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Remedial options for the sustainability of rice-wheat cropping system

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Abstract
The rice-wheat cropping system of the Indo-Gangetic Plains (IGP) has contributed tremendously to food security of the region. However, of late there has been a significant slowdown in yield growth rate of this system and the sustainability of this important cropping system is at stake. A decline in soil productivity, particularly of organic C and N, deterioration in soil physical characteristics, a delay in sowing of wheat, and decreasing water availability are often suggested as the causes of this slowdown in productivity. Therefore, a paradigm shift is required for enhancing the system's productivity and sustainability. Resource-conserving technologies involving zero- or minimum tillage with direct seeding, improved water-use efficiency, innovations in residue management to avoid straw burning, and crop diversification should assist in achieving sustainable productivity and allow farmers to minimize inputs, maximize yields, conserve the natural resource base, reduce risk due to both environmental and economic factors, and increase profitability.

Keywords: agronomic practices, food security, rice-wheat rotation, sustainability

1. Introduction
Rice-wheat (RW) is the most important cropping system for food security in South Asia, providing food for more than 400 million people (Ladha *et al.*, 2003) [34]. In India, the system contributes 26% of total cereal production and 60% of total calorie intake (Gupta *et al.*, 2003) [18] and contributes about 40% of the country's total food basket (Sharma *et al.*, 2015) [52]. The area under the RW system covers around 32 and 42% of total rice and wheat area, respectively (Saharawat *et al*., 2012) [45]. The productivity and sustainability of the system are threatened because of the inefficiency of current production practices, shortage of resources and socio-economic changes (Ladha *et al.*, 2003) [34]. Pressure is increasing on the limited land, water and environmental resources for producing more food to match the demand of the burgeoning population.

During past 2 decades, the RW system is showing the sign of fatigue because of continuous use of traditional practices which resulted in to yield stagnation and declining factor productivity (Ladha *et al*., 2003; Bhatt *et al*., 2016) [34, 4]. In addition, there has been enormous damage to available natural resources (soil, water and energy). The declining soil fertility (Jat *et al*., 2014, Kakraliya *et al.*, 2017) [31], depletion of ground water, increasing shortage of labour and energy, rising problem of salinity and alkalinity (Bhattacharyya *et al.*, 2015) [6], multiple micronutrient deficiency, emergence of herbicide resistant and shift of weed flora besides environmental pollution through emission of greenhouse gases (GHGs) and large scale burning of rice straw are very complex and serious issues in RW belt of IGP (Hobbs *et al*., 2008; Yadav *et al.*, 2016) [18]. These emerging challenges have put a big question mark on the sustainability of RW cropping system.

The conventional farmers' practices of transplanting rice seedlings manually after repeated dry and wet tillage (Puddling) followed by conventionally tilled wheat seed broadcasting contributes significantly to the challenges described above and making RW system unsustainable. Conventional practices are water, capital and energy intensive and deteriorate soil health (Sharma *et al.*, 2003) [48]. Intensive puddling in rice increase in soil strength in surface and sub-surface layers due to illuviation of clay, iron and manganese compounds; decrease in hydraulic conductivity and infiltration leads to water stagnation, poor root development, and low recharge of aquifers (Gathala *et al.*, 2011; Bhushan and Sharma, 1999) [49, 45]. Economically, RW cropping system is becoming less and less profitable because of increasing input costs involved with conventional tillage (CT) practices (Gathala *et al.,* 2014) [9]. Also the results of long term field trails in Indian IGP have shown declining trends in the productivity of RW system with 0.02 t/ha/year even after using the recommended dose of fertilizers (Duxbury *et al.*, 2000) [13]. The use of blanket nutrient management recommendations in India has led to low nutrient use efficiencies, lowered profits and increased environmental problems (Pampolino *et al.*, 2012) [41]. Nutrient recommendations in India are based upon crop response data averaged over large geographic areas and do not take into account the spatial variability in indigenous nutrient supplying capacity of soils (Sapkota *et al.*, 2014) [46]. Such unbalanced and inadequate use of nutrients can decrease the nutrient use efficiency and profitability and may increase environmental risks associated with loss of unutilized nutrient through emission or leaching. This further increases the agriculture's share to total GHGs emissions. High temperature during wheat maturity suppress the current photosynthesis, inhibits starch synthesis (Sharma *et al.*, 2015) [52], shortens grain filling duration and rate of grain filling (Lobell *et al.*, 2012) [36] and all leading to shrivelled grain, poor grain quality and lower yields. For example, about 51% of the Indo-Gangetic Plains may become unsuitable for wheat crop, a major food security crop for India, due to increased heat-stress by 2050 (Lobell *et al.*, 2012) [36]. Pathak *et al.* (2003) [34] reported a yield loss of 15-60 kg ha^{-1} day^{-1} if wheat planting is delayed beyond mid-November in NW India.

Therefore, adaptation to climate change is no longer an option, but a compulsion to minimize the loss due to adverse impacts of climate change and reduce vulnerability (IPCC, 2014) [24]. Moreover, while maintaining a steady pace of development, the region would also need to reduce its environmental footprint from agriculture. Considering these multiple challenges, agricultural technologies that promote sustainable intensification and adapting to emerging climatic variability yet mitigating GHG emissions (climate smart agricultural practices) are scientific research and development priorities in the region (Dinesh *et al.*, 2015) [12].

There are a wide range of agricultural practices that have the potential to increase adaptive capacity of production system, reduce GHGs emissions or enhance soil carbon storage. The portfolios of climate smart agriculture (CSA), a set of smart management practices involving *water smart* (direct seeded rice, laser land levelling, tensiometer and weather forecast based irrigation), *nutrient smart* (site specific nutrient management through nutrient expert tools, green seeker, slow release nitrogen fertilizer and right placement of fertilizers), *carbon smart* (residue retention and incorporation), *weather smart* (index based crop insurance, weather forecast), *energy smart* (laser land levelling, direct seeded rice and zero tillage) and *knowledge smart* (Information and communication technology); are such innovative approaches that have demonstrated as the potential strategies to enhancement farm profitability, making crop production resilient to changing climate and to reduce ecological footprint of agricultural production system for sustainable food security (Kumar *et al.*, 2017) [15].

2. The rice-wheat production system in the Indo-Gangetic plains (IGP)

In South East Asia, *Green revolution* facilitated the expansion of area under rice (*Oriza sativa*)-wheat (*Triticum aestivum*) rotation and now estimated to be about 14 million ha which confined to IGP. IGP covers nearly one-fifth of the total geographical area in four countries i.e. Pakistan, India, Nepal and Bangladesh, occupies by 2.2, 10.5, 0.5 and 0.8 M ha, respectively (Hobbs and Morris, 1996; Ladha *et al.*, 2003) [34, 19]. Rice-wheat cropping systems (RWCS) covered about 32% area under rice and 42% under wheat in these four countries with one quarter and one-third of total rice and wheat production. This system is predominant cropping system of the Indian IGP.

In India where, rice and wheat are grown in rotation on about 10.5 M ha and it contributes about 40% of the country's total food basket (Sharma *et al*., 2015) [52]. The area under RW rotation in India increased substantially from 4.0 M ha to 12.3 M ha during the last four decades (Hobbs and Morris, 1996; Ladha *et al*., 2003) [34, 20]. During this period, Haryana and Punjab became rice growing areas even with their semi-arid climate, fallow and salt affected soils. These two small states have less than 3% of the total geographical area of India but contribute about 69% of the total food procurement by the Government of India (about 54% of the rice and 84% of the wheat) (Singh *et al.*, 2003). This huge increase in production of rice and wheat, known as the "Green Revolution" was the result of expansion of cultivated area as well as crop productivity due to the introduction of high yielding varieties (HYV), higher chemical fertilizer, pesticides, irrigation and mechanization. The crop establishment practices of transplanting rice seedlings manually after repeated more dry and wet tillage (Puddling) followed by conventionally tilled broadcasting seeding of wheat are prevailed in the IGP farmers. This RW rotation ensures employment, livelihood and income to small land holder and food security through comparative productivity, profitability and stability than other cropping systems (Ladha *et al.*, 2015) [35].

3. Major issues of rice-wheat cropping system

Despite these practices, RW system is suffering from a number of ecological, agricultural, livelihood, technical, and social issues as listed in table 1.

Table 1: Major issues of rice-wheat cropping systems

Ecological issues	Agricultural issues	Livelihood issues	Technical issues	Social issues
• Environment pollution • Declining underground water table • Ground water pollution • Diverse weed flora • New diseases and insect pests • Reduced biodiversity	• Deteriorating soil health • Large management yield gaps • Residue management • Least attended Intervening period • Labour shortage • Declining crop response	• High energy requirement • Decreased land productivity • Decreased water productivity • Decreased efficiency of water use • Poor incomes. • Climatic issues	• Low mechanization • Lack of appropriate seeders especially for small and medium scale farmer • Lack of adoption rate of new technology	• Population expansion • Farmers mindset with traditional practices • Youth moving away from farming • Land holding- getting smaller and fragmented

3.1 Ecological issues

In India, each year more than 501 M t crop residues are produced as greater than 90% the acreage under wheat– rice cultivation is combine harvested, which left back loose straw in windrows. The issue of proper management of left over rice straw (>7 t ha^{-1}) is a crucial challenge. The burning of rice residues is mostly adapted by Indian farmers owing to its easiness and quickness in disposing which cases considerable air pollution (Gupta *et al.*, 2003) [18]. The burning of crop residues results in great loss of soil nutrients, death in beneficial soil microbes in surface few cm soil, and loss in soil physical and biological health (Singh and Sidhu, 2014). Cereal contribute 70% of the total crop residues (352 Mt) comprising 34% by rice and 22% by wheat crops. About 25–30% of N and P, 35–40% of S, and 70–75% of K uptake are retained in wheat residue. Besides, to maintain a proper water level in the field, rice demands assured water availability. The traditional method of rice cultivation generally requires 1500 mm of water during its life cycle. Furthermore, the raising of seedling and their subsequent transplanting requires 50 mm of water. This excess demand of water for irrigation purpose is fulfilled by the over exploration of ground water. Therefore, this huge water demands by rice cultivation greatly depleted the ground water level since last four decades. In Punjab alone, annual water shortage of 1.2 M ha meters has been reported. The declining ground water table is becomes an alarming task which needs an immediate attention of scientists as well as the policy makers. Similarly, over use of agrochemicals including synthetic fertilizers in RWs deteriorate the ground water quality owing to runoff and leaching of chemical residues and thus dissolving in ground water. Consequently, the use of this contaminated poor quality ground water for irrigation purpose invites several diseases of cops, and livestock which ultimately affect the human health and livelihood (Bhatt *et al.,* 2016) [5]. This indiscriminate and unbalanced nitrogenous fertilizer application makes groundwater nitrate rich which a serious concern to human health. This becomes worse in sandy soils in which the nutrient use efficiency remains less and thus more nitrate will leach in lower soil horizons. The proliferation of diverse weed pool also became a matter of concern in RWs threatening sustainability of agricultural system. The intensive RWs system brings the emergences of more grassy weeds in the field which compete with crop plants for light, water, space, and nutrients which in turn decreases the overall productivity of the system. This cause's serious yield reduction as it is a major biotic constraints in sustainable agricultural production (Chauhan, 2012). Both the crops in the system are grown in lavish environment and so both these needs higher amount of fertilizers and irrigation water which increases the insect-pest outbreak. Outbreak of the diseases and insect-pests attack is mainly responsible for the lower water and land productivity and is considered a serious issue in the way to sustain- able agriculture.

3.2 Agricultural issues

The declining soil health at an alarming rate results in deficiencies of various macro and micro nutrients in one and another part of the country (Kakraliya *et al.,* 2016) [32]. Extensive tillage practices breaks the larger soil aggregates further coupled with poor contact with seed, thereby reduces potential yields. Therefore, puddling in rice is a water, labour and emery consuming process which deteriorates the soil physical structure. The disking, tilling and planking operations in the conventional wheat cultivation exposes of hidden soil organic matter on the surface of soil which promotes rapid oxidation of organic matter. In RWs, the on farm residue management is a key issue. The what residue is used for animal consumption but not the rice straw because the higher silica content in rice straw make it appropriate for animal consumption. Similarly, soil incorporation of rice residue enhance N immobilization due to its wider C:N ratio which in turn drastically decreases crop yield. In general, rice growing farmers burns rice straw infield for timely sowing of succeeding wheat crop and to reduce yield loss in wheat due to delayed sowing. The rice residue burning causes environmental pollution, global warming, killing the beneficial insects, create net negative nutrient balance and also degraded the soil, decreases organic matter levels and finally results in the soil health deterioration. As we know the rice-what system is a labour intensive system, therefore, the labour shortage is an emerging issue in the prevailing RWCS due to narrow window period and legal binding to transplant paddy after 10th of June. This labour shortage is more prevails since last few years due to assured working days offered under MANREGA scheme of Govt. of India and thus flow of labour to region is decreased to a remarkable extent (Bhatt et al., 2016) [5]. Lower labour availability is responsible for higher wage rates. Before 1960s, only the major plant nutrients was provided through the use of chemical fertilizers, although with time micro-nutrients also being provided through chemically formed fertilizers due to decline in micro-nutrient availability in several regions under RWs. In coarse textured soils of Punjab, wheat grown after rice suffered from manganese deficiency. In rice–wheat cropping sequence, decline of wheat yields due to boron deficiency was found in soils of West Bengal. Selenium toxicity is also an emerging issue coming out of intensive RWCS in the region, however, under maize–wheat cropping rotation, no selenium toxicity was observed. The yield decline in rice– wheat sequence was highest when N-fertilizer was applied alone @ 120 kg ha^{-1} while P-fertilizers responded to crop yield after 10 years while response from K-fertilizer started to increase after 5 years. Main reasons behind low response of crops to N-fertilizers are its low use efficiency (especially in rice where it is only 30–40% of applied N) due to surface runoff, ammonia volatilisation, leaching and denitrification.

3.3 Livelihood issues

The decline of underground water levels associated with replacement in centrifugal pumps by submersible pumps which lifts up water from the deeper depths are serious concern in RW cropping system. However, there is already a power shortage in the state and energy is diverted from the industrial sector to the agriculture sector, with drawing more power will create unemployment as then industry sector has to close for some-time. Further, free electricity provided by the government to the farmers in agricultural sector further compounded this problem as farmers are now having no interest in saving irrigation water. With an effect the water levels below the ground declining at an alarming rate. As per the current situation, by 2023, in Punjab state of north India, the electricity cost for pumping ground water from a depth of 43 m would increase by 93% compared with that for 2006. In the time of ever increasing population and hungry stomachs, decreasing land productivity might be quite dangerous. About 2.5% growth in cereal production will be required to meet the future food demands (Hobbs and Morris, 1996) [18]. From the last 30 years, production goal has been able to keep pace with population growth and this is only possible through an increase in the area and yield growth. Increased demand by urban areas and industry creates a competition for land allocation to different sectors including the agriculture. Some studies reported stagnant or even lesser yields in RWCS because of different factors and their compounded effects (Dawe, 2000; Duxbury *et al.*, 2000) [13]. Water productivity is the quantity of irrigation water used to produce per unit of the grains. But decreased water productivity is a major cause of concern as reported by many workers through-out the region under different agro-climatic conditions (Humphreys *et al.*, 2010; Bhatt, 2016) [5]. Thus, there is a need to improve the declining water productivity either it is irrigation, total or real water productivity. Efficiency of water use is different from the productivity in terms that the former deals with total water discharged from the tube well up to the field and include the conveyance losses while the latter is the grain yield obtained from a particular volume of applied water to a particular field and it does not include the conveyance losses. It was reported that around 35 to 55% of applied water for the main field was lost before reaching the main field. Besides, degradation of the soil structure, formation of hard pan and declining underground water table along with outbreak of in various biotic and abiotic stresses usually result in lowered land productivity. Lower land productivity mean lower grain yield produced per piece of land. Land holdings are already shrinking with generation after generations. Therefore, by keeping in mind these facts, the issue of agricultural sustainability is of great concern throughout the RW growing areas.

4. Rice-wheat cropping system and climate smart agriculture (CSA)

Climate smart agriculture strives to sustainably increase productivity and profitability build resilience and adaptive capacity; where possible reduce greenhouse gas emissions (GHGs). CSA is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security with changing climate. CSA aims to tackle three main objectives: (i) sustainably increasing agricultural productivity and incomes (ii) adapting and building resilience to climate change (iii) reducing and/or removing GHGs, where possible (FAO, 2010). Development of appropriate adaptation, mitigation of GHGs and food security strategy under rice-wheat production condition is important to cope with the progressive climate change and variability. Jat and Aggrarwal (2014) under the CGIAR research program on climate change, agriculture and food security (CCAFS) and international maize and wheat improvement centre (CIMMYT) initiated the climate smart village program in Haryana. The project calls for community based and local adoption planning to address the challenges of climate change. The CSV adopts a portfolio of interventions that cover the full spectrum of farm activities these include; *Water smart*- (Interventions that improve water use efficiency by adopting direct seeded rice, laser land levelling, tensiometer, micro- irrigation, rainwater harvesting, raised bed planting and weather forecast based irrigation application), *Nutrient smart*- {Interventions that improve nutrient use efficiency by adopting site specific nutrient management (SSNM); nutrient expert tools, green seeker, slow release nitrogen fertilizer and right time, optimum amount and proper placement of fertilizers (need based)}, *Carbon smart* - (Interventions that improve carbon stock in soil and reduce GHG emission by adopting inclusion of legumes, residue retention and incorporation and zero tillage) *Weather smart*- (Interventions that provide services related weather advisories to farmers by using short and long term weather forecasting, weather based crop insurance) *Energy smart*- (Interventions that improve energy use efficiency by adopting laser land levelling, direct seeded rice, zero tillage or minimum tillage) and *knowledge smart* - (Use of combination of science and local knowledge- Information and communication technology, cooperative societies) (Fig 1).

These interventions work in combination may help in adapting to climate risks and building resilience to extreme weather and climate variability of varying degree under diverse production systems and ecologies and mitigation of GHG emission and ensures future food security (FAO, 2010). The CSAPs in isolation may or may not work effectively due to their poor interactions with other factors. But, layering of various CSAPs may have synergies and lead to multiple effects of these practices together compared to that in isolation.

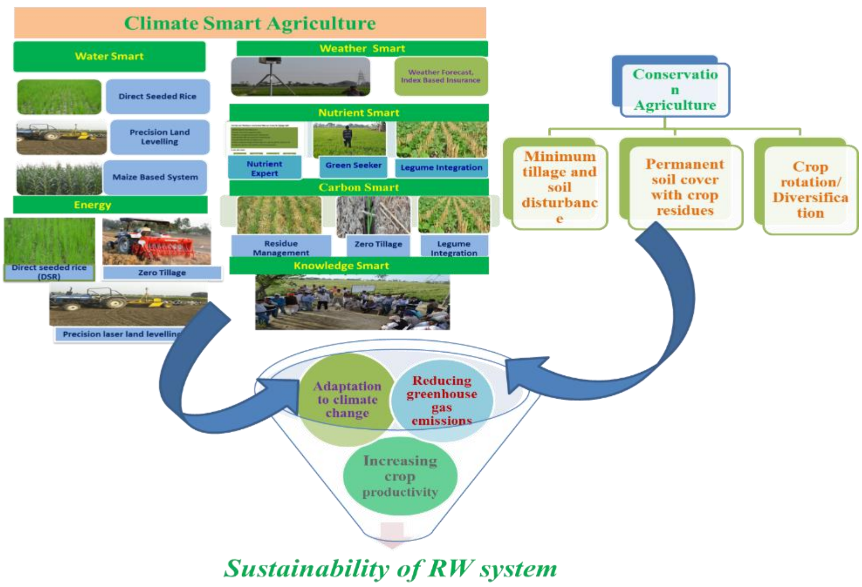

Fig 1: Climate smart agricultural and conservation agriculture based management practices for sustainability of RW system

4.1 Effect of climate smart agricultural practices (CSAPs) on growth and yield

Rice

The DSR in moisturized soil produced taller plants, more dry matter and tiller density than transplanted rice (Sarkar *et al.*, 2003). Choudhary (2016) reported tallest plants at harvest under ZT DSR treatments and lowest being with puddled transplanted rice. Yadav *et al.* (2011) ascribed that number of tillers per m^2 and dry matter accumulation was significantly higher with DSR than PTR at all growth stages. Mahajan *et al.* (2011) observed similar grain yields between aerobic DSR and conventional puddled transplanted rice. In contrast to above Akhgari and Kaviani (2011) reported that transplanted rice yields more than DSR. They opined also that lesser yield is compensated by reduction in production cost. Hobbs *et al.* (2002) [20] revealed that panicle number per unit area was almost 150% higher in DSR than PTR, but grain weight per panicle was higher in the transplanted crop. This compensation of various yield components under DSR resulted in statistically similar grain yield. Kaur *et al.* (2012) observed that precision land levelling (PLL) increased rice yields by 4.3% over traditional land levelling (TLL). Rickman (2002) showed a 24% or 530 kg ha^{-1} increase in the yield of rice due to PLL over TLL at the same level of variety and fertilizer use.

Wheat

Zero tillage (ZT) has been widely adopted by IGP farmers in wheat production, mostly in NW India. ZT facilitate early planting of wheat in areas where rice is harvested late and reduced production cost ultimately increase yield and net return (Ladha *et al.*, 2015) [35]. With the mechanized of planting equipment that can easily manage loose straw left in field after combine harvesting of rice and drill seed and fertilizer directly through the residues at appropriate depth (e.g. Turbo happy seeder) (Sidhu *et al.*, 2015). Sidhu *et al.* (2015) reported that yield performance of wheat was better under ZT with residue retention situation as compared to CT wheat. Erenstein and Laxmi (2008) reported that ZT increased wheat yields by 5-7% compared to CT wheat. Yadav *et al.* (2005) showed that 15% increase in the yield of wheat due to residue incorporation as compared to CT wheat. Sidhu *et al.* (2007) revealed that grain yield increase by 9-11% with ZT wheat plus rice residue as compared to farmer`s practices (CT wheat). Kader *et al.* (2017) reported higher yields of wheat under ZT with residue retention that might be due to the cumulative effects of better light interception, favourable soil and canopy temperature, more soil moisture that resulted into more yield attributes than CT practices. Nawaz *et al.* (2017) ascribed that productive tillers, grains per spike, 1000-grain weight, biological yield, grain yield, harvest index and water productivity of wheat was significantly higher under zero tillage wheat (ZTW) as compared to CTW. Further, other smart practices like site specific nutrient management (SSNM) approach arrests the spatial and temporal variability in soil fertility in smallholder production system and provides an approach to “feeding” crops with all the required nutrients based on crop’s needs and thus improves the crop yield along with higher nutrient use efficiency (Singh *et al.*, 2015). Jat *et al.* (2016) across South Asia and Latin America also revealed that improved management practices have high adaptive capacity to combat climatic adversities in agriculture. The weather forecast and early warning systems will helpful in minimizing the threats of climate losses.

4.2 Effect of CSAPs on RW system productivity

Ladha *et al.* (2015) [35] reported that improved management practices leads to increase yield, reduce water and energy consumption and decrease negative impacts on the environmental quality in rice-wheat rotation. DSR followed by zero or conventional tillage wheat has been reported to improve the total productivity of the rice-wheat cropping system (Yadav and Yadav, 2012). DSR produced significantly higher grain and straw yield of rice and succeeding wheat crop. A long term experiment was conducted to evaluate performance of CA base technologies in RWC system at BISA farm Samastipur, Bihar by Jat *et al.* (2014) concluded that the higher grain yields and economic benefit of CA was realized after 2-3 years as the adaptation of CA based practices evolved over the time. In medium term, CA based systems to be agronomically and economically better than CT based systems for rice-wheat rotation in Eastern IGP of South Asia.

4.3 Effect of CSAPs on soil properties

Bulk density (BD) is a soil physical parameter used extensively to quantify soil compactness. Alam *et al.* (2017) observed that BD and porosity do not significantly vary due to different tillage practices {minimum tillage (MT) and deep tillage (DT)} after three cropping cycles but numerically difference was observed in BD with conservation based tillage practices, as the highest BD was found in MT and the lowest being in DT while the largest porosity in DT and the lowest in MT. In case of residue management, the lowest BD (1.40 g/cm^3) was recorded with crop residue retention treatment while the highest BD (1.44 g/cm^3) with no crop residue treatments. Bhattacharyya *et al.* (2008) [6] opined that after harvest of rice and wheat, the laboratory estimated hydraulic conductivity (Ksat) values in the 0-15 cm soil depth under no tillage plots were higher as compared to the tilled plots.

Soil organic carbon (SOC) is essential to sustain the quality and productivity of soils. The important effect of SOC on crop productivity and environmental quality is through its role in supplying nutrients and stabilizing soil structure (Das *et al.*, 2016). Singh *et al.* (2003) reported that organic matter content and soil K supply increases with the residue incorporation in soil. Soil organic carbon was influenced by the interaction effect of tillage practices and crop residue management. The significantly highest SOC content (0.87%) was found in minimum tillage (MT) and three crop (rice, wheat and mung bean) residues retention combination whereas the lowest 0.44% SOC content was obtained in combined treatment of (deep tillage) DT with no crop residues retention. The increase of SOC might be due to slow decomposition of high amount of residue retained on soil under MT (Alam *et al.*, 2017). The increase of N content in soil suggests N-supplying capacity of soil which can be improved by returning straw to the soil and reducing tillage operation (Malhi *et al.*, 2011). Adoption of reduced tillage, fertilization and crop diversity can increase organic N and mineralizable N stored in the soil (Das *et al.*, 2016), thus improving soil fertility and nutrient supplying capacity of soil. The grain yield and plant N, P and K accumulations were increased by 10-15% and 12-20%, respectively in SSNM approach as compared to farmers’ fertilizer practice (FFP).

4.4 Effect of CSAPs on resources use efficiency

For future sustainability of rice production in South Asia, particularly in India direct seeded rice (DSR) is a feasible alternative to continuously flooded puddled transplanted rice (TPR) with good potential to save water without yield reduction (Gathala *et al.,* 2014; Nawaz *et al.,* 2017). Jat *et al.* (2009) revealed that precision land leveling (PLL improved RW system productivity by 7.4% in 2 years compared to traditional land leveling (TLL). Total irrigation water savings under PLL versus TLL were 12-14% in rice and 10-13% in wheat. Compared with CT systems, double ZT consumed 12–20% less water with almost equal system productivity and demonstrated higher water productivity. Short-term weather forecasts could reduce average water application by 27% when 5 day perfect rainfall forecasts were used (Mishra *et al.*, 2013).

4.5 Energy input and energy productivity

The higher energy input was associated with tillage operations, labor, irrigation and nitrogenous fertilizers and other crop production inputs. Srivastava (2003) reported that intensive tillage under conventional farmer practices which required about one-third of the total operational energy that could be saved without adversely affecting the yield with zero tillage. Barut *et al.* (2011) and Ladha *et al.* (2015) [35] also found that intensive tillage for crop establishment, higher amount of irrigation water, higher labor and fertilizer inputs are the major factors for higher energy usage under business as usual scenario but least energy under improved management scenarios due to ZT coupled with precise nutrient and water management practice.

4.6 Effect of CSAPs on economics

Avoiding tillage, puddling and manual transplanting and adaption of zero-till DSR reduced costs by about 25%. Gathala *et al.* (2014) have been reported higher cost of production and lower net return in conventional puddled transplanted rice compared to DSR. Nawaz *et al.* (2017) also reported relatively higher net benefits that obtained with DSR than PTR which may be attributed due to lower production cost. Lower production cost was recorded under DSR compared to TPR (Saharawat *et al.,* 2012) [45].

4.7 Effect of CSAPs on mitigation of GHGs

Atmospheric carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) had been accepted as the potential source of greenhouse gases (GHGs) that had significantly contributed to global warming due to their great radiative forcing (IPCC, 2007) [23]. Global agriculture contributed 10-12% to the net anthropogenic greenhouse gases (GHG) emissions estimated as 5.1-6.1 Pg CO_2-equivalents year^{-1} in 2005 (IPCC, 2007) [23]. However, there could be a great potential to reduce total GHGs emission in agriculture by improving soil organic carbon (SOC) storage and/or decreasing CH_4, N_2O and CO_2 emissions through improving crop production techniques (Smith *et al.,* 2008).

5. Rice-wheat cropping system and future food demand

Many studies have revealed that feeding a more populated and more prosperous world will approximately require a doubling of agricultural production by 2050 (Ray *et al.*, 2013) translating to around 2.4% rate of crop production growth per year. The world faces a looming and growing agricultural crisis. Yields are not improving fast enough to keep up with projected demands in 2050. However, opportunities do exist to increase production through more efficient use of current arable lands coupled with best management practices and closing yield gaps under different management regimes across the globe. A portion of the production shortfall could also be met by expanding croplands, but at a high environmental cost to biodiversity and carbon emissions. We hypothesized that whether CSAPs will helps in maximizing crop productivity and profitability, water and energy use and reducing the greenhouse gases (GHGs) while reducing the associated climatic risks effects by improving adaptive capacity thorough layering of smart technologies.

6. The emerging challenges

Over the years, the rice–wheat systems in the north-western part of IGP have become largely mechanized, input-intensive, and dependent on the conjunctive use of surface and groundwater. In contrast, the rice–wheat systems of the eastern IGP have remained largely labour- intensive and less mechanized. Farmers use low inputs because of socio-economic constraints and serious problems of drainage congestion and rainwater management. In all parts of the IGP farmers rely on tube-well irrigation to supplement rain water or to meet full water requirements for crop production. Evidence is now emerging that continued intensification of input use since the adoption of GR technologies is providing lower marginal returns. At the same time, it is known that inappropriate use of applied inputs and overexploitation of natural resource base, principally land and water, is in many situations leading to secondary salinization in low-quality aquifer zones, groundwater table recession in fresh water aquifer zones, physical and chemical deterioration of the soil and water quality due to nutrient mining and pollution of ground water in some locations due to over application of nitrogenous fertilizers and of environment through crop residue burning and pesticide use (Gupta *et al.*, 2003) [18]. Consequently, there are now serious concerns about the future potential for productivity growth and long-term sustainability of the irrigated rice–wheat systems of the IGP. A recent study has revealed that rice–wheat systems suffer from stagnation in productivity in spite of large production potential yet to be tapped in large areas of middle and lower Gangetic plains. The challenges in rice wheat production system are highlighted in fig 2.

Fig 2: Challenges for rice wheat production system

7. Conclusions

Rice–wheat cropping system in South Asia has contributed immensely to fill the increasing empty stomachs but has consequently led to many sustainability issues viz. declining water resources, degrading soil health and environment degradation which is further responsible for stagnating/decreased land and water productivity. Hence, alternate tillage and establishment methods must be invented, tested and recommended for the sustainable establishment of rice–wheat cropping system as a whole including the intervening period so that land and water productivity, soil health and environment must be improved for overall lifting of the livelihoods of the farmers of South-Asia. Performance of these technologies is, however, site-specific and changed depending upon the soil textural classes and agro-climatic conditions. This suggests that farmers must pick them up from the many as per their soil texture and agro-climatic conditions. Conventional indigenous age-old practices are responsible for all the earlier discussed un-sustainability issues which must be replaced with more advanced and sustainable re- source conservation technologies (RCTs). Therefore, the role of these RCTs to achieve sustainable food production with minimal impact on the soil, underground water and the atmosphere and in improving the declining land and water productivity become more important now than ever.

8. References

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