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Adaption of new technologies for rice and wheat in North India

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Abstract
One of the most predominant agricultural systems in the country is the rice wheat cropping system (RWWS) of Indo-Gangetic Plains (IGP), which enjoys the responsibility of regional food security but is experiencing challenges in sustaining itself increasingly. Whereas the green revolution was enabled by the use of high-yielding varieties and enhanced irrigation techniques, yield stagnation, resource degradation and global warming now pose a danger to the long term sustainability of the green revolution. This review paper summarises peer reviewed literature about the use of new technologies in the planting of rice and wheat in North India with a specific emphasis on Punjab, Haryana and the Uttar Pradesh. Some of the notable innovations are the introduction of better crop varieties, resource-conserving technologies (RCTs) like zero tillage, direct-sown rice, and laser land leveling, and also the mechanization and precision agriculture. The practices have lowered input expenses, provided better water and nutrient efficiency and also enhanced sustainability of the environment. Regional inequalities exist despite these developments, and they are most pronounced on the eastern part of the IGP where yield differentials are very high as the result of low levels of technology transfer, weak organizational condition, and socio-economic restrictions. Digital solutions to the challenges face-to-face interventions and climate-sensitive approaches are advised as crucial to the reduction of groundwater, rising production expenditures, and greenhouse gases. This paper highlights the importance of combined efforts that involve technological innovation, efficient knowledge transfer and positive policies in order to guarantee a resilient, productive and sustainable RWCS in North India.

Keywords: Rice-wheat system, resource-conserving technologies, precision agriculture, climate-smart practices, sustainable intensification

Introduction
Rice-wheat cropping (RWS) in the Indo-Gangetic Plains (IGP) is an important agricultural development complex of South Asia, which has grown considerably and is now popular in the 1960s and 1970s with the expansion of the canal and tubewell irrigation systems [1]. High yields varieties (HYVs) of rice and wheat also increased the speed in uptake of RWS and the result was the Green Revolution [1]. This has become one of the most extensive, industrially farmed and significantly critical to the food security and the agricultural success in the area [1]. RWS has been estimated to be practiced on more than 14 million known hectares of arable land and is providing almost two-thirds of the current cereal sources in the region [1].
The area covered by the RWS in India is around 10 million hectares with about 50 percent of the regions in Uttar Pradesh [2]. These two states with Bihar make almost 70 percent of the total RWS area [2]. But compared to an average of 8 tonnes/ha in Haryana and Punjab, crop production in these eastern states (UP and Bihar) is relatively low with the combined rice and wheat yield 3-5 tonnes/ha [2]. This classification defines RWS in India into high productivity zones (Punjab and Haryana) and low productivity zones (UP, Bihar and other regions in the eastern part). Recent sources show that the RWS is experiencing a number of stresses in Indo-Gangetic plains [3]. The increase in the crop production in the North-western plains of India particularly, Punjab, Haryana and western Uttar Pradesh are slowing down [3]. This system is growing in strength placing pressures on the land and water resources as well as the environment [3]. The difficulties encountered with climatic changes further reinforce these unwanted trends by the fact that they would cut down the gross domestic product of agriculture by 4-5% and up to 30% on crop yield [3, 4]. It has raised a lot of concern that food security in the region can be put at risk in case these trends are not handled with appropriate

technological and policy interventions [3]. Although the word climate change and the stress of land and water resources are clearly noted in the document, depletion of groundwater and the diminishing factor productivity are not explicitly covered as individual issues highlighted, but are connoted by the broad issues. Integration of research efforts from CGIAR Centres and national agricultural research systems, along with mobilization of international resources, has been pursued through various programs and research consortia [5]. Major thrust areas have included the development of high-yielding varieties of rice and wheat, tillage and crop residue management, weed control, reclamation of salt-affected lands, and water and nutrient management [5]. The results of these programs have been huge including resource conservation technologies such as zero and reduced tillage crop production that has caused a huge impact [5]. Work is being done on methods of producing rice with little water consumption, but the effects of these on the fields of farmers remain to be seen [5]. Adoption of new plant varieties and practices in managing resources is essential so as to take care of issue being experienced by the RWS [6]. The purpose of the study was to examine the implementation process of new plant varieties, and new forms of resource management, in an express group of states within India, which were Punjab, Haryana and Uttar Pradesh [6]. The article is especially concerned with more recent developments in the RWS, adoption and the economic consequences concerning the introduction of new plant varieties and resource conservation technologies [6]. The empirical data of the study contains only the Indian area of the RWS [6]. Critical gaps and research opportunities in the field of precision agriculture also significantly emerge in the review in the changing dynamics of remote sensing and machine learning technologies to support crop yield forecasting. The rice-wheat system of cropping is crucial to food security in North India, and is currently confronted by a slow down in yields, resource strain and climate change. To promote the long-term sustainability and productivity of this important system of agriculture, it is necessary to embrace new technologies, interventions based on research.

New Technologies in Rice and Wheat Cultivation

Crop Varieties

High-yielding wheat and rice varieties (HYVs) have contributed majorly to the growth of the rice-wheat cultivation system (RWS) and the Green Revolution [7]. Making these varieties has been one of the major areas of agricultural research [8]. The number of superfine rice varieties developed have also been on the rise in the last two decades [9]. If the suitable varieties in the irrigated situation, planted in RWS, take up a fair share of newly being considered varieties; 29.5 percent rice, 40 percent wheat over the previous decade [10]. The private sector also contributes significantly to the sale of seed ranging between 48 percent in Uttar Pradesh to 81 percent in Punjab in rice and 25 percent in Bihar, though 59 percent in Haryana in wheat [11]. Recent releases, like Pusa 1121 and CSR 30 as basmati rice varieties, have been shown to be superior to older types, especially by their yield [12].

Resource-Conserving Technologies

Such technologies have an important influence on the RWS; resource conservation technologies (RCTs) [13]. Particularly, the empirical evidence of zero and subsoil levels of tillage has resulted and shown significant positive impacts [14]. The introduction of wheat with zero-tillage has been introduced in the Indo-Gangetic Plains (IGP) and has now occupied large area of wheat [15]. Advantages of such technology are that a pathism will be less expensive because of less or no tillage and a waste of water used in watering wheat will be lessened [16]. Moreover, when paddy stubbles are added, it enriches the soil resulting to moderate yield improvement in certain areas [17]. Punjab, Haryana and western Uttar Pradesh are among the few good examples of adopting the technologies [18]. Among other solutions to overcome issues in the RWS, laser land leveling, direct-seeded rice (DSR), aerobic rice and systems of rice/wheat intensification are solutions [19]. DSR is pointed out as an important conversion to puddled-transplanted rice production in irrigated places in particular where levels of water scarcity and elevated wages are dominant [20]. System of rice Intensification (SRI) is also listed among water saving techniques [21].

Mechanization & Precision Agriculture

In the document, it is highlighted that future research studies are needed in accuracy agriculture, specifically regarding the changing nature of remote sensing tools, and machine learning methods to improve crop yield forecasting [22]. It also notes that mechanization, such as mechanical transplanting of rice, is being adopted to address issues like labor scarcity and high labor costs [23]. The use of a zero-till drill or a happy seeder for wheat seeding is also mentioned as an agronomic practice that can increase yield and water productivity [24].Water and nutrient management are critical areas of research [25]. Efforts are underway to implement water-saving methods for rice cultivation, although their widespread impact on farmers' fields is yet to be fully realized [26]. Zero-tillage technology also contributes to water saving in wheat cultivation [27]. The review suggests that adopting proper irrigation and fertilizer scheduling based on soil tests can minimize leaching losses and improve profitability [28]. Technologies like alternate wetting and drying (AWD) and micro-irrigation are considered effective approaches to increase water productivity, especially when applied to DSR [29]. The document also points out that the eastern IGP (Uttar Pradesh and Bihar) has a significant yield gap, implying the need for effective water and nutrient management strategies to achieve substantial yield gains through technology transfer and assured input supply [30].

Digital & Climate-Smart Innovations

The document acknowledges that climate change poses a serious threat to agriculture, with projections indicating a reduction in agricultural gross domestic product by 4-5% and crop yield by up to 30% [31]. It underscores the necessity of suitable technological and policy interventions to counteract these negative trends and safeguard food security [32]. While not detailing specific digital tools like mobile apps or AI-based weather forecasting, the review highlights opportunities for future research in precision agriculture, including remote sensing and machine learning techniques for crop yield predictions [33]. These techniques are fundamental for developing climate-smart agricultural practices. Furthermore, adopting low-duration and less water-requiring varieties, water management, residue management, and resource-conserving technologies (RCTs) in RWS can help mitigate environmental pollution [34]. The rice-wheat cropping system in North India is undergoing a technological transformation driven by the continuous development of high-yielding and resource-efficient crop varieties, the widespread adoption of resource-conserving practices like zero tillage and DSR, and the increasing integration of mechanization and precision agriculture. While advancements in water and nutrient management are crucial, the overarching challenge of climate change necessitates further digital and climate-smart innovations to ensure the long-term sustainability and productivity of this vital agricultural system.

Determinants of Technology Adoption in Agriculture

While the provided document does not explicitly detail socio-economic factors such as farm size, income, education, or gender roles as direct determinants of technology adoption, it implicitly acknowledges the role of farmers' decision-making and the impact of economic parameters on the adoption of new varieties. As an example, new varieties are launched when they exhibit considerable difference in terms of better agronomic and economic factors [35]. Economic benefits among farmers, such as the reduction of the costs and water saving phenomenon, fuel the adoption of technologies such as zero-tillage to cultivate wheat [36]. Other disparities between rice and wheat in terms of share of old stock sold to the private sector are also pointed out in the document, indicating that it occurs differently among different states, implying a regional change in markets and possibly farmer preferences or economic affiliations [37]. Moreover, the lack of water and wages are mentioned as the issues that could make direct-seeded rice (DSR) to be practiced, which suggests that economic considerations can impact the decisions regarding technology [38].

The paper does not directly state that institutional support systems such as cooperatives, Farmer-Producer organisation (FPOs) or Krishi Vigyan Kendras (KVKs) are factors of technology adoption. But it has a mention of importance of technology transfer and guaranteed input supply to record high gains of yields especially in areas where yield gap are high such as the eastern part of the Indo-Gangetic's Plains (UP and Bihar) [39]. It means that good institutional frameworks should be in place to promote the use and diffusion of new technologies and supply required resources to farmers. Policy incentives like subsidies, Minimum Support Price (MSP) and crop insurance are directly not discussed as determinants of technology adoption in the given text. Nonetheless, the document indicates appropriateness of the technological and policy interventions to redress the unwanted trends perpetrated by climate change and averting the risk of compromising the food security [40]. This implies that the policy has a significant part in forming the agricultural landscape and it shapes taking the practices that have solutions to significant challenges. The pretentiousness of knowledge and awareness is brought about by the extension services, demonstrations, and training thus it is inherently understood as being a critical factor in the success of technology adoption. As demonstrated in the document, mass importation of technology is required to bridge the yield gaps especially in the eastern Indo-Gangetic Plains [39]. This means that information and training should avail themselves to the farmers as they can adopt new technologies. The need to make informed decisions by farmers concerning their farms is also mentioned in the review and this would require a source of knowledge on how to maintain their crops, soil structure, and moisture levels [41]. Moreover, the issue of the high difficult nature of precision farming methods, including the analysis and control of information, proves the need to spread knowledge and educate farmers [42]. Although, the document has not clearly outlined all the categories of determinants, it highlights economic viability, successful transfer of technology and policy interventions as the factors contributing towards the adoption of new technologies in agriculture. The necessity of farmers to make informed decisions and the input of the private sector in supplies of the seeds also attract attention to the implicit significance of socio-economic factors and knowledge distribution.

Future Directions and Policy Recommendations for Sustainable Technology Adoption

Technology transfer is important to reduce the yield gaps, especially in areas such as the eastern Indo-Gangetic Plains (UP and Bihar) [7]. Although the document does not explicitly explain mechanisms to strengthen the research-extension-farmer linkages, it points at a necessity to transfer the technology at scale [7] and Mr. and Ms. Farmers should make informed decisions [8]. This means there is a solid knowledge distribution system and clear presentation of best practices, including irrigation, management of fertilizers, control of pests and an awareness of the long-term impact on the health of the soil [9]. These associations would facilitate the relevance of research results in adoptable workable technology and needs and feedback provided by farmers guiding future research directions. The paper points out that traditional transplanted rice depends too much on the availability of labor and that automated transplanting is being viewed to curb labor shortage and prohibitive expenses [10]. It also reports about the necessity of significant enhancement of current technologies to large-scale implementation of these technologies by resource-poor and low-skilled farmers [11]. This implies that public-private partnerships can be used to make machinery, including Happy Seeder, accessible and affordable particularly considering that the machine is yet to be used in its use as it is only in need of a significant improvement to become widely used [11]. Although this is not stated explicitly, digital tools would conform to the requirement of decision-making, which is informed on issues related to crop, soil and moisture conditions by farmers [8], and this means that technology has a role in offering data-driven solutions.

Climate-Smart Policies for Rice-Wheat Systems

The review clearly indicates that they require applicable technological and policy interventions to correct unfavorable trends as influenced by climate change to avoid the threat of undermining food security [12]. This involves such issues as lowering groundwater tables and green house emissions [13]. Practices that would probably be encouraged by climate-smart policies include conservation agriculture, zero-tillage, direct-seeded rice (DSR) and diversified cropping systems, which have also been established as successful methods of sustainable rice-wheat production [14]. According to the document, the policy should also deal with overuse of fertilizer and its effects on groundwater pollution [15] and facilitate implementation of resistant cultivar to cut down the use of pesticides [15]. The challenge of high prices of production and process of diminishing profit margin in the traditional method of farming in rice-wheat has proven to be a major challenge [16]. An expanding difference between the minimum support prices (MSP) of rice and wheat and the cost of production adversely impacts on the overall profitability [17]. Smallholder incentives would require that these economic obstacles are overcome somehow, perhaps by subsidising cost-effective technologies such as zero-tillage of wheat [18] or DSR [19]. Among the factors mentioned in the document is the fact that technologies must be made available to the resource-poor and low-skilled farmers [11] meaning that incentives ought to be designed to meet the unique requirements and financial limitations of this group. Its general conclusion is that a great necessity to transition traditional rice-wheat crop systems to conservation agriculture and implement best-suited practices, which in sustainable crop production are based on need, and are optimal [20]. This demands a holistic solution that creates a balance between the productivity and sustainability [20]. Examples of interventions that should be combined in a roadmap include varietal development, water and nutrient management, resource conservation technologies (e.g. laser land leveling, DSR, aerobic rice, zero/minimum tillage) [14]. It would also have to address the long term impacts on the soils, water sources and environmental standards [20], with a co-ordinated approach among all parties in order to have sustainable food security.

Conclusion

Increasing the use of technology is essential in the maintenance of the rice-wheat cropping system (RWCS), a major system in the Indo-Gangetic Plains, a system that is vital in food security on a global scale [21]. The review notes that release of new varieties is done only when they show a considerable difference in relation to agronomic and economic parameters [22]. Some of the technologies such as zero-tillage of wheat, direct-sedded rice (DSR) and conservation agriculture are introduced as the main measures to overcome issues that included reduced factor productivity, degraded resources and high production cost [14]. The technologies present chances of productivity improvement, educating and saving money, using less natural resources. The document continually reminds repeatedly on the need to create a balance between productivity and sustainability. Although the RWCS has played a key role in meeting food grain demand, the continued adoption of the scheme has resulted in the serious loss of natural resources, a reduction in the productivity of the factors, and high prices of production [14]. This must then be transformed to the long-term sustainable management that leads to greater productivity and sustainability [14]. This entails adopting practices which strengthen healthy soil, water resource conservation and reducing environmental pollution [20]. This is to meet the needs of increasing populations as well as to achieve long term sustainability of agricultural systems [23]. It concludes the review by implying that the status quo RWCS principle should not be maintained, but should be replaced with conservation farming and introducing need-based best-suited practices on sustainable crop production [20]. It will involve adequate interferences in technology and policies [12] and action of all the stakeholders. Adoption of combined solutions of dealing with the challenges of varietal development, water and nutrient management in addition to resource conservation technologies are important measures to ensure resilient food security [14]. Such cooperative approach will be necessary in order to overcome the disadvantages of the existing system and preserve food production in the future [20].

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