sesbania led to improvement in soil aggregation, reduced bulk density, and enhancement of water flow properties, ultimately increasing crop growth (Mandal et al., 2003).

3. Purpose of the Study

This study has been conducted in the selected areas of the rain-fed zone in Pakistan. The study aims to investigate three crop rotation treatments (1) soybean-wheat, (2) mung bean-wheat, and (3) sesbania-wheat impact on the yield of subsequent wheat crop and assess the feasibility of these interventions based on benefit-cost ratios (BCR). For this purpose, 15 farmers were targeted after consultation with the concerned agriculture extension department. The Legume-based fallow system is ideal for smallholder farming and nutrient-depleted soils due to continuous cultivation. Instead of employing a traditional bare summer fallow period, catch crops can be sown and subsequently integrated into the soil before planting winter wheat. This approach aims to reduce reliance on chemical fertilizer inputs (Yang et al., 2014). We hypothesize that legume-wheat rotation leads to an increase in wheat crop yield resulting in higher income for the farmer. The study is organized as follows: section 4 introduces the study sites and describes the methodology. Section 5 highlights the findings, and the discussions and section 6 conclude the study.

4. Methodology

4.1. Study areas

The Consortium for Scaling-up Climate Smart Agriculture (C-SUCSeS) project has been implemented by Pakistan Agricultural Research Council (PARC) in Pakistan. The project aims at improving the resilience of smallholder farmers by promoting the uptake of climate smart pro-poor innovations that increase productivity and water management efficiency. Under the project, three crop rotation experiments were carried out in 5 cities that characterize a rain-fed (barani) cropping system located in the Northern Punjab region of Pakistan, commonly known as the Potohar Plateau: Attock, Chakwal, Gujjar Khan, Kallar Syedan, and Taxila. The plateau constitutes Pakistan's largest block of rain-fed agriculture as 96 percent of the agriculture production is dependent upon rain while the remaining 4 percent of the cultivated land is irrigated (Majeed et al., 2010). The streams are deeply entrenched and not very suitable for irrigation purposes. The area is located between the Indus River and the Jhelum River and stretches from the salt range northward to the foothills of the Himalayas and is approximately between 32.5°N and 34.0°N latitude and 72°E and 74°E longitude (Amir et al., 2019). The total area of the region is approximately 13,000 square kilometers, and its altitude ranges from 305 to 610 meters above sea level (Amir et al., 2019). The region has a varied topography with highly rolling terrain. The region experiences a semi-arid to humid climate and is characterized by low fertility and erratic rainfall. About 80 percent of the rain fall occur during July through October (Sarwar et al., 2016). The annual precipitation ranges from 250 mm in the southern region of the Salt Range to more than 1500 mm in Islamabad. The winter temperature typically ranges between 4°C and 25°C while in summer, the temperature is between 15° C and 40° C. Major crops cultivated in the region include wheat, maize, barley, millet, gram, groundnut (Rashid and Rasul, 2011).

Attock is situated near the Haro River, 80 kilometers (50 miles) from Rawalpindi and 100 kilometers (62 miles) from Peshawar. Hills, plateaus, and divided plains make up most of the district's topography. The district receives rainfall throughout the year with varying intensity. The annual temperature varies from 39°F4°C to 104°F.[1] Chakwal district is bordered by Rawalpindi on the northeast, Attock district on the northwest, by Jhelum district on the east, by Khushab district on south and the Mianwali district on the west. The district spans a total area of 7,547 square kilometers. Chakwal is a barani (rain-fed) district located in the Potohar plateau. The landscape is hilly, covered with scrub forest in the southwest, and flat plains with dry rocky patches in the north and northeast. [2] [3]

Gujar Khan is situated in the southeast of Islamabad (Hussain, 2004) with Jhelum River on the east. The climate in the region is characterized as subtropical desert, with an annual temperature of 32ºC which is higher than the average temperature in Pakistan, and an annual precipitation of 48.99 rainy days.[4] [5] Kallar Sayedan is located northeast of Rawalpindi, approximately 4.5 kilometers away. The region has a subtropical humid climate. [6] [7] Taxila is located off the Grand Trunk Road, 32 kilometers to the northwest of Islamabad Capital Territory and Rawalpindi. Taxila lies 549 meters (1,801 ft) above sea-level. The winters are calm and pleasant with temperatures ranging from 5° to 15° C. The summers are extremely hot, with temperatures rising to a maximum of over 40° C.[8]

4.2. Experiment set-up and treatments

Farmers keep their land fallow and plough up the land numerous times to conserve soil moisture for wheat crop cultivation during Kharif season in rainfed areas. The predominant system for the past decades has been fallow-wheat. The traditional practice of fallow system involves leaving the land uncultivated for a specific duration to replenish soil nutrients and moisture. This approach, however, renders the land unproductive and unprofitable for farmers during this period. Cultivation of legume crops in the fallow period is an effective alternative strategy to conserve soil moisture as a mitigation for erratic rainfall (Abhiram and Eeswaran, 2022).

The experiment for conducting soil amendments through legume-wheat rotation commenced in June 2022 with legume crop cultivation in summer and wheat cultivation in winter. The three crop rotation experiments were laid out according to randomized complete block design under a split-plot arrangement where two sets of wheat crops were grown, one was grown after the selected legume crop cultivation and second after the

[1] Available at: https://attock.punjab.gov.pk/climate
[2] Available at: https://chakwal.punjab.gov.pk/geography
[3] Available at: https://www.findpk.com/cities/explorer-pakistan-chakwal.html#:~:text=Lying%20at%20the%20beginning%20of,in%20the%20north%20and%20northeast.
[4] Available at: https://www.prideofpakistan.com/pakistan-city-details/Do-you-know-Gujar-Khan-is-also-referred-to-as-the-Land-of-the-Shaheeds/23
[5] Available at: https://tcktcktck.org/pakistan/punjab/gujar-khan#google_vignette
[6] Available at: https://rawalpindi.dc.lhc.gov.pk/PublicPages/HistoryOfDistrict.aspx
[7] Available at: https://en.db-city.com/Pakistan--Punjab--Rawalpindi--Kallar-Syedan
[8] Somuncu, M., & Khan, A. A. (2010). Current Status of Management and Protection of Taxila World Heritage Site, Pakistan. *Ankara Üniversitesi Çevrebilimleri Dergisi*, *2*(1), 45-60.

fallow period. Crop rotation treatments included: (1) soybean-wheat, (2) mung bean-wheat, and (3) sesbania-wheat. All the three legume crops were sown in end June – beginning of July and harvested in the soil in end August - beginning of September. Sesbania and mung-bean were used as green manure, a rotovator was used to mix sesbania and mung-bean in the soil.

Technical support was provided to farmers by the agriculture scientists at PARC and department of extension representatives such as information regarding timely planting of crops, timely and judicious application of different inputs such as fertilizers and weedicides. A field demonstration was held on each farmer's land, and farmers were provided with free of cost seeds and fertilizers to expand the experiment on their total land area. Capacity building of farmers was done through participatory farmer field days. One farmer-field day was held in each targeted city for knowledge sharing. Moreover, four monitoring visits were conducted on each site to assess if the rates and timing of the fertilizers were as per the recommendations made by the PARC team. These crop rotation experiments were designed to study the effects of growing legume crops on the yield of subsequent wheat crops.

4.3. Benefit-Cost Analysis of the CSA Intervention

Numerous studies on climate adaptation research have employed cost-benefit analysis (CBA) to gauge the profitability of climate related interventions (Akinyi et al., 2022; Ng'ang'a et al., 2017a; Ng'ang'a et al., 2017b; Kashangaki and Ericksen, 2018; Daigneault et al., 2016; Boardman, 2004). CBA helps determine the efficiency of a climate-smart agriculture (CSA) approach when compared to Business-as-Usual (BAU) scenario (Ng'ang'a et al., 2020), and helps farmers in selection of the best strategy given the scarce resources (Chanda et al., 2019). The Benefit-Cost Ratio (BCR) greater than 1 implies that benefits obtained through the adoption of CSA strategy completely offset the incurred costs while also leaving some residual benefits (Gittenger,1982; Kanton et al., 2017; Fürtner et al., 2022). Literature highlights that CSA practices are adopted mainly for economic reasons. (Emmanuel at al., 2016; Tsinigo and Behrman, 2017; Kassie et al., 2013).

In July 2023, the research team at the International Food Policy Research Institute (IFPRI), Pakistan, visited the farmers in their fields in each of the 5 cities to collect data on economic yield, input usage, as well as the associated costs and benefits to assess the feasibility of the intervention. In addition, a Focal Group Discussion (FGD) was conducted at PARC, Islamabad which was attended by a total of 07 farmers from Attock, Gujjar Khan, Taxila and Chakwal. Farmers were provided with a stipend to cover their travel costs and were provided with refreshments. The second FGD was conducted in Kallar Syedan with a total of 05 farmers. The data was analyzed using STATA 2019. Farmer recall information was used to collect data on costs and benefits associated with CSA and BAU practices. One acre of land per farmer in the study was used as the unit of analysis for comparing the profitability with and without the CSA practices. The profitability of these CSA practices (legume-wheat) was evaluated by determining increase in productivity (yield multiplied by the market price (PKR) of output) compared to the Business-as-Usual (BAU) scenario (fallow-wheat). The costs included expenses implementation, operational and maintenance costs and did not include fixed costs such as land value, interest on capital and depreciation. Benefit-cost ratio (BCR) was calculated by dividing the total income by total expenditure.

5. Findings

5.1. Characteristics of the participants

All the participants in our survey were male and were serving as household heads. Of all the participants, 1 farmer had completed primary education, 2 had completed elementary education, 8 farmers were matriculate (less than high school), and 4 had university degree. The average age of the respondents was 51 years, with a minimum age of 35 years and a maximum age of 69 years. In terms of land ownership, respondents, on average possessed approximately 13.46 acres (5.5 hectares) of land, with the largest landholding being 50 acres (20.2 hectares) and the smallest at 2.5 acres (1 hectare). Most of the respondents (8 out of 15) reported that the rainfall in their region to be sporadic, unpredictable, and often characterized by sudden cloud bursts. All the respondents in the survey were found to be aware of the crop rotation practice and had been implementing the crop rotation practice in the previous years. Furthermore, a substantial majority of 14 out of 15 respondents expressed their intention to continue implementing crop rotation in the future.

5.2. Benefit cost analysis of BAU (fallow-wheat) vs. CSA Practice (legume-wheat rotation)

We find that the benefit-cost ratio for 14 out of 15 farmers who adopted the legume-wheat rotation was greater than 1. This implies that benefits accrued with the implementation of CSA practice can fully cover the associated costs (*see Figures 1, 2 and Table 1)*. The yield of wheat increased considerably for twelve out of fifteen farmers in the legume-wheat rotation.

Figure 1: Wheat Yield/Acre for BAU and CSA Practice

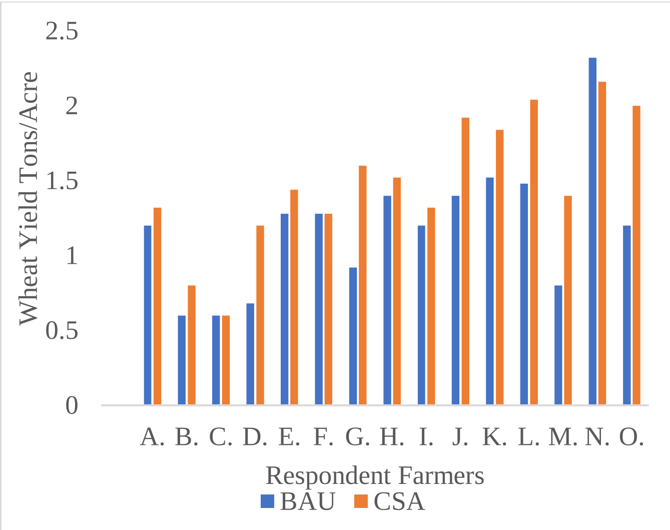

Figure 2: Benefit Cost Ratio for BAU and CSA Practice

Source: Data collected through Field Survey

Farmers reported that soybean-wheat rotation benefitted them through cost cutting in terms of decreased use of urea and di-ammonium phosphate (DAP) fertilizers. The farmers shared that soybean cultivation has drastically improved the quality of soil. Two out of three farmers experienced an increase in the yield of subsequent wheat crop. Farmers highlighted that they were unaware of any soybean markets to sell their produce, leading them to utilize their produce for domestic purposes such as cooking oil. They considered formation of strong community groups and linkages with the cooperatives important for marketing their soybean produce. At the household level, soybean cultivation boosted food and nutritional security.

Table 1: Benefit cost analysis of fallow-wheat (BAU) vs. CSA Practice (legume-wheat rotation)

ID of Farmers	City	CSA practice	Total costs (PKR per acre)		Yield (Tons per acre)		Price of wheat/ton (PKR)	Gross benefits (yield * Price)		Benefit-Cost Ratio (BCR)	
			BAU	CSA	BAU	CSA		BAU	CSA	BAU	CSA
A.	Gujjar Khan	Soybean	75,248	82,453	1.2	1.32	113398	136,078	149,685	1.81	1.82
B.	Attock	Sesbania	63,287	73,615	0.6	0.8	117934	70,760	94,347	1.12	1.28
C.	Attock	Soybean	66,987	72,610	0.6	0.6	90718	54,431	54,431	0.81	0.75
D.	Attock	Mung bean	63,287	72,055	0.68	1.2	117934	80,195	141,521	1.27	1.96
E.	Chakwal	Sesbania	63,068	63,608	1.28	1.44	90718	116,120	130,635	1.84	2.05
F.	Chakwal	Mung bean	63,568	62,048	1.28	1.28	90718	116,120	116,120	1.83	1.87
G.	Kallar Syedan	Sesbania	75,425	58,465	0.92	1.6	79379	73,028	127,006	0.97	2.17
H.	Kallar Syedan	Mung bean	106,580	62,048	1.4	1.52	90718	127,006	137,892	1.19	2.22
I.	Kallar Syedan	Mung bean	70,725	64,055	1.2	1.32	102058	122,470	134,717	1.73	2.10
J.	Gujjar Khan	Sesbania	61,330	69,808	1.4	1.92	102058	142,882	195,952	2.33	2.81
K.	Kallar Syedan	Mung bean	67,037	57,705	1.52	1.84	88451	134,445	162,749	2.01	2.82
L.	Gujjar Khan	Sesbania	69,630	78,108	1.48	2.04	90718	134,263	185,066	1.93	2.37
M.	Gujjar Khan	Sesbania	46,230	54,708	0.8	1.4	88451	70,760	123,831	1.53	2.26
N.	Taxila	Mung bean	53,425	56,905	2.32	2.16	124738	289,392	269,434	5.42	4.73
O.	Attock	Soybean	84,425	62,610	1.2	2	108862	130,635	217,724	1.55	3.48

Source: Data collected during field survey

Farmers unanimously agreed that residue incorporation of mung bean and sesbania resulted in considerable soil improvement. Three out of six farmers who adopted sesbania-wheat rotation reported that they reduced application of inorganic fertilizers such as urea and DAP to their soil. Others who continued with applying DAP reduced the usage to half in comparison to the BAU scenario. The limited to no use of urea and DAP led to huge cost savings for the farmers as it was reported that on average one bag of urea costs PKR 3,000 and one bag of DAP costs PKR 14,000. Farmers raised the concern that prices of fertilizers are often at the discretion of dealers in the market, with the prices of DAP sometimes getting raised overnight. The farmers reported that, apart from high cost of fertilizers, sub-standard quality of fertilizers available in the market as well as the timely availability of fertilizers, such as DAP, are other issues.

All the farmers reported that crop-rotation practices has eliminated the ploughing costs incurred during the fallow period. Farmers expressed satisfaction with the cost-effectiveness of crop rotation practices when it comes to operational and maintenance expenditures. After the adoption of crop-rotation practice, the operational costs incurred due to ploughing dropped significantly as it required 10 ploughing before sowing wheat under BAU. However, with legume-wheat rotation, the number of ploughing have declined from three to zero.

Legume-wheat rotation practice was deemed a much better alternative than the fallow-wheat practice by all the participating farmers except one. They reported soil improvement and higher wheat yield after legume cultivation as a major reason behind their willingness to continue with the legume-wheat rotations in the next seasons. Some farmers believed that if they had received the seeds a little earlier, the yield increases could have been greater. A farmer dissatisfied with the legume (mung bean)-wheat rotation in Chakwal region cited no change in yield and unavailability of the fertilizers at the time of cultivation as reasons for his decision to discontinue with the legume-wheat rotation in the next cropping cycle. Soybean cultivation was relatively new for the targeted farmers but its adoption is expected to increase as it was regarded by as a reliable alternative soil fertility management approach by the farmers. The establishment of effective marketing channels to facilitate the sale of soybean produce in the market at a reliable price may further accelerate the adoption process.

Farmers reported that effects of climate changes such as increase in temperatures and variability in rainfall over the years has made it difficult for them to manage their farms. The unavailability of canal water was highlighted as a major concern by most of the farmers. They highlighted their increasing reliance on groundwater extracted through tube wells. Farmers were of the view that there is a disconnect between the government, research departments, extension departments, and the farmers. Crop rotation receives substantial attention at the policy level and is actively adopted by large-scale farmers. However, small-scale farmers with limited resources often struggle to implement these innovative solutions. All participating farmers unanimously considered the targeting approach employed in the program to be ineffective, as they believed it overlooked small-scale farmers during program execution. The farmers who took part in the program noted that nearby farmers have begun adopting crop rotation practices after witnessing the significant improvements in wheat yield after legume-wheat rotation.

Research departments have embarked on initiatives to educate farmers on the proper utilization of urea and DAP and planting dates, but their efforts have thus far only reached a fraction of the farming community. One major constraint pointed out by all the farmers was the unavailability of quality seed of mung-bean in the market. Farmers believed that the government should facilitate by setting up seed distribution centers for ensuring timely availability of quality seeds. Research centers act as a linchpin in the agricultural system, and it is imperative that they focus on producing high-quality seeds capable of withstanding the evolving climatic conditions. Farmers highlighted that inadequate seed quality in previous cycles led to diminished crop yields. Another issue considered significant by the farmers was the decline in the availability of agricultural land. They pointed out that housing societies are acquiring land at a greater speed forcing them to come up with innovative and efficient ways for improving yield per unit area on the limited land available for agriculture. Capacity building programs were considered crucial by the participant farmers for building adaptive capacity as the weather conditions in rain-fed areas are unpredictable. Engaging farmers with extensive firsthand knowledge and decades of practical experience in designing agricultural activities, policy making, and program implementation is essential.

6. Conclusion

Our findings suggest that legume-wheat rotation stimulated wheat yield in comparison to wheat crop grown after the fallow period. The BCR analysis revealed that all the three treatments: soybean-wheat, -mung bean-wheat and sesbania-wheat, are viable with a benefit-cost ratio greater than 1 (except for one farmer). A comparison of BAU (fallow-wheat) with CSA (legume-wheat) practice revealed that BCR for thirteen out of fifteen participants is higher in under CSA scenario compared to BAU scenario. The highest BCR of 3.48 was observed with wheat-soybean-wheat rotation in Attock District.

It is acknowledged that soybean fixes nitrogen in the soil leading to increase in productivity while reducing fertilizer usage (Kasasa et al., 2000; Chianu et l., 2009). Farmers reported that soybean consumption for domestic purposes boosted food and nutritional security at the household level. Worldwide, soybean is considered a major source of protein and cooking oil (Graham and Vance, 2003; Orf, 2010; Pagano & Miransari, 2016). A lack of awareness about soybean management in terms of processing and marketing was reported by the participating farmers.

Using mung bean and sesbania benefited farmers through increases in wheat yield and cost-saving from reduction in usage of fertilizers. Farmers were satisfied with the nitrogen fixing properties of the legumes. The results indicate that employing mung-bean and sesbania as a green manure in soil during wheat cultivation is a viable environmentally friendly alternative to chemical fertilizers and is an easy and practical approach for improving crop production in a cost-effective manner. Our findings resonate with previous studies. Shah et al., (2003) reported that grain yields were higher after retaining the residues of mung-bean. Green manuring has proven to be beneficial in substantially increasing wheat grain yield in four of the six growing seasons (Ghuman and Sur, 2006). The improvement in wheat yield resulting from the incorporation of green manure could be attributed to the enhanced efficiency of fertilizers, particularly phosphorus (P), along with an increase in organic matter content (Sultani et al., 2004). Sharma and Prasad (1999) reported that incorporation of sesbania or mung bean residues into the soil resulted in a notable productivity of rice-wheat cropping by 0.5 to 1.3 t ha -1 y-1. Based on our findings, we suggest that an integrated approach of wheat cultivation with crop rotation using legumes should be adopted for sustainable food production and preserving soil characteristics while reducing the usage of chemical fertilizers.

Based on our discussions with the farmers, we propose that for successful adoption of crop rotation practices, a multifaceted approach is required, that includes necessary action at all tiers, namely research, extension, policy and development. A concerted strategy in needed to promote crop-rotation practices encompassing:

i. Development of improved seed varieties can result in higher crop yields especially in the face of changing climate conditions.

ii. Development of appropriate seed varieties for minor crops.

iii. Ensure timely availability of quality seed, fertilizers, and pesticides.

iv. Establish community-based mechanisms to pool resources such as farmer cooperatives and village-based organizations.

v. Provide oil-expeller machines at the community or domestic level for extracting soybean oil. This would help the rural population by substituting soybean oil for more expensive cooking oil available in the market. This will also help in saving foreign exchange spent on importing cooking oil.

vi. Periodic capacity building training to educate farmers on climate smart practices. This training must also include knowledge building on crop processing, value addition and marketing channels.

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Appendix 1- Climate Smart Technologies Identified for Adoption in South Asia

	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka
1	Bed planting (BP)	Protected Agriculture technology	Direct Seeded Rice	Crop system (DSR in Rice-wheat system + Brown manuring-Sesbania)	Zero Tillage Wheat Planting in Rice-Wheat Cropping System	Crop diversification - Sandwich cropping systems using short-aged legume types (third-season cultivation)
2	Integrated Nutrient Management (INM)	Sustainable Land Management	Laser Land Levelling	Laser land leveling	Direct Seeding of Rice in Rice-Wheat Cropping System	Multi-purpose soil conservation bunds
3	Zero tillage (ZT) or strip planting (ST)	Automated/Smart Irrigation Technology (SIT)	Broad Bed Furrow (Soybean)	Alternate wetting and drying	Alternate Wetting and Drying of Rice in Rice-Wheat Cropping System	Solar-powered water pumping systems/ micro irrigation
4	Mixed or intercropping		Conservation Agriculture	Zero tillage wheat	Zero Tillage Happy Seeder / Pak Seeder Wheat Planting in Rice-Wheat Cropping System	'Parachute" method of paddy seedling broadcasting
5	Mulch and residue retention		Zero tillage	Maize based intercropping	Raised Beds / Ridge Planting of Wheat in Rice-Wheat Cropping System	Protected agriculture for high-value crops
6	Agroforestry system		Micro irrigation (Drip) in cotton	Drought-tolerant varieties in rice	Resilient Cropping Systems (Mung-Wheat, Soybean-Wheat) in Rainfed Areas	Rainwater harvesting techniques
7	Quesungual Slash and Mulch (QSMAS)		Plastic Mulching	Green manuring in rice	Resilient Cropping Systems (Sesbinia-Wheat) in Rainfed Area	Cultivation of climate-smart crops - Stress resistant varieties
8			Resilient intercropping system	Flood tolerant	Drought-Tolerant Varieties in Rainfed Area	Application of biochar
9			Improved seed variety (Foxtail millet (SIA-3085))	Integrated nutrient management		Alternative Drying and Wetting irrigation in paddy cultivation
10				Drip irrigation		Climate forecasting based Agro-met advisory & alerts
11				Raised bed planting		Home gardening with self-produced organic manure
12				Conservation agriculture		