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Sustainable Intensification of Cereal based Systems in Semi-Arid North West India – *Climate and Non-climate Drivers of Change*

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Introduction

Semi-arid tract of North West (NW) India is important for national food security and it contributes appreciably in the nation food basket. In this tract, rice-wheat cropping system is the dominant system which confined to Punjab, Haryana, Western U.P. and Hanumangarh and Ganganagar districts of Rajasthan. Agricultural intensification increases food production by utilizing maximum use of fixed resources (land, light and temperature etc.) along with optimum use of agri-inputs for attaining sustainable production levels in a defined agro-ecosystem. Increasingly, *sustainable intensification* is being considered as "an important component of the overall strategy for ensuring food security, poverty alleviation, health for all, rural development, enhancing productivity, improve environmental quality and preserve natural resources". With limited scope for further expansion of area under agriculture in India, production gains can be accomplished through intensification of agriculture by pursuing one or more strategies including: (i) increasing yields per hectare; (ii) increasing cropping intensity per unit of land and (iii) changing land use. South Asian agriculture is currently facing twin challenges of resource fatigue and decelerating productivity growth of cereal crops. Also, there exist large yield gaps more particularly *'management yield gaps'* ranging from 14-47%, 18 to 70% and 36 to 77% in wheat, rice and maize, respectively (Jat *et al.,* 2011). Conservation agriculture (CA) is defined as a process of *'sustainable intensification of agriculture'* for enhancing and sustaining production at lesser costs, without deteriorating soil health while maintaining the flow of environmental services. Cropping systems such as rice-wheat, still the backbone of food security, now face serious challenges due to their rising production and environmental costs. Thus, the sustainable agricultural systems/ resilient systems by definition should be less vulnerable to shocks and stresses and have to be more profitable to the practitioners. Sustainable intensifications opportunities (including viable diversification & cropping system optimization options) while addressing the challenges of NW India/ Western IGP (water shortages, natural resource degradation, emerging climatic variability) for national food security is of utmost importance.

Sustainable intensification opportunities includes (i) promotion of improved production technologies for higher productivity; (ii) restoration soil health through crop diversification; (iii) adoption of integrated crop and resource management (ICRM)/integrated farming system (IFS) is required to address the issues of North western IGP (Indo-Gangetic plains), India (water shortages, natural resource degradation, emerging climatic variability) for national food security is of utmost importance. Climate change in the recent past led weather variability, crop season shifting, temperature alterations and precipitation patterns affect different aspects of crop production and integral agricultural ecosystem. Climate change forced to develop resilience cropping system by using improved CA based management and IFS approaches as per the demand driven scenarios.

Factors Governing Sustainable Intensification in NW India

In recent past, the multiple challenges associated with plow based conventional production practices in RW system including declining factor productivity, shrinking farm profits due to increasing energy and labour costs, emerging crisis for irrigation water and recent challenges of changing climates are leading to a major threat to food security and it will be exacerbated further by the projected threats to agriculture due to the consequences of natural resources degradation and projected climate change effects. Depletion of underground water, declining fertility status associated with multiple nutrient deficiencies, increased concentration of GHGs in the atmosphere owing to large scale burning of rice and wheat residues are some of the end results of this farming system.

Emerging climatic variability

Indian subcontinent is at high risk because of the climate change leading to weather variability, crop season shifting, temperature alterations and precipitation patterns which ultimately affect different aspects of crop production and agricultural ecosystem. Such effects resulted changes in nutrient cycling and soil moisture, as well as shifts in weed flora, pest occurrences and plant diseases, all of which will greatly influence crop production and ultimately food security. The IPCC has projected a rise in temperature from 0.5 to 1.2°C by 2020 and from 0.88 to 3.16°C by 2050 in the South Asia region due to an increase in the concentration of green house gases (GHGs) (CO_2, CH_4, and N_2O). Increases in temperature reduce crop duration, increase crop respiration and reduce crop yield, also affect survival and distribution of pest populations. Nutrient mineralization and fertilizer use efficiency hastened by increase in evaporation. The projected increase in temperature would decrease the growth duration and yield of both the crops (rice and wheat). Crop models (WTGROWS and INFOCROP) have also predicted a decline in rice productivity by 0.75 t ha^{-1} with a 2°C rise in mean air temperature. In a simulation study, an increase in temperature by 2°C led to a 10-20% decrease in grain yield of both rice and wheat. Climate change which could have negative consequences for agricultural production has generated a desire to build resilience into agricultural systems. Crop diversification and sustainable intensification can improve resilience in a variety of ways: by using improved CA based management practices and resilient system under future climate scenarios. Agriculture plays an important role in mitigating the GHG emission. There is need to address climate change through adaptation strategies and mitigation potential aimed at reducing GHGs and increase removal of CO_2 from the atmosphere. Tillage results in large decline in soil organic carbon due to significant flush of CO_2 and perturbs the soil system causing a shift in the gaseous equilibrium by releasing CO_2 to the atmosphere. As CA involves practices such as zero or minimal mechanical disturbance, crop residues retention, permanent organic soil cover, diversified crop rotations, precise placement of agro chemicals, in field traffic control etc. resulting in GHG mitigation and more carbon sequestration in soil. Different cropping systems yield different amount of soil carbon.

Ground water depletion

RW system have become so important for this region that rapid expansion of the tube well network in the NW-IGP has led to the groundwater pumping for irrigation of these crops. Rice is sown in puddled soil and requires large amount of irrigation water (>200 cm/ha) resulting in ground water depletion in NW India at a speedy rate. Since the early 1970s, there has been a steady increase in the depth to the groundwater due to the over exploitation in most of the RW area of NW (Punjab, Haryana and Western Uttar Pradesh) India. The groundwater table in this region during one decade (1993-2003) has gone down by about 0.50 m yr^{-1}. However, in some areas of NW-IGP, the water table is now being depleted at nearly 1 m yr^{-1}. By 2009, 103 out of 138 administrative blocks in Punjab and 55 out of 108 blocks in Haryana were already overexploited.

Ecological degradation

The continuous cultivation of rice-wheat cropping system for almost five decades in NW India has set in the processes of degradation in the natural resources *viz.* water, soil, climate and biodiversity. Resource degradation due to the RW production system can take many forms: loss of organic matter; mining of soil nutrients; build-up of biotic (weeds, diseases and pests) and abiotic (waterlogging, salinity and sodicity) stresses. Flora and fauna diversity is also affected by the continuous cultivation of RW system in the region which is very much required for ecosystem stability. Apart from these, the labour charges continue to increase, high prices of inputs with low factor productivity make the RW production system less profitable and unsustainable which forces the farmers to migrate from villages to urban areas and sometimes compel them to sell their agriculture lands.

Monoculture

In NW India, to remove the barriers of monoculture (RW system), diversifying the area from rice to alternate remunerative crops is the need of time to overcome the second generation problems of this system to sustained soil fertility, crop productivity and to enhance farmer's income. Maize has the potential to be as productive and profitable as rice but with up to 90% less irrigation water. Less pumping of fresh groundwater would build-up less salt in the soil profile as salinity increases with water table depth in this part of the country. Thus, preventing productive lands to turn in to saline lands would be the key to sustain agriculture growth and productivity in this region. Inclusions of other crops like pigeonpea, soybean, mungbean etc. also act a means of supplying N through biological nitrogen fixation to the system.

Biotic and abiotic stress

Green revolution in the country improved the productivity of cereal crops but at the same time *Phalaris minor* in wheat crop was also introduced. *Phalaris* has developed strong resistance to the commonly used herbicides and farmers shift to new and more expensive herbicides. Continuous cultivation of RW system leading to decline in soil organic matter and multiple nutrient (major- N, P, K, and S; minor- Zn, Fe, and Mn) deficiencies due to their overmining from soils. Excessive pumping of fresh water aquifer is prone to salinity and sodicity problems lead to impaired physical and biological environment; the soil and plant growth is adversely affected. As in Punjab, the salinity of the groundwater increases with depth. The rate of salinization of the aquifer can therefore be slowed by management practices that minimize the amount of irrigation water applied to crops. On one side, excessive pumping leading to declining fresh water aquifer zones, while inadequate drainage is causing waterlogging and salinity on another side. Socioeconomic and agriculture problems are interrelated and tend to be concentrated in areas where farmers practice continuous RW systems.

Poor management of residues

In North-west India, combine harvesting of rice and wheat is now a common practice leaving large amount (> 6 t ha^{-1}) of crop residues in the fields. In most of the region, to clear the fields for the timely sowing of wheat, majority of the paddy straw is burnt in-*situ* by the farmers causing environmental pollution and loss of plant nutrients and organic matter. Burning of residues emits a significant amount of GHGs. For example, 70, 7 and 0.7 % of carbon present in rice straw is emitted as CO_2, CO and CH_4, respectively, while 2.1% of N in straw is emitted as N_2O upon burning. The main reasons for burning crop residues in field include unavailability of turbo seeder, use of combines without spreader, mindset of farmers and high cost in removing residues. Burning of crop residues leads to loss of plant nutrients (all amount of C, 80% of N, 25% of P, 50% of S and 20% of K), which had adverse impacts on soil physico-chemical and biological properties. About 25-40% of the N, 30-40% of the P, 70-85% of the K, and 40-50% of the S absorbed by rice and wheat crop retained in residues. At harvest, rice straw contains about 5-8 kg N, 0.7-1.2 kg P, 12-17 kg K and 0.5-1 kg S per ton while one ton of wheat residue contains about 4-5 kg N, 0.7-0.9 kg P, and 9-11 kg K nutrients on dry weight basis. Residue retention are the primary source of organic matter (as C constitutes about 40% of the total dry biomass) and enriches soil and provides favorable micro climate for stability of agricultural ecosystems.

Labour shortages and Energy prices

Labour shortages during the crucial period of crop production *viz*., sowing/transplanting and harvesting becoming the major challenge before the farmers of NW India. Rice transplanting requires lot of labors which is a huge task before the farmers in this region because of less migration of agricultural labors from the eastern part of the country. Farmers ready to pay the double amount than the announced labour wages as per the concerned Governments and even than labour is not available for agricultural operations. In this burgeoning situation, CA may be one of the ways to sustain the farmer's livelihood and national food security. The resource requirements of different crops are different as it depends on the genetic potential and their interaction with the environmental indices. Rice is a C3 plant and having less photosynthetic efficiency, high energy requirement and resulted in low yield potential than maize, being a C4 plant. The resource requirement of both the crops varies with soil and climatic conditions and resource availability. Conventional-till rice requires at least five times more fuel than direct seeded rice (DSR) and ZT maize. To overcome the ill-effects of puddling on soil structure and to reduce drudgery of rice planting without yield penalty, a suitable method of rice seeding (dry/wet direct seeded rice; DSR) is very much essential on the larger area. CA based sustainable intensification/crop diversification is one of the options to cope up e labour shortages and energy consumption.

Cost of production

The key drivers for adoption of CA by farmers are labour and cost incurred in diesel and electricity. The RW system is labor, water and energy intensive and it becomes less profitable as these resources become increasingly scarce and the problem is further aggravated with deterioration of soil health and emerging challenges of climate change. Timely availability of agriculture labour is a major hurdle in the production of transplanted rice in NW India. Puddling in rice not only disturbs the soil structure, soil compaction, and suboptimal permeability in subsurface layer but also increase the cultivation cost by many folds. The youth in NW India are not showing much interest in agriculture and because of that the demand for labour will increase in near future with a great speed. There is need to explore the ways and means by which farmers could reduce the cost of production to make this business profitable.

Climate and Non-Climates Drivers

Rice–wheat (RW) cropping system of NW India is fundamental to India's food security (Timsina and Connor, 2001). Since *Green Revolution*, RW system has played a significant role in the food security of the region. However, recent years have witnessed a significant slowdown in the yield growth rate of this system and the sustainability of this important cropping system is at risk due to second-generation problems. Therefore, it is essential to diversify the area from rice to alternate remunerative crops not only to improve soil fertility and arrest ground water depletion but also to enhance the farmer's income. In relation to agricultural sustainability, "diversification" is probably one of the most frequently used terms in the recent decade. In this perspective what exactly diversification is? Diversification originated from the word "diverge", which means to move or extend in a different direction from a common point. Sustainable intensification acquires special significance in this region because of the ecological and environmental problems and strain on natural resources associated with the green revolution technology, and difficulty in sustaining growth in output and income (Chand, 1999). Drivers of intensification/ diversification for the NW India along with opportunities and challenges are presented in Table 1.

The concerns relating to diversification and intensification in NW India came to fore when net profit accruals showed diminishing trend. System intensification can be achieved through (i) promotion of improved production technologies for alternate crops to diversing rice; (ii) restoration soil health through less nutrient intake crops which having residual effect on succeeding crops; (iii) adoption of integrated crop and resource management (ICRM)/integrated farming system (IFS). The household level food and employment security as also risk was an important

Table 1. Drivers of change and sustainable opportunities in IGP

Intensification Drivers	Maize for kharif rice ; Rice-wheat-MungbeanRelay cropping of wheat in cotton; Sugarcane intercropping;IFS for small holders
Drivers of change (Climate)	Declining water tables; Variable rainfall pattern
Drivers of change (Non-Climate)	Internal demand; Enabling policies; New and innovative cropping systems; Factor productivity; High yielding genotypes
Opportunities	Resource conservation techniques; System intensification
Challenges	Soil salinity management; Biotic stresses; Diversification a core policy priority?

consideration in farming system approach. Crop diversification is intended to promote technological innovations for sustainable agriculture and enable farmers to choose crop alternatives for increased productivity and income. In the light of stagnation of employment in agriculture and other sectors of the economy and the high annual growth rate of labour, it became necessary to generate gainful employment in agriculture. Farming system approach, i.e. diversification of crop sector and integrating the labour intensive enterprises like dairy, poultry, vegetables, fruits, mushrooms, etc. with crops is also essential for small holders to ensure food and nutritional security at farm level.

Sustainable Intensification Opportunities

The spread of the rice-wheat (RW) system in India has brought forth several edaphic, environmental, ecological and social implications. Continuous cultivation of rice-wheat system has led to an over-exploitation of fresh ground water reserves, poor soil health, low carbon content and multiple nutrient deficiencies. A number of problems have cropped up in the region with the cultivation of rice and wheat in a system mode for the last five decades, threatening the sustainability of the system. Increased cultivation cost, labour shortage and climate change all pose additional threats to the sustainability of this system in NW India. Evidence is accumulating that the RW system is now showing signs of fatigue and yields of rice and wheat in this region have reached a plateau or are declining, the soils have deteriorated, the groundwater table is receding at an alarming rate, total factor productivity or input-use efficiency is decreasing, cultivation costs are increasing, profit margins are decreasing, and the simple agronomic practices that revolutionized RW cultivation in the IGP are fast losing relevance, output growth, employment generation and natural resources sustainability. To overcome formidable problems of RW system in North-West India, sustainable intensification on the principles of conservation agriculture (CA) has emerged an important alternative to attain the objectives of improved and sustained productivity, increased profits and food security while preserving and enhancing the natural resource base and the environmental quality in NW India. The CA based agro-technological package, intensified cropping system and holistic farming approach not only saves natural resources but may help in producing more at low costs, improves soil health, promotes timely planting and ensures crop diversification, reduces environment pollution and adverse effects of climate change on agriculture. Implementation of agricultural diversified systems intensification in NW India may be a productive way to build resilience into agricultural systems for national food security. Sustainable intensification is an important component of the overall strategy for ensuring food security for coming generations in NW India.

Crops and cropping systems

The sustainability of RW system in the NW India is at risk owing to higher irrigation water requirement, high cost of cultivation and inefficient input use. This calls for identification of suitable cropping systems and diversification of RW system under irrigated conditions. Maize, cotton, sugarcane, soybean and pulses are suitable alternative crops to rice in the *kharif* season in NW India because of their relatively low water requirement and comparative remunerations. Sustainable intensification aimed to devise strategies for RW rotation as well as designing futuristic cereal based systems in this region. System intensification through resilient cropping system and management scenarios were compared with business as usual farmer management scenario in the region to address the issues of deteriorating natural resources, plateauing yields, water, labour and energy shortages and emerging challenges of climatic being faced by the farmers (Gathala *et al.,* 2013). In north-western IGP, Rice based cropping systems like; rice-wheat, rice-potato-maize and rice-potato-sunflower cropping system found best in a particular typological domain. Rotating crops having divergent and distinct morphologies, growth habits, life cycles, differing cultural practices, and nutrient and water needs can all potentially affect the community composition and distribution of weed flora. Inclusion of legumes in cropping systems has also been found to be effective in reducing nitrate leaching in lower profiles. Mungbean helps in absorbing residual NO_3-N of the wheat crop before it joins the water table (aquifer) in monsoon season. Therefore, it appears to be a good strategy to promote relay planting of mungbean in wheat to have twin benefits of increased wheat yield and reduced NO_3-N pollution of aquifers which is on the rise in NW-IGP (Chandna *et al.,* 2010). CA based intercropping systems including wheat, vegetables and flowers have shown promising results with autumn planted sugarcane with respect to productivity and monetary gains. The cost of cultivation of sole sugarcane crop found at par with intercropping of garlic, wheat, onion, cauliflower, gram and lentil. Sugarcane productivity in intercropping system with garlic, onion and lentil was at par with sole sugarcane crop but farmers benefited most from an additional yield of intercrops (equiv. to INR 128250, 64350, 53280, 44325, 37980 and 32985 $ha^{-1}$from garlic, cauliflower, lentil, gram, wheat and onion, respectively).

Cotton–wheat cropping system is the second most important wheat based system in India (2.6 M ha) and contributes significantly to the national food security. Cultivation of cotton–wheat system under permanent beds with residue retention is found profitable under irrigated conditions in this region due to its potential of increased productivity, profitability and resource conservation. Relay planting of wheat in cotton is found helpful in increasing the productivity and net returns in relay planting of wheat in cotton. The serious bottleneck in extending this technology to the farmers is the availability of high clearance tractor for relay sowing of wheat in late planted BT and long duration cotton composits. The new prototype of high clearance tractor has been developed by BISA, Ludhiana to address this issue. Alternative crops to rice, such as maize, soybean, pulses and cotton, have much lower irrigation water requirement than rice (Jat, 2006; Ram *et al.,* 2005). Depending on the distribution and amount of the monsoon rains and soil type, these crops require from none to four to five irrigations after sowing, with total irrigation application to maize and soybeans of the order of one-fifth to one-tenth of that for puddled rice.

Evidences from NW India (Western IGP)

Technologies like direct seeded rice (DSR), zero-till (ZT), reduction in ponding depth, raised beds (RBs), nutrient management (green seekers, SPAD, nutrient expert, LCC etc.) in different agro-ecological regions have been introduced to reduce water use and increase input use efficiency RW system. Many studies conducted across the production systems under varied ecologies of IGP have revealed the potential benefits of CA based technologies. CA based management helped in increasing the yield gain and water saving resulted in higher productivity. The yield gain ranged from 112-810 kg ha^{-1}, whereas water saving increased the irrigation water productivity (WP_I) and ranged between 0.08-0.58 kg m^{-3} under different practices (Table 2).

Table 2. Effect of CA based technologies on yield gain, water saving and increase in WP_I over conventional practice in IGP of South Asia

Technologies	Cropping system	Yield gain (kg ha^{-1})	Water saving (cm)	Increase in WP_I
Laser levelling	Rice–wheat	750–810	26	0.06
ZT	Maize	150	8	0.21
ZT + mulch	Rice–wheat	500	61	0.24
ZT + mulch	Wheat	410	10	0.13
DSR	Rice	112	25	0.08
RB planting	Wheat	310	16	0.58

Source: modified from Chauhan *et al.* (2012) and Kukal *et al.* (2014)

In NW India, abrupt rise in temperature (terminal heat) at grain filling coincided with dry westerly winds which enhance the drying processes leading to forced maturity, and shrivelled grains resulted a penalty of 20% in wheat.

CA based adaptation strategies (Jat *et al.,* 2009) included (i) advancing planting time using NT, (ii) crop residue retention (canopy temperature lowered by 1-1.5 °C), (iii) irrigation scheduling, and (iv) balanced plant nutrition offers the solution of terminal heat. Maize, cotton, sugarcane, soybean and pulse based cropping systems are suitable alternative to RW system (Jat, 2006). System intensification through resilient cropping system and management scenarios were compared using a wide range of indicators (crop rotation, tillage, crop establishment, crop, water and residue management) with business as usual farmer management scenario in the region to address the issues of deteriorating natural resources, plateauing yields, water, labour and energy shortages and emerging challenges of climate being faced by the farmers. On system basis, three years average data recorded 14% increase in yield in scenario III compared to farmers' practice (scenario I), while saving other resources.

Similarly, the futuristic system (scenario IV) showed 11% increase in yield compared to scenario I (Table 3). A substantial reduction of around 33% in water applied in scenario III on

Table 3. System yield, irrigation water saving and energy saving in different scenarios (3 years average; 2009-2012)

Scenario	Systems	Residue management	System yield (Rice Equiv)	Irrigation water (mm)	Energy use (MJ ha^{-1})	SOC (%)
I- farmers practice	Rice-wheat (CT/TPR)	No residue	13.0	2687	73832	0.46
II- partial CA based	Rice-wheat-mungbean (CT/TPR-ZT-ZT)	Retention of full (100%) rice and anchored wheat residue, while full mungbean residue were incorporated	15.8	2073	56543	0.52
III- full CA based	Rice-wheat-mungbean (ZT-ZT-ZT)	Retention of full (100%) rice and mung bean; anchored wheat residue	14.8	1793	51582	0.56
IV- full CA based	Maize-wheat-mungbean (ZT-ZT-ZT)	Retention of maize (65%) and full mungbean; anchored wheat residue	14.5	766	36457	0.58

system basis compared to scenario I, whereas, in scenario IV, only 29% water applied to that of scenario I (Sharma *et al.,* 2014). In a period of 3 years around 34, 44 and 50 tons of crop residues were recycled in scenario II, III and IV respectively which resulted an increase of SOC by 13, 22 and 26% in the respective scenario from the initial soil SOC (0.45%).

A Holistic Approach (Integrated Farming Systems; IFS)

Integration of crop and livestock management systems provides an opportunity to introduce variable production system that are more resilient, resource efficient, economically profitable, socially acceptable and provide "*Biological Insurance*" and/or climate proofing to cover the risk in farming systems at the failure of any one or two component. By adopting multienterprise model/IFS the problem of regular income and inadequate distribution of labor throughout the year can be solved at farmer's level as this system provides regular income and employment (Gurbachan Singh *et al.,* 2010). Besides a source of regular income it acts as the most vital technology in conserving resources, water and energy at farm level as by-products of the components system recycled to ensures environmental quality. The average revenue generation of INR 4,11,799 was recorded after expending of INR 1,40,954 annually from IFS model (2 ha area) with a B:C ratio of 1.92. Jat *et al.* (2013) recorded the 50, 48, 34, 61 and 52% net income of the IFS model with fodder, grain, flower, horticulture and vegetable production systems respectively on the same area basis. This model may help in generating the round year employment (875 man days) for the farmer's family and rural poors. Moreover, employment generation by IFS (438 ha^{-1}) was almost uniformly distributed throughout the year whereas in RW system (150 ha^{-1}) it was only during the sowing and harvesting operations. Hence, IFS approach suggested better means for providing regular employment to the rural masses.

Conclusion and Way Forward

To overcome formidable problems of RW system, sustainable intensification has emerged an important alternative to attain the objectives of output growth, employment generation and natural resources sustainability in NW India. The CA based agro-technological package, intensified cropping system and holistic farming approach not only saves natural resources but may help in producing more at low costs, improves soil health, promotes timely planting and ensures crop diversification, reduces environment pollution and adverse effects of climate change on agriculture. IFS may provide an opportunity to overcome the resource fatigue and improved the economic viability of the system by developing resilient farming system through climate proofing. In NW India, policy initiatives were taken for crop diversification in three states (Haryana, Punjab, Western Uttar Pradesh) in order to divert 5% area of rice to other alternative crops fitting in the prevalent RW system to arrest natural resource degradation. Implementation of agricultural diversified systems intensification in NW India may be a productive way to build resilience into agricultural systems for national food security.

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