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Precision Agriculture for Transforming Rice-Based Food Systems under Stress-Prone Environments

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Introduction

Rice is the major staple food for nearly 4 billion people worldwide and 800 million people in India. Despite considerable advancements in rice research and development, a number of issues and challenges have put rice farming in a precarious position. In Asia, rice is primarily grown in four different types of ecosystems: flood-prone, upland, rainfed lowland, and irrigated. But the primary hotspots for the concurrent occurrence of abiotic (drought, submergence, and/or salinity) stresses are the rainfed rice ecosystems in South and Southeast Asia. Abiotic stressors can affect about 16.33 million hectares (m ha) of rainfed arable land in India, including salinity (3.79 m ha), flood (5.36 m ha), and drought (7.18 m ha) (3.79 m ha). Resource-poor small and marginal farmers in these areas mostly depend on the rice-based cropping system (RBCS) for their food and livelihood. But the productivity of fragile rainfed environments often becomes low due to multiple stresses along with different biophysical and socio-economic issues (Singh *et al.*, 2017). Emerging vulnerabilities to monsoon variability and climate change make rainfed agricultural systems contribute around 44% of the food production from about 56% of the net cultivated area in the country. Farmers are still faced with a problem that results in risk-averse input management and prevents them from taking advantage of the regular (non-stress) year because of the monsoon aberrations and extreme weather events that are becoming more frequent (Singh, 2021). Location intelligence through precision rice farming is needed to address the variability at different scales. As the first line defense against climate threats and vulnerabilities, it is imperative to deploy stress-tolerant rice varieties (STRVs). In addition, precision agronomy, including improved management interventions, provide numerous opportunities to unlock the untapped potential of improved rice genotypes and bring the resilience of rice-based food systems under stress-prone environments.

Major challenges

Rice production under both the irrigated and rainfed systems in Asia are still being impacted by climate change. To continue producing enough rice to feed the growing population, there are numerous challenges to address and overcome. The major challenges include degrading natural resource base (soil and water), low input use efficiency, extreme climatic vulnerabilities, inadequate farmers' awareness (traditionalism in rice farming and burning rice straw), labor migration from rural to urban areas (growing shortage and high wages), inclusion of women and young people (unemployed youths), fragmented and small landholdings, diminishing profit margins (low incomes of many rice farming households) and environmental concerns. There is an urgent need to address these emerging challenges for improving the livelihood, nutrition, and income of smallholder farmers and their families. The International Rice Research Institute (IRRI) has been working with R&D institutions (both national and international), farmers, extension agents, policymakers, and other stakeholders to deliver consolidated research and education support services for achieving the major Sustainable Development Goals.

Agronomic Innovations and Interventions

i) Drought management

Drought is the most important abiotic stress that affects about 23 m ha of rainfed rice in South and Southeast Asia. The drought-tolerant rice varieties (DTRVs) of short- to medium-duration groups yield about 0.8-1.0 t/ha under severe drought stress situations, where the majority of farmers' preferred varieties typically succumb and produce insignificant or nominal yields (Dar *et al.*, 2020). The DTRVs (DRR Dhan 42, DRR Dhan 44, DRR Dhan 46, DRR Dhan 47, Sahbhagi Dhan, Shusk Samrat, etc.) can withstand dry spells for up to two weeks during the active tillering stage and even produce more or less double the yields of popular rice varieties (Dar *et al.*, 2020). Even they can perform better than the currently grown popular rice varieties (Damini, Moti, Sarju 52, Lalat, Swarna, etc.) under normal conditions in drought-prone areas (Singh, 2021). DTRVs can efficiently withstand drought stress and exhibit about 9-20% higher rice productivity over the recommended dose of fertilizers (RDF) alone when supplemented with the exogenous application of nutrients (calcium, zinc, and iron), which are inadequate under moisture stress conditions (Lal *et al.*, 2019). Optimal nutrition is a powerful drought-escaping strategy that greatly influences the water circulation within rice plants. Foliar application of potassium can improve the source-sink relationship as well as grain productivity through the retention of chlorophyll pigments during water shortage (Kumar *et al*., 2017). Other management interventions include choosing the appropriate crop establishment methods, seed priming, integrated weed management, using soil conditioner (hydrogel), soil/dust/straw mulching, etc. (Singh *et al*., 2020). While the improved (drought-tolerant) varieties and best management practices (BMPs) can provide about 14 and 12% yield advantages over the farmers' preferred varieties and farmers' management practices (FMPs), respectively, combination of improved varieties and BMPs together can give about 20% yield gains over the farmers' varieties and their own management in rainfed upland areas.

ii) Submergence management

Submergence is another significant abiotic stress that affects nearly 15-20 m ha of rice fields in South and Southeast Asia (Singh, 2021). According to field trials, SUB1 introgressed rice varieties (Swarna-Sub1, Samba-Sub1, BINA Dhan 11, CR 1009-Sub1, IR 64-Sub1, etc.), even after 10-15 days of flooding, can yield about 1-3 t/ha more than their recurrent parents (Singh *et al*., 2009). Proper nursery management (sparse seed rate, balanced nutrition), use of healthier and sturdier seedlings (35-40 days old), and post-submergence nutrient management (20-20 kg additional N-K_2O/ha at 5-7 days after de-submergence) help improve better crop survival with an additional yield gain of 0.5-1.0 t/ha in the STRVs under flood-prone rainfed lowland environments. Only improved management can give about a 19% yield advantage over the FMPs in coastal rainfed lowlands, whereas the stagnant flood tolerant rice varieties (such as Amal-Mana) with matching management practices (MMPs) involving transplanting of 2 seedlings/hill at a spacing of 15 cm x 15 cm and application of nutrients at 50-30-15 kg N-P_2O_5-K_2O + 5 t FYM/ha) exhibit about 73% higher grain yield than the farmers' preferred varieties grown with the existing practice (Sarangi *et al*., 2016).

iii) Salinity management

Rice productivity often becomes very low (<1.5 t/ha) in salt-affected areas of Asia, which remain either under-exploited or unexploited due to the presence of excess salt and other soil-related problems (Singh, 2021). A number of rice varieties such as CSR 36 (Naina), CSR 43, CSR 46, CSR 60, Jarava, Luna Sampad, Luna Suvarna, DRR Dhan 58, Narendra Usar Dhan 2008, Gosaba 5, Gosaba 6, etc. have been identified or developed for growing on degraded soils, compared with normal soil areas, the salt-affected areas need precision management practices for rice cultivation. The major recommendations for growing salt-tolerant rice varieties in coastal areas include using adequate organic manure (FYM, green manuring with *Sesbania* or *Azolla* as a biofertilizer), higher nitrogen doses (100 kg N/ha) in the nursery, transplanting three to four seedlings per hill at a spacing of 20 cm x 15 cm, and applying 150-60-40-5 kg N-P_2O_5-K_2O-Zn/ha in the main field. While the tolerant rice varieties (such as CSR 43) provide about 16% yield gain over the farmers' preferred varieties (such as Ganga Kaveri, Moti and Narendra 359), the same STRVs with the appropriate management practices (MMPs) increase the grain productivity by about 8 and 16% over current recommendations (BMPs developed by the ICAR-Central Soil Salinity Research Institute) and FMPs, respectively. Combining the MMPs with improved varieties can exhibit about 35% higher yield than the farmers' varieties and FMPs (Singh *et al.*, 2016).

iv) Management of multiple stresses

Successive occurrences of abiotic stresses such as heat, drought, submergence, and/or salinity within the same cropping season have led to incremental rice yield losses at farmers' fields. The Bill and Melinda Gates Foundation (BMGF)-funded project, 'Stress-Tolerant Rice for Africa and South Asia' (STRASA), has assisted millions of farmers who grow their crops primarily in rainfed environments to achieve remarkably higher yields despite abiotic challenges like drought, flood, cold, salt, and iron toxicity. With the use of IRRI breeding materials, climate-smart rice varieties such as CR Dhan 801, CR Dhan 802 (Subhas), and DRR Dhan 50 have been developed to combat multiple stresses in India. The Nepal Agricultural Research Council has also released Bahuguni Dhan 1 and Bahuguni Dhan 2 for flood- and drought-prone areas. BRRI Dhan

78, released by the Bangladesh Rice Research Institute, can tolerate vegetative stage flooding and reproductive stage salinity. The multiple STRVs provide 4-5 t/ha yield under normal conditions and 2.9-4.0 t/ha under varying levels of abiotic stresses (Singh, 2021). Since climate change poses a big challenge to smallholder resource-poor farmers, giving them better access to Green Super Rice (GSR) varieties is imperative. Many farmers are highly reluctant to apply external inputs in harvesting more output due to unpredictable weather patterns. Promising GSR genotypes are highly input-efficient, and they can withstand multiple abiotic stresses. Advancing agronomy of new GSR genotypes would significantly boost rice production and productivity in stress-prone vulnerable areas (Singh, 2021).

v) Precise and mechanized direct-seeded rice

Direct-seeded rice (DSR) has been emerging as a cost-effective and climate-resilient alternative to puddled transplanted rice (PTR) in South and Southeast Asia. Despite its multiple benefits, several studies have questioned the medium- to long-term sustainability of DSR-based systems because of yield decline, early season flooding, low germination under anaerobic conditions, irregular stand establishment, intense weed problems, soil sickness (micronutrient deficiencies), etc. Recently identified anaerobic germination (AG)-tolerant lines (like IR 14-D-177, IR 15-D-1072, etc.) with an improved management package provide a ray of hope for the popularization of DSR in rainfed lowland and other suitable environments (Singh, 2021). Lal *et al.* (2018) reported higher grain yields of IR 64-AG (21%), IR 64-Sub1 (16%), and IR 64 (19%) with the tailored management practices. Screening of weed competitive cultivars and their better bet agronomy is an innovative strategy for precise DSR. Dry-DSR (drill-DSR and precision broadcast-DSR), in combination with integrated weed management (IWM) may offer a pathway for simultaneously reducing costs and markedly increasing productivity (Panneerselvam *et al.*, 2020). The herbicide-tolerant (HT) rice varieties can be a game changer in improving crop performance and facilitating wider adoption of DSR. There is also a need to assess the extent of water saving, system productivity and resource budgeting of rice-based production systems under different micro-irrigation systems (surface and sub-surface drip). However, DSR can be made robust, mechanized and precise for its multiple advantages at the system level, not only during the rice phase.

vi) Precision agronomy

One of the most recent advancements in precision agriculture is a data-driven agronomic intelligence system, which uses machine learning techniques to deliver soil and crop management recommendations for each location (even at the 250 m pixel level). This geographic information assists fertilizer producers in creating custom blended fertilizers to address specific regional soil fertility problems and positioning the fertilizers where a high response is anticipated. Seed, pesticides, and the market sector can all benefit from similar intelligence to reduce costs while increasing resource use efficiency. The IRRI has developed Rice Crop Manager as a decision-making tool that offers site-specific fertilizer recommendations in irrigated and stress-prone rice-based systems (Singh *et al.*, 2022). To improve yield benefits and reduce greenhouse gas (GHG) emissions in rice production, farmer-friendly tools like Green Seeker and leaf colour chart (LCC) are helpful (Singh *et al.*, 2022). Similarly, IRRI has developed a number of digital tools (such as Easy Harvest, GHG Emission Calculator, Rice Doctor, RKB, SeedCast, WeRise, etc.) to support the research and farm management requirements in the rice sector. In addition to preventing eutrophication and water resource pollution, nano-fertilizers are expected to improve crop performance in terms of ultra-high absorption, nutrient use efficiency, etc. Scaling of alternate wetting and drying (AWD), sprinkler and drip irrigation systems issue under rainfed environments. AutoMon^{PH} is an Internet of Things (IoT) solution that makes it possible to schedule irrigation, monitor and report in real-time, and compute methane emissions more easily. Laser land levelling improves crop establishment and uniform maturity, increases input use efficiency, boosts yield, reduces weed infestations, etc. For precise site-specific weed management, IRRI and collaborating partners are also developing an Android-based beta version of WeedApp. Geographic Information Systems (GIS) and related Earth-observing technologies like Remote Sensing (RS), Global Navigation Satellite System (GNSS), and Unmanned Aerial Vehicles (or drones) offer a variety of applications, including crop growth monitoring, modelling and forecasting, damage assessment, pesticide applications, rice-fallow mapping, data-driven dynamic agro-advisories *etc.*, which would help increase the productivity and sustainability of rice-based systems (Singh *et al.*, 2022).

vii) System diversification, intensification, and optimization

Building the resilience of RBCS under climate change becomes sensible and cost-effective through crop diversification and intensification in space and time. The effects of harsh weather conditions, such as the unpredictable and variable monsoon in rice and the terminal heat stress in wheat, can be alleviated with proper crop management and timely crop establishment. Transformative gains in the wheat yields are achievable only when rice and wheat are managed as a coupled system in eastern India (McDonald *et al.*, 2022). It has been revealed that wheat yield becomes 8-10% higher when grown after DSR as compared to when grown after PTR (Kumar and Ladha, 2011). Food security, profitability, and climate resilience will benefit from the efforts to "keep time" through improved management of the annual cropping calendar both now and as a base for adaptation to progressive climate change (McDonald *et al.*, 2022). Short- to medium-duration STRVs can create new potentials for transforming rice-based systems through diversification, intensification, and optimization when combined with alternate crop establishment methods and scale-appropriate mechanization. As experienced with the Cereal Systems Initiative for South Asia, timely rice establishment along with shorter-duration STRVs like Sahbhagi Dhan (115-120 d) allows better utilization of residual soil moisture for the succeeding crop and permits mustard planting in early October, followed by mungbean or maize in spring. This results in an increase in system-level productivity by nearly 63% and system-level net income by 88–122%, compared with the current practice of long-duration rice varieties followed by late planting of wheat (Singh, 2021). When combined with the proper technological interventions and best management practices, the introduction of *rabi* pulses (lentils, Lathyrus, and chickpea) in rice fallows under *paira* (*utera*) conditions with residual moisture conservation not only aids in the conversion of mono-cropped areas into double-cropping systems but also expands the opportunities for improving system productivity, soil health, and diet nutrition (Singh *et al.*, 2020).

Conclusion

Rice production is highly vulnerable and unreliable to climate change. Risks and concerns are further intensifying due to knowledge gaps among the farmers who usually grow rice varieties with conventional practices, including suboptimal crop management. Compared with irrigated rice, rainfed rice typically confronts greater risks and hazards. The STRVs of short- to medium-duration groups aid in accommodating the diversified, resource-efficient, and remunerative crops in succession while offering farmers yield insurance. Being tolerant enough to endure weather aberrations and abiotic stresses, the STRVs become elastic to fit into the climate-resilient cropping systems and give significantly more grain yield than their recurrent parents with and without stress conditions. They can produce an additional yield of 0.5-1.0 t/ha when raised using tailored management practices. In conclusion, precision agriculture needs to be summed up as a holistic approach from the crop planning to the post-harvest processing phase of production, deploying improved genotypes, cutting-edge technologies, best-bet management practices and scale-appropriate mechanization with a view to enhance the system resilience, productivity, and profitability of the RBCS under stress-prone fragile environments.

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