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Pakistan: A Cost-Benefit Analysis of Puddled Planted Rice vs. Direct Seeded Rice

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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Notices

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1. Introduction

Rice-wheat, a major cropping system of Pakistan, is vulnerable to the negative impacts of climate change, manifesting in the form of yield reduction (Syed et al., 2022; Chaudhry, 2017; Ali et al., 2017; Ahmad et al., 2013). Among various crops, rice is often identified as the most at-risk food crop which is prone to a substantial drop in yield because of climate change and weather variations (Khan et al., 2022; Ali et al., 2017). It is estimated that the yield of wheat and rice may decline by 14.7 percent and 20.5 percent, respectively, by 2050 due to changes in climate (Ahmad et al., 2015). It is expected that Pakistan could potentially incur a climate change-related loss of $19.5 billion by 2050 due to reduced wheat and rice crop yields (Khan et al., 2020) due to water scarcity, rising average temperatures, and less precipitation (Asif, 2013; Ali and Erenstein, 2017; Janjua et al., 2021). Research indicates that if current climate change patterns persist and farmers do not adopt suitable climate resilient methods, rice production in Pakistan could decline by as much as 36 percent by the year 2099 (Ahmad et al., 2015).

Rice cultivation in Pakistan mainly relies on the conventional 'puddled transplanted rice' (PTR) method (Mann et al., 2007; Iqbal et al., 2021; Ali et al., 2021). puddling is a method employed to regulate percolation and weed growth in submerged soil conditions, achieved through plowing, harrowing, and field leveling (Bouman et al., 2007; Awan et al., 2015; Hassan et al., 2022). Puddling requires substantial capital and a significant quantity of water (Sharma and De Datta, 1986; Bhatt et al., 2023). Puddling is a method employed to regulate percolation and weed growth in submerged soil conditions, achieved through plowing, harrowing, and field leveling (Bouman et al., 2007; Awan et al., 2015; Hassan et al., 2022). Puddling requires substantial capital and a significant quantity of water (Sharma and De Datta, 1986; Bhatt et al., 2023). Transplanting rice is carried out by laborers at a high cost (Mann et al., 2007). This method involves raising a rice nursery in a separate seedbed which are then transplanted into well prepared, puddled fields after the seedlings are 25-35 days old. During the early stages following the transplanting of the rice nursery, a consistent water level is maintained to facilitate proper crop establishment and effective weed control (Singh et al., 2001; Ali et al., 2021). Puddling accounts for 25–30 percent of the overall irrigation water used in the PTR method (Kakraliya et al., 2018), used for raising nursery, puddling, transplanting, and frequent flooding in order to maintain the soil. This popular method results in huge water losses from the puddled soil due to percolation, seepage, and evaporation, leading to increased water consumption because it forms a hardpan that hinders water retention (Raj et al., 2023; Farooq et al., 2009). It has been estimated that approximately 3500-4500 liters of irrigation water is used to produce 1 kilogram of rice, which is three times higher than other cereal crops (Joshi et al., 2013).

Excessive water usage for puddling during the peak summer season leads to issues such as declining groundwater levels and the availability of poor-quality water for irrigation (Raj et al., 2023). Moreover, the requirement for standing water in the traditional puddling practice delays the transplanting of rice by one to three weeks (Ladha et al., 2009). Substantial water usage, labor costs, and labor demands associated with traditional puddled rice lead to low yield, productivity and profits (Pandey and Velasco, 1999; Fatima et al., 2020; Younas et al., 2015). Repeated puddling also has a negative impact on the physical properties of the soil by dismantling soil aggregates, reducing permeability in subsurface layers, and forming hardpans at shallow depths (Sharma et al., 2003; Kukal and Sidhu, 2004; Kukal and Aggarwal, 2003; Kalita et al., 2020; Chaki et al., 2021). These effects can have a negative impact on the non-rice crops that follow, for example, wheat that is grown after puddled rice (Chaki et al., 2021; Tripathi et al., 2005). This is because various factors can limit wheat yields in these post-rice soils, including the long time it takes for the soil to recover, poor soil quality for planting seeds, compacted subsoil, inadequate drainage, limited air circulation, development of subsurface hardpans, and significant resistance to root growth (Sharma et al., 2003). It has also been reported that the wheat yield experiences an 8% reduction when cultivated following puddled transplanted rice as compared to wheat grown otherwise (Kumar et al., 2008). Additionally, conventional rice production systems contribute significantly to global climate change through the emission of greenhouse gases (GHGs); carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) gases into the atmosphere because of prolonged flooding resulting in lack of oxygen (anaerobic) conditions in soil (Mboyerwa et al., 2022; Jena et al., 2023; Islam et al., 2020). Emission of these GHGs from rice fields contribute to the overall increase in global temperatures (Khalil and Aslam, 2009).

A comprehensive, resource-efficient, climate-resilient, and cropping system-based management approach is needed to maintain sustainable rice crop production and maintenance of soil health. Over the last decade, many attempts have been made to explore alternatives to the traditional puddled transplanted rice practice. The direct seeded rice (DSR) method has attracted attention due to its low-input requirements (Farooq et al., 2011). The direct-seeding method offer various advantages in comparison to transplanting. These advantages encompass faster and easy crop plantation, reduced labor intensity, lower water consumption (Bhushan et al., 2007; Jehangir et al, 2007), greater suitability for mechanization (Khade et al., 1993), earlier flowering resulting in shorter crop duration (Farooq et al., 2006 a & b; Santhi et al., 1998), maturity occurring 7–10 days earlier, and diminished methane emissions (Balasubramanian and Hill, 2002; Pandey and Velasco, 1999) compared to traditional transplanting methods. DSR eliminates the need for nursery establishment, seedling transplanting, and puddling (Brown et al., 2021), consequently resulting in a substantial reduction in labor requirements of up to 50% (Kumar and Ladha, 2011). The DSR method also has advantages in terms of providing greater flexibility in choosing planting dates, thus mitigating potential labor supply constraints (Kaur and Singh,2017). In addition to labor efficiency gains, DSR also contributes to significant reductions in fuel consumption, up to 60% when compared to traditional puddled transplanting (Pathak et al., 2011).

Notably, since DSR does not necessitate puddling, it has the potential to reduce irrigation water usage by approximately 12% to 33% (Kumar and Ladha in 2011), while improving soil physical properties, curtailing the need for labour, and consequently decreasing production cost (USD 9–125 per hectare) (Chaudhary et al., 2023). Furthermore, DSR leads to reduction in methane emissions (10–90%) (Chaudhary et al., 2023). The term "direct seeding of rice" pertains to the method of initiating rice cultivation by directly sowing rice seeds in the field, as opposed to the conventional practice of transplanting seedlings from a nursery. The DSR encompasses three primary approaches: (i) dry seeding (sowing dry seeds into dry soil/prepared seedbeds)); (ii) wet seeding (the process of sowing pre-germinated rice seeds into a puddled soil), and (iii) water seeding (involving the sowing of rice seeds into standing bodies of water) (Farooq et al., 2011).

However, the transition from traditional transplanting puddled rice to direct-seeded rice (DSR) entails various challenges, including elevated weed proliferation, the emergence of weedy rice strains, heightened occurrences of soil-borne pathogens (such as nematodes), nutrient-related issues, suboptimal crop establishment, lodging, and increased susceptibility to diseases like blast and brown leaf spot, among others (Singh et al., 2001; Azmi et al., 2012; Rani et al., 2012; Kaur and Singh, 2017; Kaur et al., 2017; Raj and Syriac, 2017; Bhatt et al., 2023). The estimated losses attributed to weeds in rice cultivation are approximately 10% of the total grain yield, but they can vary significantly, ranging from 30% to 90%. These weed-related losses not only compromise grain quality but also escalate production costs (Rao et al., 2007). The Food and Agriculture

Organization (FAO, 2014) advocates for an integrated approach that encompasses preventive, cultural, and chemical methods, for achieving effective and sustainable weed control in DSR. Furthermore, weed surveillance could also offer advantages when it comes to choosing appropriate herbicides and strategies for weed control (Singh and Meena., 2012).

The aim of this study is to evaluate two rice cultivation methods: the conventional Puddled Transplanted Rice (PTR) method and Direct Seeded Rice (DSR) method. We hypothesize that DSR may lead to increases in rice crop yield and decrease in cost when compared to PTR. This study is structured as follows: Section 2 introduces the study areas and outlines the research methodology. Section 3 presents the research findings, and Section 4 offers discussions and recommendations.

2. Methodology

2.1. Study areas

The Pakistan Agricultural Research Council (PARC) has experimented Direct Seeded Rice in three districts of the Punjab, Pakistan, with the support of the Consortium for Scaling-up Climate Smart Agriculture in Pakistan to promote adoption of climate-smart innovations tailored to the needs of marginalized communities: Gujranwala (Tehsil Kamokee), Hafizabad (Tehsil Hafizabad), and Wazirabad district (Tehsil Wazirabad). These districts are representative of the rice-wheat cropping (RWC) zone and are most suitable for this study.

The province of Punjab is stratified into four primary agro-ecological zones: the Irrigated Plains, the Rain-fed (barani) region, the Thal region, and the Marginal land (Abid et al., 2016), further delineated into 11 sub-zones (Ahmad et al., 2019). Gujranwala is situated geographically between latitude 31.81° N to 32.58° N and longitude 73.68° E to 74.59° E (Mahmood et al., 2019). In terms of its geological context, Gujranwala is in the Rechna Doab, which constitutes a smaller unit of the Indo-Gangetic Plain (IGP) (Faheem et al., 2008). Gujranwala Division occupies a distinct geographical position, delineated by the Chenab River to the north and the Ravi River to the south. Gujranwala Division spans over an area of approximately 17,206 square kilometers[1]. The climate in Gujranwala is characterized as hot and semi-arid during the summer season and relatively cooler temperatures in the winter. The monsoon season typically begins in July and lasts through September. On average, the annual rainfall in the eastern division is 2660.07 millimeters. The soil in this area is primarily alluvial and highly fertile.[2] Sub-surface geological composition in this region reveals the existence of both fine and coarse-grained soils, encompassing clay, silt, sand, and their combinations in varying proportions (Faheem et al., 2008). Agricultural practices in the region rely significantly on canal irrigation, with the primary crops cultivated being wheat, cotton, rice, barley, and millet [3].

Gujranwala district, covering an area of 2,433 square kilometers, is situated between two prominent cities: Gujrat to the north and Sheikhupura and Lahore to the south. Its northern boundary is separated by the Chenab River, while beyond the river, it shares its boundaries with Wazirabad district to the north, Sialkot district to the east, Sheikhupura district to the south, and Hafizabad district to the west. Gujranwala district and is

[1] Available at https://gujranwaladivision.punjab.gov.pk/geographic_conditions
[2] Available at https://gujranwaladivision.punjab.gov.pk/division_climate
[3] Available at https://www.britannica.com/place/Gujranwala

subdivided into four Tehsils: City Gujranwala, Sadar Gujranwala, Kamoke Town, Nowshera Virkan.[4] This study specifically focused on Kamoke Tehsil due to its global recognition for producing the world's most renowned variety of rice. Kamoke stands as the largest rice market in the subcontinent, where a wide array of delectable and aromatic rice varieties, such as Basmati, Super Basmati, Karnal, and others, are cultivated, processed, and exported to international markets worldwide.[5] Kamoke is located about 25 kilometers from Gujranwala city and approximately 60 kilometers from Lahore[6]. Several factors contribute to Kamoke's prominence as a significant hub for rice cultivation in Pakistan such as extensive network of canal and access from the Chenab rivers[7] ensuring an adequate water supply for irrigation, and a rich alluvial soil.

Hafizabad covers an area of 2,367 square kilometers and is bounded by Gujranwala to the East, Jhang, Sargodha, and the Chenab River to the West, Faisalabad to the South, Mandi Baha-ud-Din to the Northwest, and district Sheikhupura to the South East. The district experiences a climate characterized by hot and arid conditions in the summer and moderately cold temperatures during the winter. Due to its proximity to hills, the Eastern part of the district receives more rainfall compared to the Western part. The soil in the region is alluvial and fertile, and the landscape is predominantly flat, extending in an East to West direction. Due to these suitable conditions, Hafizabad is known as the "City of Rice" and serves as the largest rice market in the area.[8]

Wazirabad, located in Gujranwala region, has a sub-tropical humid climate. During the summer months from May to September, temperature rises to 36–44 °C, while the coldest period usually occurs from November to February, with average temperatures plummeting to around 7 °C. July and August are the months with the highest levels of precipitation, while the remaining months have an average rainfall of 628 millimeters. The driest months are typically from November to April, with minimal rainfall.[9] [10] [11]

2.2. Experiment set-up and treatments

In Pakistan, rice and wheat crops are grown in similar agro-climatic zone in a regular rotation pattern (Bokhari et al., 2017). Puddled transplanted rice (PTR) is the primary rice cultivation practice among the farmers in Punjab. This conventional practice, however, poses several inherent challenges: firstly, it is a labor-intensive activity, leading to labor shortages during peak rice cultivation seasons with high labor cost; secondly, labor often fails to meet the recommended plant population, which ultimately hinders crop yields; and thirdly, it is a water intensive process. To enhance productivity, increase income, reduce resource inputs, and promote environmental sustainability, adopting direct seeded rice (DSR) emerges as an effective alternative strategy.

The experiment, initiated during the Kharif 2022 season, aimed to achieve multiple objectives, including the reduction of labor costs, time savings, soil moisture conservation, and decreased water usage. A targeted group

[4] Available at https://gujranwala.punjab.gov.pk/geography
[5] Available at https://mckamoke.lgpunjab.org.pk/about-us/history/
[6] Available at https://words.pk/kamoke/#aioseo-economy
[7] Gujranwala District Report Water Supply, Sewerage and Environment Sector Gujranwala Regional Development Plan 2020-2030
[8] Available at https://hafizabad.dc.lhc.gov.pk/PublicPages/HistoryOfDistrict.aspx
[9]Available at https://en.db-city.com/Pakistan--Punjab--Gujranwala--Wazirabad
[10]Available at https://weatherandclimate.com/pakistan/punjab/wazirabad#:~:text=Located%20at%20an%20elevation%20of,12.29%25%20higher%20than%20Pakistan's%20averages.
[11] Punjab Cities Program Gap Analysis of Municipal Services infrastructure & service delivery in Wazirabad City. Available at: https://pmdfc.punjab.gov.pk/system/files/Wazirabad-Situation-GAR.pdf

of 07 farmers was selected for this intervention following consultations with the relevant agricultural extension department. The DSR experiments were organized using a randomized complete block design within a split-plot arrangement. In this setup, two distinct rice cropping systems were established: one utilizing puddled transplanted rice (PTR) method, and the other employing the direct seeded rice (DSR) cultivation method.

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 experiments were designed to compare the performance of PTR and DSR methods in terms of crop yield, resource use (such as labor and water), and overall cost-effectiveness. Costs and benefits were evaluated to gauge the financial advantages of both methods, considering input costs and potential returns. Understanding farmers' preferences, adoption rates, and their perceptions of benefits and challenges associated with PTR and DSR is also crucial. Ultimately, these experiments aim to provide comprehensive recommendations for best practices to guide farmers and policymakers in adopting the most suitable rice cultivation method based on the local context and specific goals related to sustainability, productivity, and economic viability.

2.3. Cost and Benefit Analysis

The research team from the International Food Policy Research Institute (IFPRI), Pakistan conducted field visits in August 2023 to evaluate comprehensive cost-benefit analysis to assess the economic implications of conventional Puddled Transplanted Rice Method (PTR), puddled and manual methods, and Direct Seeded Rice (DSR) method during the Kharif season in the year 2023. These visits included interactions with farmers across three distinct rice-wheat regions of Punjab namely Kamokee, Wazirabad, and Hafizabad with the aim of collecting data regarding the costs and benefits associated with both the conventional PTR approach i.e., business-as- usual approach, and Direct Seeded Rice (DSR) method under climate smart agriculture (CSA) scenario. Data on economic yield, input utilization information, and the corresponding cost-benefit analysis were systematically gathered to evaluate the viability of the intervention. A structured Focus Group Discussion (FGD) was also conducted to gain deeper insights into the experiences and perspectives of the participating farmers.

The present study uses Benefit-Cost Ratio (BCR) as the main indicator (Nawaz et al., 2020). The profitability of these CSA practices was evaluated by determining the increase in productivity (yield multiplied by the market price (PKR) of output) compared to the Business-as-Usual (BAU) scenario. 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. A BCR greater than 1 implies that benefits obtained through the adoption of the adaptation 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 the grounds on which a practice is adopted are mainly economic (Emmanuel at al., 2016; Tsinigo and Behrman, 2017; Kassie et al., 2013). 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. Literature review was conducted to validate the findings after comparison with other similar studies.

3. Findings

3.1. Characteristics of the participants

The survey comprised 07 male participants. Four out of seven farmers serve as household heads. Out of all the participants, 2 farmers had a Master degree, 1 farmer had an undergraduate degree, 02 farmers had completed their intermediate education, 1 farmer had completed matriculation and 1 farmer had completed grade 6. The average age of the respondents was 46 years, ranging from 26 years to 70 years. On average, the respondents owned 39 acres of land, with the largest landholding being 101 acres and the smallest at 10 acres. Four out of the seven participating farmers reported rainfall patterns to be similar over the years, while the others perceived that rainfall had increased over time. One farmer in particular expressed concern regarding the sporadic and unpredictable rainfall patterns. All surveyed participants were well-informed about and actively practiced Direct Seeding Rice (DSR).

3.2. Benefit cost analysis (Puddled Transplanted Rice (BAU) vs. Direct Seeded Rice (CSA))

Our analysis demonstrates that the adoption of DSR resulted in enhancement in rice yields across all participating farmers compared to the puddled rice for all the selected farmers (Figure 1). Each farmer that adopted the practice of direct seeded rice (DSR) achieved a benefit-to-cost ratio > 1, indicating that the accrued benefits from implementing this practice adequately offset the incurred costs. Furthermore, when we juxtaposed this with the Business-As-Usual (BAU) scenario (PTR), benefit-cost ratio increased for each farmer following the implementation of CSA practice (DSR). This compelling evidence emphasizes the pronounced benefits that were achieved after the adoption of DSR, as illustrated in Figure 2. Table 1 presents the data for each of selected farmers adopting CSA practice.

Figure 1. Yield of Puddled Transplanted Rice (BAU vs. Direct Seeded Rice (CAS) in Tons/Acre

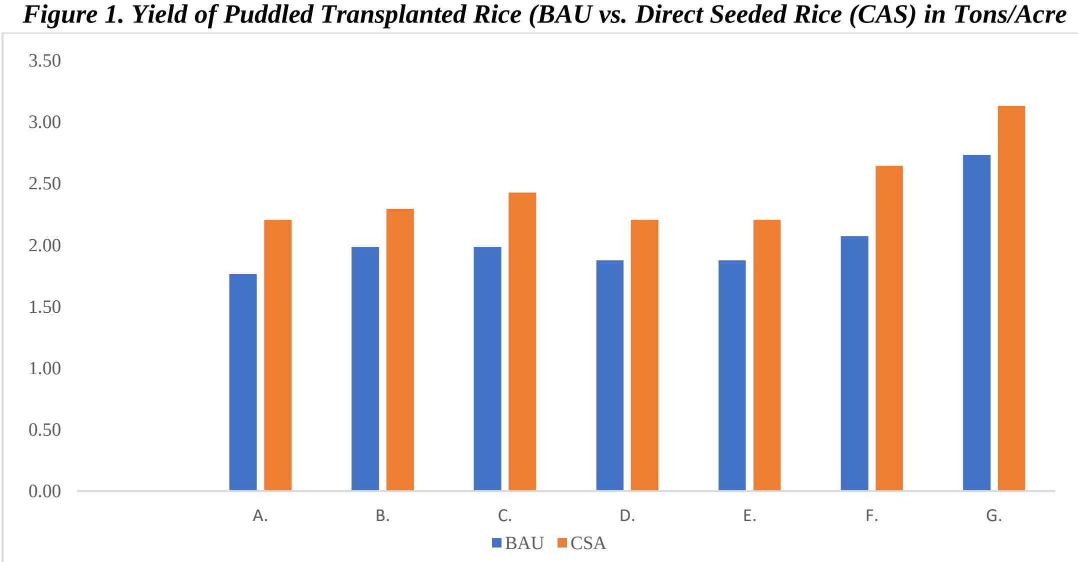

Figure 2: Benefit- Cost Ratio (BCR)-Transplanting Rice vs. Direct Seeded Rice

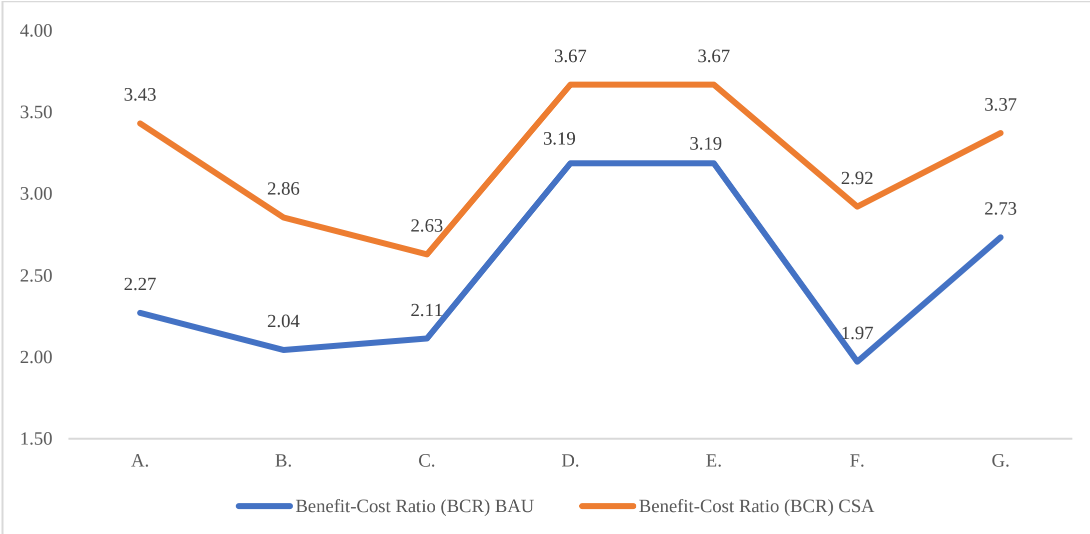

Table 1: Benefit cost analysis (Puddled Transplanted Rice (BAU) vs. Direct Seeded Rice (CSA)

ID.	City	Total costs (PKR per acre)		Yield (Tons per acre)		Price of rice (PKR per ton)	Gross benefits (yield * Price)		Benefit-Cost Ratio (BCR)	
		BAU	CSA	BAU	CSA		BAU	CSA	BAU	CSA
A.	Kamokee	88,070	72,840	1.76	2.20	113,398	200,000	250,000	2.27	3.43
B.	Kamokee	88,070	72,840	1.98	2.29	90,718	180,000	208,000	2.04	2.86
C.	Kamokee	68,120	66,940	1.98	2.43	72,575	144,000	176,000	2.11	2.63
D.	Kamokee	66,670	68,140	1.87	2.20	113,398	212,500	250,000	3.19	3.67
E.	Kamokee	66,670	68,140	1.87	2.20	113,398	212,500	250,000	3.19	3.67
F.	Wazirabad	76,270	65,706	2.07	2.65	72,575	150,400	192,000	1.97	2.92
G.	Hafizabad	96,370	89,490	2.73	3.13	96,388	263,500	301,750	2.73	3.37

The benefits of adopting DSR outweigh the associated costs, this is exhibited by the benefit cost ratio greater than 1 for the all the participating farmers, ranging between 2.63-3.67. The highest BCR was observed for the farmer in Kamokee region at 3.67 after the adoption of DSR. The direct seeded rice benefited the farmers through decreasing costs in terms of reduction in labor requirement for land preparation, preparing seedlings and transplanting, and cutting back on irrigation water required for puddling. As discussed above, DSR reduces or eliminates the need for extensive puddling of the fields required in traditional rice cultivation methods. After adoption of DSR, farmers also reported higher plant population per acre. The reduction in costs combined with increased yield led to higher profits. Farmers, however, have reported that weed infestation poses a significant challenge in the implementation of DSR. Effective weedicides that have the potential to control new weeds attacking the crop such as ghora ghaas (stubborn weeds) are not available in the market. The costs associated with implementing plant protection measures for controlling weed and disease infestations, fertilizers and micronutrients, are significantly higher in DSR compared to puddled transplanted rice (PTR). Farmers suggested that this issue can be resolved by implementing effective management practices and ensuring the availability of weedicides and herbicides in the market that are appropriate for both pre-emergence and post-emergence application in rice farming. Additionally, the adoption of herbicide-tolerant (HT) seeds and bacterial blight-resistant varieties offer potential solutions to mitigate this issue.

All participating farmers unanimously reported a significant reduction in manual labor costs after adopting the DSR method when compared to the conventional approach. Farmers reported a substantial increase in the application of fertilizers such as urea, a nitrogen-rich fertilizer, in their rice cultivation practices under the DSR system. Additionally, four out of the seven participating farmers reported an increase in the incorporation of Di-Ammonium Phosphate (DAP) into their soil. All the farmers reported that herbicides and weedicide sprays are intensively used to combat weeds in the DSR method. A farmer noted that "although Direct Seeded Rice (DSR) is expected to offer cost-effectiveness due to its lower labor requirements compared to the conventional method, but the increased use of insecticides/weedicides led to an increase in the costs." In DSR, weedicides application is required two to three times more than the conventional method. In addition to the elevated expenses associated with fertilizers, weedicide and herbicides, farmers encountered a concurrent challenge wherein governmental reductions in electricity subsidies resulted in heightened costs for water extraction during rice cultivation. The farmers were of the view that meticulous land preparation and diligent control of weeds is essential in the DSR method to experience yield gains.

Farmer shared that temperature variability and shift in precipitation patterns, create favorable environment for the proliferation of pests and diseases that affect rice and wheat crop. DSR upscaling has been hampered by a combination of factors. All the farmers emphasized that they face significant challenges when it comes to the unavailability of (i) appropriate weedicide and herbicide, (ii) herbicide-tolerant (HT) seeds, and (iii) bacterial blight-resistant varieties, in the market. Farmers shared that pre-emergence and post-emergence application of weedicides and herbicides has helped them in effectively containing weeds in during DSR.

Farmers expressed the view that the government should take a leading role in developing an effective weed management strategy. This includes development of effective weedicides by the government research departments and ensuring their availability in the market. They also emphasized the importance of the extension department playing a more active role in promoting Direct Seeded Rice (DSR) particularly providing knowledge on land preparation, seed rate, sowing timing, and pest control measures. Such efforts are crucial for widespread adoption of this practice because farmers are keen to embrace new methods in rice production, given the substantial costs associated with conventional puddled transplanted rice method. Research centers are central to the agricultural system, and it is crucial that they prioritize the production of high-quality HT seeds, resistant to evolving climatic conditions and capable of combating weeds and pests. Farmers stressed that the previous inadequacy in the availability of these inputs has resulted in reduced crop yields. Furthermore, the absence of subsidies on electricity has led to increased expenses for groundwater extraction. Farmers have expressed that the government should consider providing subsidies to farmers in the rice-wheat zone to help offset operational costs. Farmers participating in the program observed that neighboring farmers have started embracing Direct Seeded Rice (DSR) method due to the noticeable reductions in labor costs, water conservation, and improvements in rice yields.

4. Discussion

Our research findings indicate that the adoption of the direct seeded rice (DSR) method has the potential to stimulate rice yields when compared to the traditional puddled transplanted rice (PTR) approach. The Cost-

Benefit Analysis (CBA) conducted in our study demonstrates the viability of DSR, as it exhibits a benefit-cost ratio (BCR) exceeding 1 for all the participating farmers. A comparative analysis between the BAU (PTR) scenario with CSA (DSR) scenario revealed that BCR for all the participants is notably higher in the CSA scenario compared to the BAU scenario. Our results are in line with the findings of Awan et al., (2007) and Younas et al., (2016); both the studies report higher BCR in case of DSR when compared to traditional transplantation method. DSR exhibits greater potential for reducing production costs through decreased water and labor inputs when compared to the conventional approach. DSR offers numerous advantages over PTR. However, all farmers reported that this transition has introduced certain challenges, particularly in weed and herbicide management. Limited availability and the high cost of weedicides and herbicides has been highlighted as a significant challenge by the farmers It is essential to recognize that while DSR presents a promising alternative, efficient and timely access to effective weedicide and herbicide solutions is crucial for it to yield the benefits that it has the potential to. Based on our findings, following recommendations are made to address the challenges associated with the adoption of DSR.

i. Targeted awareness campaigns should be initiated with the primary goal of educating farmers about the numerous advantages that DSR offers, such as the potential to significantly reduce production costs and reduction in the emission of GHGs. These campaigns should emphasize the environmental benefits and increased efficiency associated with DSR, making it an appealing alternative to traditional transplanting methods (Kakumanu et al., 2019). The government should prioritize the enhancement of the educational attainment of rural farming communities through the establishment of additional educational institutions in rural areas.

ii. It is crucial to strengthen agricultural extension services. These services should be expanded to provide farmers with comprehensive knowledge and training on DSR practices. This includes guidance on land preparation techniques, effective pest control strategies specific to DSR, and demonstration of DSR in the farmer fields. Specialized training programs must be designed for extension officers to equip them with up-to-date knowledge on DSR methods and technologies (Singh and Shahi, 2015).

iii. Education and training, and incentive programs or subsidies can be instrumental in driving DSR adoption, especially in the regions where concerns about water scarcity and high labor costs persist, these programs can offer financial incentives to farmers who make the switch from traditional PTR to DSR method. These incentives serve as a compelling motivator, reducing the financial barriers associated with the initial transition. Policy frameworks should be formulated to extend support to educated farmers by providing attractive incentives.

iv. To ensure success of DSR cultivation, it is imperative to guarantee the availability and accessibility of essential inputs such as weedicides, herbicides, and HT seeds. Government interventions can play a pivotal role in this regard by regulating the supply chain and making these inputs readily available to farmers at affordable prices.

v. Providing subsidy on diesel to lower cultivation costs can create a more favorable economic environment for farmers (McDonald et al., 2019).

vi. Widespread adoption of DSR can be achieved by giving priority to resource allocation and fostering collaboration through public-private partnerships (PPPs) (Singh and Shahi, 2015).

vii. Significant investment in research and development is necessary to produce high-quality herbicide-tolerant (HT) seeds tailored specifically for Direct Seeded Rice (DSR) (Grover et al., 2020). These seeds should possess the necessary traits to effectively control weed infestations, enhancing the overall efficiency of DSR-based rice cultivation.

viii. Efforts should be directed towards developing crop varieties that are resistant to bacterial blight, a common disease that can lead to substantial yield losses in DSR-based rice farming (Sagare et al., 2020).

ix. In addressing weed and pest management, comprehensive research endeavors are essential. The exploration of effective weed control methods, including the development of appropriate herbicides for both pre-emergence and post-emergence applications in rice farming, is imperative. Furthermore, it is essential to investigate and promote integrated pest management strategies to effectively tackle the pest and disease challenges that arise in DSR cultivation. These integrated approaches should not only reduce reliance on chemicals but also enhance pest control while maintaining ecological balance (Horgan, 2017).

x. Establishing a robust monitoring and evaluation system is crucial to gauge the impact of these initiatives. This system should comprehensively assess the effects of DSR adoption on various aspects, including rice yields, labor costs, water conservation, and overall agricultural sustainability. Additionally, there should be a concerted effort to collect comprehensive data on the economic, environmental, and social benefits of DSR. This data would serve as a valuable resource to inform policy decisions and guide future research initiatives, ensuring that advancements in seed development, pest management, and overall agricultural practices are grounded in evidence and continue to contribute positively to the agricultural landscape.

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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		