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RICE WHEAT CROPPING SYSTEMS-CONSTRAINTS AND STRATEGIES : A REVIEW

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ABSTRACT

The rice-wheat cropping system (RWCS) in the Indo-Gangetic plains (IGP) of South Asia with the help of Green Revolution in the early 1970's greatly contributed to India's food self-sufficiency and livelihood of millions of peoplethus, became the country's primary source of food-grain production. However, deterioration of soil health and quality, ground water depletion, water stress, labour shortage, introduction of new weeds and pests particularly *Phalaris minor*, *Scirpophaga incertulas* and climate change have all contributed to a major production standstill and deterioration in recent years by which the sustainability of rice wheat cropping system is now at jeopardy. Traditional agronomic practices had various negative implications on the sustainability of rice wheat cropping system with the introduction of HYVs. So, a paradigm shift is required to achieve long-term productivity, sustainability and allow farmers to minimise inputs, optimise yields, enhance profitability, maintain the natural resource base and reduce risk owing to both environmental and economic issues through resource-conserving technologies (RCTs) including zero/minimaltillage, PUSA decomposer, bed planting, crop residue management, mechanical rice transplanter (MRT) and crop diversification. This article focuses some of the issues that need to be addressed in the RWCS in order to achieve the goal of increasing regional productivity and assuring food security while maximising the effective use of natural resources, enhancing rural livelihoods and aiding in poverty alleviation.

Keywords: PUSA decomposer, resources conservation technology, rice-wheat cropping system, sustainability.

Introduction

Over the last three decades, the rice-wheat cropping system (RWCS) which is found on 13.5 million hectares and 9.77 million hectares (Yadav *et al.,* 1996) in south Asia and India respectively has become a main production system in the Indo-Gangetic plains region of South Asia, spanning mainly in four countries: Bangladesh, India, Nepal and Pakistan, accounting for nearly 25% of grain production and nearly 60% of the population's calorie intake (Abrol *et al.,* 1990). In Indo-Gangetic Plains the RWCS is the most predominant system adopted by many farmers as rice and wheat are the staple source of diet of millions of Indians. The rice–wheat cropping system practiced mostly in Punjab, Bihar, Haryana, Uttar Pradesh and Madhya Pradesh. In north-western India Punjab and Haryana provide roughly 50 % of the rice and 85 % of the wheat procured by the Indian government (Deep *et al.,* 2018). However, in the last few decades yield of rice-wheat cropping system and land productivity in South Asia, particularly in the north-western IGPs, have either stagnated or decreased, resulting in numerous environmental consequences. In comparison to the region's climatic crop production potential of 12.0–19.3 tonne ha^{-1}, the yearly system productivity in IGP is low (3–5 tonne ha^{-1}) (Pathak *et al.,* 2003) mainly due to the fact that South Asia comprises of low to middle income countries, where declining groundwater tables, deteriorated soil health and quality, multi-nutrients deficiencies, frequent and widespread insect pest infestation, climate change, open-field burning of crop residue (particularlyrice residue), shrinkage of land and water resources and population increase are currently the most important issues and concerns for sustainable development. Current land-use practises in South Asia, notably in the rice–wheat cropping system, are energy, capital, water and labour intensive, upsetting the ecological balance and depleting groundwater and soil organic carbon (SOC), as well as having negative effects on soil physio-chemical qualities (Srinivasarao *et al.,* 2019). Intensive tillage and puddling for rice have resulted in a number of issues, including the development of hard plough-pan, poor input-use efficiency, lower yields, increased insect pest outbreaks and global warming (Bhat *et al.,* 2021). For more than 30 years with the advent of diverse range of resource-conserving technologies (RCTs) has been tested and distributed across RWCS in the IGPs to support sustainable crop production.

Importance of Rice-Wheat Cropping System in Indian Context

Agriculture, together with its allied enterprises are indisputably India's most important source of revenue, especially in the country's vast rural areas, where it accounts for around 16.38% of GDP and employs over 63% of the population (www.statisticstimes.com). Among these, rice-wheat cropping system is a significant sector which contribute to the one quarter of total food production. Food grain production increased significantly from 55 million tonnes in 1951 (Srivastava and Mukhopadhyay, 1997) to a record 305.44 million tonnes (www.pib.gov.in) in 2020-21 as a combined effect of greater utilisation of the HYVs with natural resources and fertilizer consumption. Rice production in India increased from 28.3 thousand tonnes in 1951-1952 to 121.46 million tonnes in 2020-21, while wheat production increased steadily from 61.2 thousand tonnes in 1951-1952 to 108.75 million tonnes in 2020-21 (www.pib.gov.in). The government of India purchases rice and wheat to distribute through the public distribution system (PDS). It was revealed that 36 % of wheat supplies and 31 % of rice were diverted at the national level (www.planning commission.gov.in). In the Northern, Eastern and North-Eastern regions, the diversion is greater; in the Southern and Western regions. Rice diversion in Bihar and Assam is expected to reach 64 %. In the case of wheat, Nagaland has a 100% diversion rate (www.niti.gov.in). Rice and wheat are primarily supplied by the rice wheat farming system of northern-western India, which is still expanding. Rice and wheat production have maintained up with the demands despite the region's enormous population.

Conventional Agronomic Practices in RWCS

Rice and wheat require different management and edaphic microclimatic conditions. Rice is commonly grown on puddled soils under submerged condition. To produce 1 kg of rice in the conventional system, 3000-5000 kg of water is used, with puddling representing the most (Mboyerwa, 2021). In the north western IGPs, irrigation is applied 5–6 times in rice to allow land preparation and puddling for rice transplanting which breaks down soil aggregates, reduces macropores, lowers soil strength in the puddled layer, disperses fine clay particles and creates hardpan in the subsoil, allowing ponding of water. Wheat, on the other hand, is produced in highly well-tilled dry soils which is generated through numerous (6-10) tillage operations (Laxmi *et al.,* 2007). Puddling for rice and ploughing for wheat have traditionally been the major soil tillage practises in South Asian RWCS. The annual conversion of soil from aerobic to anaerobic conditions for rice and then back to aerobic conditions for wheat is one of the most important management operations of the rice-wheat cropping system. This causes a number of chemical, physical, and biochemical changes in the soil that monitor and control nutrient conversion and availability, root development, moisture availability and crop root interactions and this could have significant implications for rice-wheat cropping system such as crop establishment, organic matter depletion and nutrient, water, and soil availability. The nutritional changes caused by submergence in rice field decrease the availability of N, S and Zn beside it also pollutes the air (Timsina and Connor, 2001). For each litre of diesel fuel utilised, an estimated 2.6 kg of carbon dioxide (CO_2) is released into the atmosphere. In a conventional system, roughly 70-80 litre of diesel are consumed per hectare per year to drive a tractor for field preparation and to pump water for irrigation in IGP, resulting in CO_2 emissions of about 200 kg/ha/year (Erenstein and Laxmi, 2008). As a result, this system has raised the cost of cultivation and had an impact on the surrounding environment.

Problems Associated with Rice-Wheat Cropping System

The rice-wheat cropping system in South Asia has greatly contributed to filling the growing number of empty stomachs, but inefficient application of applied inputs and overexploitation of natural resource bases, particularly land and water, are causing a variety of problems. Evidence suggests that with the implementation of green revolution technologies, increasing input utilisation has resulted in decreased marginal returns (Ladha *et al.,* 2000).

1. Declining Nutritional security

Carbon is the most significant ingredient in determining soil fertility. However, in the rice-wheat cropping system, soil organic carbon levels have declined from 0.5 percent to 0.2 percent within 30 years (Rana *et al.,* 2016) due to a demand for dung as fuel and as tractors has displaced livestock resulting in macroand micronutrient deficiencies in the soils. Puddling for rice cultivation destroys soil aggregates, exposing the soil to organic carbon oxidation. Burning of crop residues especially rice residues, has serious consequences, including depletion of organic matter, loss of essential plant nutrients, greenhouse gas emissions etc. By burning 1 tonne of rice residue, 1515 kg of CO_2 is emitted into the atmosphere, contributing to global warming (Prasad, 2014). Thus, traditional rice-wheat agriculture depletes SOC at a rate of 0.13 t ha^{-1} yr^{-1} from 0 to 0.6 m deep in the eastern IGP (Sapkota *et al.,* 2017). The RWCS not only extracted important nutrients (N, P, K and S) from the soil, but also generated a nutrient imbalance in soil leading to soil degradation. Supply disruptions of zinc (Zn) in rice and manganese (Mn) in wheat, have arisen as difficulties to maintaining high levels of food crop productivity as a result of intensive cultivation of high yielding rice and wheat varieties. Zinc deficiency has become common in the IGP and it is now the third most limiting nutrient after nitrogen and phosphorus, especially in soils with high pH and those irrigated with low-quality water. Field-scale zinc (Zn) shortage was first detected in rice in tarai soils (Mollisols) in the Himalayan foothills, resulting in the crop's failure (Nene, 1965). Deficiencies in multiple micronutrients are now becoming more prevalent, 49 % of Indian soils are potentially deficient in zinc (Zn), 12 % in iron (Fe), 5% in manganese (Mn), 3% in copper (Cu), 3 % in boron (B) and 11% in molybdenum (Mo) (Singh, 2008). As 80-85% of the K absorbed by rice and wheat crops remains in the straw, removing all of the straw from crop fields results in alarming rates of K mining.

2. Declining water productivity and groundwater quality

Countries with per-capita water availability less than 1700 m^3 per year is categorized as water stressed, India, with per capita available water of 1545 m^3, is unquestionably a water-stressed country (www.adriindia.org). The projected per capita water availability will be 1401 m^3 and 1191 m^3 by 2025 and 2050, respectively and India is likely to become a water-stressed country (www.adriindia.org). Nowadays faulty water management practices have resulted in major resource degradation issues in South Asia. Agricultural production in Punjab, Haryana and western Uttar Pradesh may be unsustainable unless significant improvements in groundwater and canal water management are made (Hira, 2009). Water resources have been continuing to be overexploited in most parts of the state including the states of

Punjab, Haryana, Uttar Pradesh and Bihar which have more than 60% (CAPE, 2016) of their cultivated area under irrigation as a result of the Green Revolution. A lot of water is used in the traditional rice cultivation to keep the rice fields flooded. Traditional rice cultivation methods require approximately 1200 mm of water during the season, only puddling requires 200 mm of water. The groundwater resource in Punjab is overexploited, resulting in a 1.2 million ha m/year deficit in water availability (Hira, 2009). In some areas of N-W IGP, the water table is now being depleted at nearly 1 m yr^{-1} (Abrol, 1999). Throughout the Indian Subcontinent, the cost of establishing tube wells, as well as the cost of energy, have increased dramatically as Pumping water for irrigation accounts for roughly 30% of total electricity consumption in the state. This is also becoming more prevalent as the groundwater becomes deeper. Agriculture production, particularly rice and wheat production, will need to be increased to feed India's expected population of 1.35 billion in 2025, posing a future threat to rising overuse of groundwater and pollution from NO_3- as Indian soil rarely exceeds the Nitrogen use efficiency of 30-40%. The use of this low-quality water in the agricultural and dairy sectors causes the onset of various serious diseases in animals as well as a reduction in grain quality, which has an impact on human health. Arsenic levels in groundwater exceeded the WHO maximum permissible limit of 0.05 mgl^{-1} in six West Bengal districts covering 34 000 km^2 and a population of 30 million. Over 800,000 people from 312 villages/wards are drinking arsenic-contaminated water and at least 175 000 of them have arsenical skin lesions (Das *et al.,* 1996). As a result, groundwater management is critical to the region's long-term sustainability of RWCS.

3. Effective disposal of Crop Residues

Every year, India produces around 501 million tonnes (Mt) of crop residue (MNRE, 2009). Cereal crops account for 70% of total crop residues (352 Mt), with rice accounting for 34% and wheat accounting for 22% (Saia *et al.,* 2020). So, farmers are timid to invest in field cleaning with a chopper since rice straw has no economic value and this will add to the cost. Rice and wheat straw (other than that used as dry fodder) are traditionally removed from the fields for use as livestock bedding material, thatching material for housing and fuel, but these represent only a small portion of the total amount of crop residues produced by the system; the remaining rice and wheat stubbles are burned in open filed condition (Bhattacharyya *et al.,* 2016). Because of the shorter time span between rice residue incorporation and wheat sowing, low temperature, slow rate of breakdown of rice straw due to its high silica content, the management of rice residue is a big issue in the Indian subcontinent. The problem of crop residue management has become more critical with the use of combine harvester, which leaves 15-25 cm tall stubbles and scatters the rest of the straw over the field. As a result, most farmers burn the rice/wheat residue in their fields. Burning of 1 tonne rice residue emits 1515 kg CO_2, 0.4 kg SO_2, 2.5 kg CH_4, 92 kg CO, 3.83 kg NOX and non-methane volatile organic compound (Andreae and Merlet, 2001), which might exacerbate climate change. Apart from carbon, burning results in up to 80% loss of nitrogen and sulphur, 25% loss of phosphorus and 21% loss of potassium (Bijay *et al.,* 2005). The annual burning of rice trash in nearby fields is associated with increases in asthmatic patients, because smoke from crop residue burning can clog lungs and cause respiratory.

4. Biodiversity losses

Many of our agricultural biodiversity has been lost as a consequence of the green revolution. The agricultural landscape in India traditionally dominated by rice and wheat based agro ecosystems of which many old local types are gradually vanishing from the farmed landscape when farmers chose to cultivate new improved agricultural varieties and continue to cultivate for a long time with the same varieties. These traditional crop varieties were resistant to insect pests and illnesses so many improvements in contemporary plant breeding have been feasible. The widespread usage of contemporary cultivars raises concerns about production stability and poses a risk of endemic disease or insect attacks. Biodiversity has intrinsic worth and contributes to the natural ecosystem, with the diversity declining natural stability become wakening. Maintaining the biodiversity is now a challenge for us.

5. Climate change and global warming

Climate change poses a variety of challenges, including temperature, CO_2 and rainfall, which affect plant development directly and indirectly through land availability, irrigation, weed growth, insect and disease outbreaks and so on (Debangshi, 2021). The mortality of useful soil fauna and microorganisms is caused by the burning of left-over wastes, which also contributes to poor air quality, human respiratory diseases and the death of beneficial microorganisms in soil due to intense heat generating. Burning of 1 tonne rice residue emits 1515 kg CO_2, 0.4 kg SO_2, 2.5 kg CH_4, 92 kg CO, 3.83 kg NOX and non methane volatile organic compound (Andreae and Merlet, 2001), Burning of farm residues emits some potent greenhouse gas, aerosols into the atmosphere which alter the atmospheric composition and have a direct or indirect effect on the radiation balance and depletion of the ozone layer. Puddled transplanted rice in RWCS and residue burning are substantial anthropogenic sources of CO_2 and CH_4 contributing the 20.9% of total GHG emission (Venkateswarlu, 2016). Due to extended flooding periods resulting in anaerobic degradation of organic material, wetland rice is a major source of atmospheric CH_4, even non-flooded soils modified with rice straw produce significant amounts of CH_4. During the life-cycle of rice, the growing process contributes the most (95%) to global warming, followed by the harvesting phase (2%) and the planting and milling operations (1%) (Bhatia *et al.,* 2012). In both the lower and higher IGP regions, the global warming potential is greater in rice cultivation than in wheat production. It is due to methane emissions from rice production. Poor nutrient management lead to nutrient leaking from the system due to low NUE. In the nitrification and denitrification processes, N_2O is formed as a leakage by-product. The RWCS system emits about 15 kg N_2O per ha^{-1} (Sass *et al.,*1992).

6. Decreased land and factor productivity

Total Factor Productivity (TFP) is the ratio of total output value to total input cost used to assess production efficiency over a short period of time (Bhattacharyya *et al.,* 2008). Increased demand from cities and industry puts pressure on land distribution to many food industries including agriculture. This could be linked to the development of a deficiency in one or more secondary and/or micronutrients (Hegde and Sarkar, 1992), growing disease and insects are the key causes of stagnant/lower land productivity and weeds which are primary cause of declining yields (Chauhan, 2010). Weeds fight for light, water and nutrients with the primary plants, lowering the total land productivity of the system. Many long-term trials undertaken in India show that depending on the soil types, even with continuous application of balanced chemical fertiliser (NPK), after a few years of continuous cropping, rice or wheat production, or both, declines (Hegde and Sarkar, 1992). Due to diminishing total factor productivity, farmers must apply more fertiliser to achieve potential yields.

7. Build-up of new insect pests in different habitat

Conventional rice-growing locations are humid to subhumid, allowing for a wide range of pest and disease infestations. Green crops with higher N-fertilizer doses and wet conditions from frequent irrigations serve as breeding grounds for insect pests and diseases (Prasad, 2005). Rice and wheat are grown in different crop seasons having different climate parameters (temperature, rainfall, humidity).The diseases and pests in the two crops are specific to rice or wheat but now as a result of continuous mono-cropping of rice and wheat, some pests and diseases are introduced in wheat also such as the rice pink stem borer (*Sesamia inferens*) has a carry-over impact on wheat crop, while the shoot fly (*Antherigona oryzae*), which used to attack rice only, may now attack both crops and is considered a general concern in India (Nagarajan, 1989). Continuous R–W cropping may allow build-up of soil pathogens, such as *Fusarium, Rhizoctonia* and *Sclerotinium. Rhizoctonia solani* and *Sclerotinium rolfsii* cause sheath blight and stem rot, respectively, in both crops (Rathore *et al.,* 2019). In the RWCS belt of Uttar Pradesh, India, mean yield losses owing to insect pests ranged from 27.3 to 69.5 % (Savary *et al.,* 1997).

8. Weed Flora Shifts and Herbicide Resistance

Excessive weed pressure and a diverse weed flora are the major issues on the road to sustainable agriculture. Weeds are a key biotic limitation to sustainable agriculture in Asia, with extreme reduction in grain output. Rice weeds *Echinochloa colona* and *Echinochloa crus-galli* are the most common in the RWCS (krishikosh.egranth.ac.in). The usage of a single herbicide or a combination of herbicides to manage *Echinochloa species* in rice has resulted in the introduction of other variety of grass, broadleaf and sedge weed species across the NW IGP in distinct ecological zones (Travlos *et al.,* 2020). The weed flora of direct-seeded highland rice differs significantly from that of transplanted lowland rice, necessitating distinct management strategies, including herbicide selection. *Phalaris minor*, the most common and troublesome weed in wheat, arrived in India with wheat seed from Mexico in the late 1960s and quickly established itself as a major weed of wheat in the RW cropping system in the north western IGPs (Singh and Singh, 2003). Due to broad spectrum of weed control, low cost and post-emergence application, the isoproturon herbicide (substituted urea group), introduced for its control in the 1970s, proved to be a potent herbicide. However, poor spraying procedures, higher rate than recommended, a higher spray concentration and year-after-year use of the herbicide finally led in the evolution of isoproturon-resistant *Phalaris minor* biotypes. During the mid-1990s, the first signs of *Phalaris minor* developing isoproturon resistance in the NW IGP appeared resulting in complete crop failure and the potential for the RW cropping system to become unsustainable in the region(Das *et al.,* 2014).

9. Labour shortage and poor incomes of the system

Rice–wheat cultivation requires a lot of water, energy, money and most importantly labour, because paddy transplanting, spraying and harvesting involve a lot of work. A labour shortage is now becoming an alarming problem in RWCS. Wage rates are higher since there is less labour available. Diminishing subterranean water table, as well as the spread of insect pests, diseases and weed pressure increase the cash flow in RWCS. Poor yields, owing to adverse climatic conditions, poor soil health, a deeper underground water table, poor quality underground water and outbreaks of insect-pests and diseases, frustrated because they were unable to repay the money they had borrowed (Bhatt *et al.,* 2016).

Smart Technologies to Address Challenges in the Rice–Wheat System

Rice farming in the future will be determined by the development of water-efficient varieties, alternative irrigation technologies and crop establishment procedures that use less water. One of the best possibilities for enhancing water use efficiency is sustainable agriculture and might be enhanced by implementing appropriate technology such as cementing the water channels, direct seeded rice (DSR), irrigation based on soil matric potential using tensiometers, laser land levelling etc.

Smart Technologies to Address The Water Security

The average annual per capita water availability decreased to 1486 cubic meters in the year 2021 as compared to 1816 cubic meters in 2001 and will further decrease to 1367 cubic meters in the year 2031(pib.gov.in). Laser land levelling, alternate wetting and drying (AWD), growing on raised beds and crop diversification are all techniques to save water in the RW system.

1. Laser land levelling

One of the major challenges faced by the agricultural sector is the high demand for irrigation water. Laser land levelling is fundamentally a water-saving technology as it maximises the water use efficiency by uniform distribution throughout the field. Compared to traditionally levelled ground, a laser levelled farm layout conserves and uses the available water and other farm resources more efficiently and effectively; reduces run-off and water logging; allows farmers to use as much water as they need in the most efficient way possible. It is practised on 1.5 million hectares in South Asia (Venkateswarlu, 2016). Laser land levelling has a number of advantages-

- Increases cultivated area by 3-6 % and improves crop establishment.
- Increases water application efficiency by 50% and saves irrigation water by 25-30%.
- Increases the efficiency of nutrient use by 15-20%.
- Improves the effectiveness of weed control

- Uniform depth of sowing of crops resulting uniform growth and development
- Provides better drainage facilities

Laser levelling is the process of automatically raising and lowering the grading instrument using a laser guidance system. It not only reduces levelling costs but also provides the appropriate levelling within a day. It aids in enhancing resource usage efficiency in surface irrigation systems by distributing irrigated water uniformly and conserving resources without harming the environment.

2. Mulching

Mulching of the soil surface with crop residue or other viz., soil, plastic, live plant materials is thought to be an effective way of soil and water conservation because it enhances water infiltration into the soil, reduces surface runoff and soil erosion and lowers overland flow velocity and sediment carrying capacity (Rahma *et al.,* 2019). Mulching has a crucial impact in rain-fed crop production to minimise water stress. Mulching has the following advantages-

- Mulches keep the soil beneath them moist for longer period and prevent evaporation and minimise water loss by 20-30% in the soil.
- Add organic matter to the soil
- Reduce the temperature fluctuation within the soil
- Suppresses weed development and thereby saving irrigation
- Synthetic mulches are important in the solarisation of soils.

3. Alternate wetting and drying

Irrigated lowland rice consumes more water causes land degradation due to excessive ploughing. Many cultivation methods have been developed in recent years to address this issue. Among them the Alternate Wetting and Drying (AWD) are the most widely used of the various water-saving methods. IRRI developed the AWD technique in collaboration with national agricultural research agencies in a number of countries (Kumar and Rajitha, 2019). AWD is defined by the drying and rewatering of the rice field on a regular basis. Using AWD, water consumption in rice production can be reduced by up to 25%. This water conservation, on the other hand, not only reduces CH_4 emissions by 11-97 percent (Lagomarsino *et al.,* 2016) without affecting yield. It can assist farmers in dealing with water constraint and improve the reliability of irrigation water supplies downstream. AWD met the physiological water demand of paddy by rationally controlling water supply during rice's key growth stages, resulting in reduced irrigation water use (Mao *et al.,* 2001). Furthermore, AWD strengthens the air exchange between soil and the atmosphere with wetting and drying cycles (Tan *et al.,* 2013), supplying sufficient oxygen to the root system to accelerate soil organic matter mineralization which increase soil fertility and produce more essential plant available nutrients to promote rice growth (Aziz *et al.,* 2018). AWD can cut irrigation costs by lowering pumping costs and fuel usage. By improving field conditions during harvest and permitting automated harvest, this strategy can also minimise labour expenses. As a result, AWD boosts farmers' net returns.

4. Direct seeded rice

Direct seeded rice has a lot of potential for reducing water usage in paddy cultivation. Transplanted rice is primarily grown in the North-Western Indo-Gangetic Plains (IGP). The adoption of dry DSR in the IGP can save a significant quantity of water used in rice production (Mahajan *et al.,* 2011). In Central Luzon, Philippines, wet seeded rice (WSR) was compared to transplanted rice (PTR) and it was realised that WSR systems used less water than transplanted rice for both land preparation and the total water use was reduced from 2,195 to 1700 mm (Kaur and Singh,2017). Direct rice seeding has the following advantages-

- Can save up to 50% water in rice
- On an average savings of 9% irrigation water when irrigation was applied on the appearance of soil hairline cracks (with 25 to 35 kPa at 15-cm depth) (Singh *et al.,* 2016).
- Reduces labour costs.
- Reduces methane production by 90% (Pathak *et al.*, 2003)
- Enhance maturity by 10-15 days which facilitates timely sowing of succeeding crop

5. Multi use of low-quality water

In the Indo-Gangetic plains, low-quality waters are frequently used in a cyclic mode. They are sometimes mixed with canal water in watercourses to increase total water supply and flow rates(Hobbs and Gupta,2003). Blending multi-quality water in on-farm water storage reservoirs not only improves the quality of waters with residual sodium carbonates and overcomes challenges connected with this water, but also enhances the use of rainwater and water production.

6. Furrow irrigated raised bed

Furrow Irrigated Raised Bed (FIRB) is one of the most advanced agricultural technologies developed by CYMMYT, that will improve the efficiency of the use of resources in general and water in particular, by reducing irrigation water usage. Water productivity and net profit increased significantly under this system and water productivity and net profit increased even more with the wide FIRB planting technique when compared to the flat planting technique (Jat *et al.,* 2005). This technique is designed to save irrigation water while also enhancing nutrient efficiency. Irrigation savings ranging from 18 to 50 % in the FIRBS (Jat *et al.,* 2005).

7. Micro-irrigation

Groundwater resources have been depleted or deteriorated as a result of the rice-wheat cropping system and traditional irrigation practises. Additionally, in the near future, non-agricultural demand such as industry, dairy, etc is projected to be addressed at the expense of agricultural water requirements, especially in light of shifting rainfall patterns through time and location. It is now time to entrust the development of irrigation techniques for higher input water productivity to scientifically qualified workforce. Micro-irrigation has yet to gain attention among the state's farmers. For the adoption of micro-irrigation in the state, viable funding solutions must be explored. This should be accompanied by specialised communication channels with farmers in order to keep them informed about the current state of dwindling water resources.

Smart Technologies to Address Residue Burning

In the current RWCS, on-farm residue management is a serious concern. Wheat straw residue is employed in the animal industry; however, rice straw is not suitable for use in the dairy sector due to its greater silica level. Because the turnover time between rice and wheat is so short that residue control is especially crucial during this period.

1. Crop residues as organic manure

Composting is a biological process in which microorganisms and earthworms use the organic matter of stubble to turn the dry waste into soil nutrients (Qian *et al.,* 2013). Converting rice stubble to compost appears to be a viable option for avoiding open field burning. On a dry weight basis, 5–8 kg N, 0.7–1.2 kg P, 12–17 kg K and 0.5–1.0 kg S per tonne of rice straw are important nutrients at harvest (Dawe *et al.,* 2000). Wastes are high in nutrients and enhances soil fertility. After five cycles of RWCS, organic C, total N, total K and accessible K were significantly greater in plots receiving crop residues compared to plots where residue was burned or removed in a study at Pant Nagar (Sharma *et al.,* 2000).

2. Residue as an activated carbon through Takachar

Takachar, a social enterprise, enables rural farmers to earn 40% more by converting crop residues on-site into fuels, fertilisers and value-added chemicals such as activated carbon (AC). It significantly increases the amount of waste biomass (post-harvest crop/forest residues) transformed into marketable products around the world and reduces air pollution associated with crop residue burning, all while ensuring a stable, renewable, pollution-free and financially lucrative raw material supply for the AC industry versus traditional fossil-based sources. By 2030, Takachar will have impacted 300 million farmers, generated $4 billion in additional rural income and jobs and reduced one gigaton of CO_2 equivalent per year. (www.unep.org).

3. Rice straw as animal fodder

Straws appear to be the best used for feeding livestock at the moment. In intensive rice growing areas such as India, all straw is still fed to livestock, despite the fact that they do not use it efficiently due to a lack of supplementary feeds. Rice straw has a higher silica content than lignin, hence it is not fully digested (Bhatt*,* 2017). Rice straw has a higher silica concentration (12–16 vs. 3–5 percent) and a lower lignin content (6–7 vs. 10–12 percent) than other straws. Rice straw stems are more digestible than leaves due to their reduced silica concentration; consequently, if the straw is to be fed to livestock, the paddy crop should be cut as close to the ground as possible (Talapatra *et al.,* 1948).

4. Rice straw as bio-fuels

Rice straw is widespread around the world, but mainly in Asia. However, due to its restricted use and low nutritional value as fodder, more than half of it is currently burned inefficiently in the field, producing acute respiratory sickness and worrying levels of pollution. Rice straw might be used in both biochemical and thermochemical systems to produce biofuels and biopower (Satlewal *et al.,* 2018). Plant ligno-cellulosic compositions are difficult to degrade and so can be used as a biofuel's raw material. Plant biomass is pre-treated for decomposition by selected microorganisms and transformed into sugars, making it an efficient biofuel (Bhuvaneshwari *et al.,* 2019). Anaerobic digesters can turn biomass into biogas. The monomers produced by anaerobic digesters are processed to produce acetate and formate which are then transformed to carbon dioxide and methane by beneficial microorganisms.

5. Use of new generation machines

With conservation agriculture and agricultural residue management, ensuring adequate seed germination and crop residue management are the key difficulties. Tarbo happy seeder, rotary disc driller and double disc opener drill are now available for post-rice residue treatment in wheat planting up to 10t/ha. The Happy Seeder is the ideal solution since it sows seed while also removing the straw, dispersing it uniformly around the field, mulching it and helping it retain moisture while also boosting seed germination. Over time, the straw decomposes organically, enriching the soil. Tips for getting the most benefit out of Happy Seeder:

- Happy Seeder operation should be avoided in the early morning hours because of excessive moisture content in residue and dew can clog the Happy Seeder.
- Before operating the machine, the operator should familiarise himself with all of the machine's mechanisms
- Before sowing the previous crop, the fields should be laser levelled (rice in this case)
- To ensure uniform crop establishment, ensure that the soil moisture content is ideal at the time of sowing.

6. Use of PUSA decomposer

The burning of rice/wheat residue is a serious issue not only at the state level but also at the national level. IARI scientists Dr. *Livleen Shukhar* and her team of senior research fellows and technical personnel created the one of the most potent residue mitigator PUSA bio-decomposer. Within 20-30 days, crop residue can be converted to manure, preventing stubble burning. To speed up the breakdown of stubble, four PUSA capsules must be dissolved in water and spray on one hectare of land. The pill contains crop-friendly fungus and has the advantage of having no negative effects. The crop remnants take about 20-30 days to degrade after being sprayed with the solution, which comes in the form of capsules that cost Rs 5-20.The fields retain some moisture as agricultural waste decomposes and the soil is nourished, reducing fertiliser need. This year, the Delhi government announced that the PUSA decomposer spray would be sprayed on 800 hectares of farmland across the city (Usha Rai*,* 2020). Some of the benefits include-

- As the stubble acts as manure and compost for the crops, the decomposer improves soil fertility and productivity, reducing fertilizer requirement
- Stubble burning depletes the soil fertility and eliminates beneficial soil bacteria and fungi, in addition to harming the environment
- It is a cost-effective, achievable and practical method for preventing stubble burning
- It is an ecologically sound and beneficial technology that will aid in the achievement of a clean environment

Smart Technologies to Address Climate Change

1. Reduction of food losses and waste

According to the Food and Agricultural Organization, nearly 40% of the food produced in India is wasted each year due to fragmented food systems and inefficient supply chains (FAO, 2017). We are generally worried with how to boost food production, yet reducing food losses enhances resource efficiency by reducing food production burden on farmers and food production enterprises. Rotate the foods in the fridge and cupboards to prevent food waste at home, process any excess or damaged fruits, vegetables, or meats. Kitchen garbage should be composted to improve soil health (Debangshi, 2021).

2. No-Till / minimum-Till system

Soil tillage practises have a significant impact on the physical qualities of soil as well as the balance of greenhouse gases (GHGs). Farmers can save money on labour and fuel by not tilling their fields, as well as can decrease soil erosion and conserve valuable nutrients. No-till also promotes the storage of soil organic carbon, resulting in carbon dioxide sequestration from the atmosphere. It has been discovered that conventional tillage systems have a net global warming potential that is 6–31 % higher than zero tillage systems (Mangalassery *et al.,* 2014). According to the Environmental Protection Agency, a no-till system can save 35 litters of diesel for land preparation. One litre diesel contains 0.74 kg carbon and emits 2.67 kg, so a no-till system can minimise a system's global worming potential (Natural Resources, Canada, 2016).

3. Integrated farming system

Agriculture production remains stagnant and factor productivity decreases due to natural resources depletion, rising biotic and abiotic stresses, poor seed replacement ratio, damages to the natural ecosystem caused, excessive and indiscriminate use of pesticides/fungicides, changing soil microbial dynamism and lack of adequate germplasm and low-cost input (Bouwer, 2002). To address such issues, the farming system approach has been widely recognised and advocated as one of the tools for ensuring the harmonious use of inputs and their compounded responses in order to ensure the sustainability of the production system (Ayyam *et al.,* 2019). An IFS is a set of resource-saving practises to achieve acceptable profits and high and consistent production levels while minimising the adverse effects of intensive agriculture and nature stewardship. In addition to reducing the risk of crop failure of RWCS areas because of weather vagaries and biotic factors like pests and diseases, the Integrated Farming System (IFS) pledges to increase farmers' food, nutrient, livelihoods and incomes.

4. Conservation agriculture

Conservation agriculture is a type of farming that conserves, improves and maximises the use of natural resources (FAO, 2010). It is a technique that conserves resources, minimal soil disturbance through organic soil covers, crop diversification, zero tillage and controlled traffic, are all critical parts of conservation agriculture (Hobbs and Gupta, 2003). Conservation agriculture strategies can also help agricultural systems become more robust to climate change. Conservation agriculture has been shown to minimise greenhouse gas emissions and improve the role of farming systems as carbon sinks in many circumstances. CA makes the following points in regards to climate change:

- Stop burning crop residues, which emit CO_2, CO, NO_2 and SO_2
- Reducing the usage of heavy machinery which reduces the consumption of fossil fuels and reduces on-farm emissions
- Soils with more organic matter emit fewer greenhouse gases
- Soils with a greater soil structure produce fewer greenhouse gases
- It enhances groundwater by improving infiltration quality
- Avoiding soil compaction minimises water runoff, improves soil aeration and contributes to increased soil carbon

5. Crop diversification

Rice and wheat production growth rates are either stagnating or declining in a number of states, including Punjab, Haryana, eastern Uttar Pradesh, Madhya Pradesh, Bihar, Himachal Pradesh and Jammu and Kashmir, raising concerns about the rice–wheat cropping system's long-term viability (Paroda,1996). Crop diversification is a strategy for transitioning from a less profitable and unsustainable crop or cropping system to a more profitable and sustainable crop or cropping system by maximising resource utilisation and changing and modifying the spatial and temporal crop/cropping activities on a farm. It can be two types: horizontal crop diversification and vertical crop diversification. The addition of more crops to an existing cropping system is referred to as horizontal crop diversification. Vertical crop diversification refers to the usage of any crop species that can be refined to make more versatile products. Maize crop diversity can lower CH_4 emissions by 90% to 100% (Venkateswarlu, 2016). Maize cultivation also has a number of environmental advantages such as reducing residue burning, enhancing soil physical properties and biodiversity, reducing groundwater contamination, etc. It will contribute to a general increase in environmental quality, which will improve people's quality of life. Because maize has a lower silicon content than rice, its biomass is more easily degradable, improving the organic matter content of the soil.

6. Site specific nutrient management

Agriculture is responsible for 70-90 % of nitrous oxide (N_2O) emissions, the most of which comes from improper application of nitrogen fertiliser (Ahmad *et al.,* 2018). By lowering total N application and/or timing applications to crop demands, SSNM minimises N_2O emissions and avoids N losses due to volatilization, leaching and runoff. As a greenhouse gas mitigation approach, SSNM is most suited to farming systems. Total reactive N (Nr: NH_3, NH_4^+, NO_3^-, NO_2^-, NO, N_2O) losses to the environment (via leaching or volatilization, for example) and N_2O emissions are reduced when SSNM is used. Implementation of SSNM procedures led in a 30% reduction in fertiliser consumption in rice (Wang *et al.,* 2007). Site-specific nutrient management, which takes these aspects into account, is needed to provide balanced and optimum nutrient usage, improved crop output and increased nutrient-use efficiency.

7. Soil carbon sequestration

Enhancing carbon sequestration through best management techniques (BMPs) such as residue management, permanent plant cover in soil to eliminate fallow periods, diverse crop rotation with legumes and agroforestry, among others. Retaining crop leftover without burning adds carbon to the soil; nevertheless, burning 1 tonne of rice residue emits 1515 kg CO_2, 0.4 kg SO_2, 2.5 kg CH_4, 92 kg CO, 3.83 kg NOX and nonmethane volatile organic compound (Andreae and Merlet, 2001), which might exacerbate climate change. Because the C:N ratio is so critical for CO_2 retention in the soil, the N supply from legumes plays an important role in controlling C-sequestration (Debangshi, 2021). Agroforestry is an excellent alternative for recarbonization by carbon sequestration, which entails the capture and long-term storage of atmospheric carbon dioxide. Carbon stored in soil in agroforestry systems ranges from 30 to 300 Mg C/ha up to 1 m (Nair *et al.,* 2010).

Smart Technologies to Address Weed Management

Future rice production is projected to be constrained by labour and water problems. The success of DSR is contingent on effective weed control. For long-term DSR production, an integrated weed management strategy is required. DSR has the ability to minimise rice cultivation's water and labour requirements. Some major components of weed management in DSR include developing rice cultivars with weed-smothering characteristics, improving seeding rate, crop geometry, residue usage and nitrogen management (Chauhan *et al.,* 2012). Weed pressure can be reduced during the early crop growing season by using the stale seedbed technique, in which the seedbed is prepared at least 7-10 days before seeding with moisture provided either by irrigation or rain to stimulate weed germination and emergence, which is then destroyed by shallow cultivation or the use of non-selective herbicides. The stale seedbed approach affects weed species that found in the top layers of soil. In the RWCS, weed-competitive crop cultivars can also help suppress weeds. A cultivar with a fast-growing and early canopy cover can cope better against weeds. Weed seedling emergence in zero-till fields can be decreased by mulching as crop residue act as an allelopathic and shade providing agent which decreased weed populations by 50-60% (www.mafiadoc.com). Crop diversification is another way to suppress the weed in RWCS. Diversification of RWCS to rice-sunflower, rice-potato-sunflower, rice-berseem, rice- maize has been advocated to reduce the infestation of Phalaris minor.

Smart Technologies to Address Socioeconomic Stability

Rice harvesting is the costlier rice production field operation, as the timing, duration and method of harvesting have a direct impact on rice quality, efficiency and farmer incomes. Rice is harvested by hand (as sickles) and threshed by hammering on a hard substance in underdeveloped countries. Compared to traditional manual harvesting, rice harvesting with contemporary rice harvesters saves time, money and labour while also reducing grain losses. Harvesting costs were reduced by 37 % for reapers and 52 % for mini-combine harvesters when compared to hand harvesting (Rathore et *al.,*2019). Rice transplanting under puddled conditions necessitates a significant amount of labour. However, due to out migration of laboursand decrease in their availability in recent decades, particularly during the transplanting time, the cost of cultivation has increased. Using a mechanical transplanter reduces labour issues and saves money. DSR, ZT wheat, permanent bed planting and the use of PUSA decomposer are examples of resource conservation technologies that limit money outflow from the managemental chain. The application of these new technologies also improves the farmer community's socio-economic condition.

Conclusion

Resource conserving technologies are a key principle to ensuring sustainable food production in India in the next decade. The necessity of partnerships, enlarged stakeholders and participatory systems is needed for adopting various resource-conserving methods in terms of improved production at reduced costs, increased natural resource efficiency, environmental benefits, enhanced farmer livelihoods and ultimately, aid in poverty alleviation.

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