CIMMYT
International Maize and Wheat Improvement Center

CGIAR
RESEARCH PROGRAM ON
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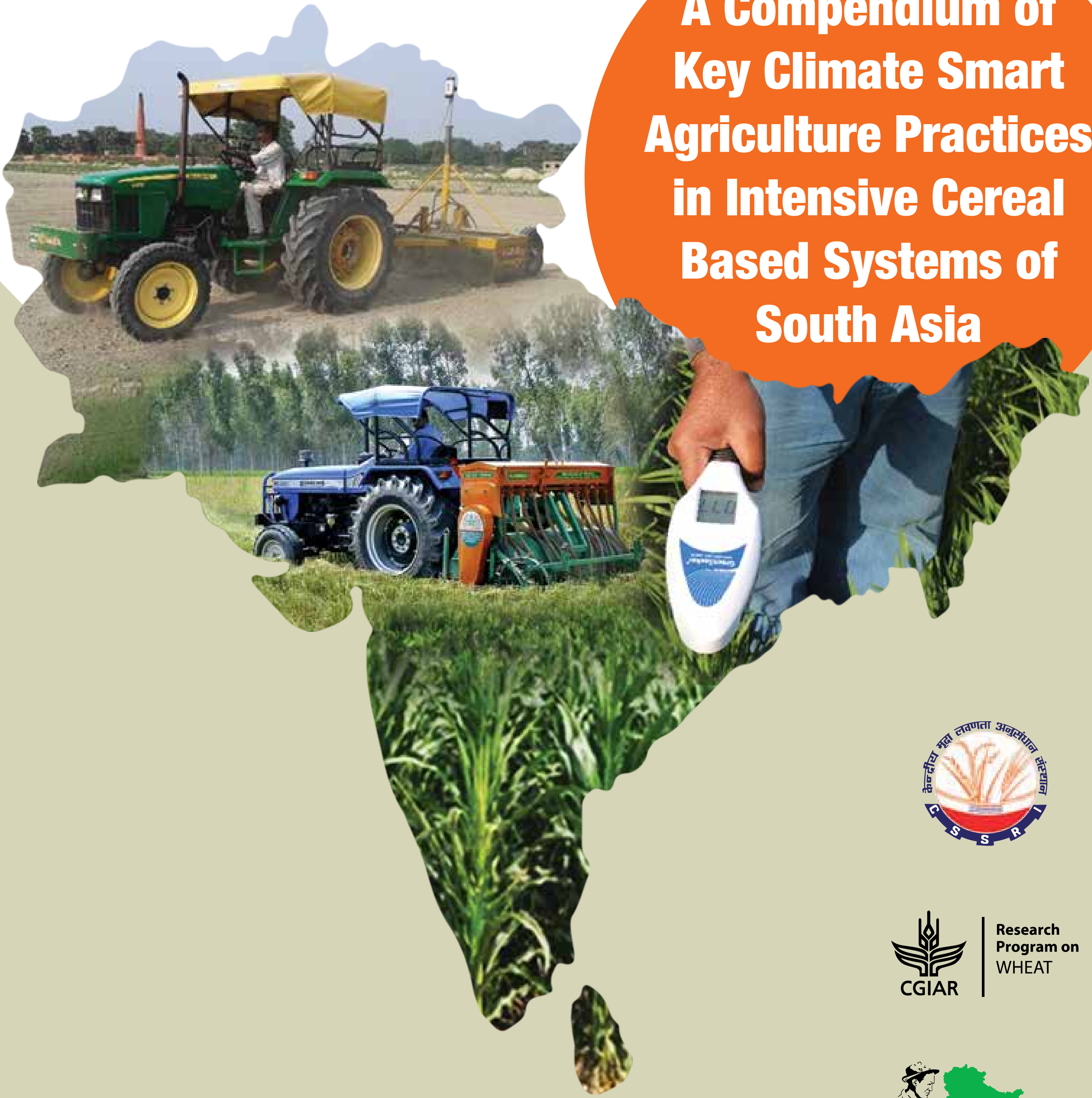
A Compendium of Key Climate Smart Agriculture Practices in Intensive Cereal Based Systems of South Asia



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International Maize and Wheat Improvement Center (CIMMYT)

A Compendium of Key Climate Smart Agriculture Practices in Intensive Cereal Based Systems of South Asia

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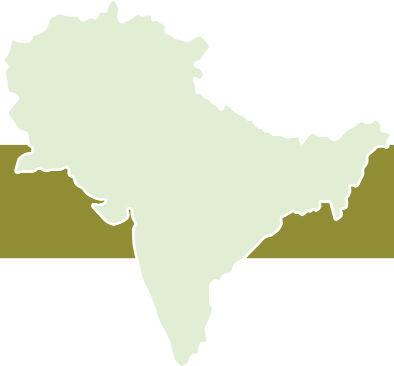

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1 Introduction

Today, the commonly used term ‘climate change’ represents the change in climate over time, whether due to natural causes, or as a result of human activities. At present, the atmospheric CO_2 concentration is over 400 ppm. In 1896, the Nobel Laureate Svante Arrhenius predicted that increases of atmospheric CO_2 from burning fossil fuels would lead to global warming. He suggested that doubling of CO_2 concentrations (then about 260 ppm) in the atmosphere would raise the temperatures of the Earth by about 2 to 6^{0}C. All these support the estimate by the Intergovernmental Panel on Climate Change (IPCC) that the Earth will warm by 1.4–5.8^{0}C during the current century. Worldwide, agriculture both contributes to, and is sensitive to climate change impacts, and is threatened by climate change. It is estimated that about three fourths of the total emissions, from agriculture and land use originate in the developing countries. Agriculture accounts for 13.5% of global greenhouse gas (GHG) emissions or about 1.8 Gt carbon equivalent/year or 6.6 Gt of CO_2 equivalent/year, mainly in the form of methane (CH_4), and nitrous oxide (N_2O) from fertilized soils, enteric fermentation, biomass burning, rice production as well as manure and fertilizer production. Agriculture and forestry captures a great deal of carbon absorption, and fixation through photosynthesis, and offers a solution to climate change. The FAO profile on Climate Change-2009 notes that agriculture has the technical potential to mitigate between 1.5 and 1.6 Gt C equivalent/year (5.5–6.0 Gt of CO_2 equivalent/year) mainly through soil carbon sequestration, in the developing countries. Studies estimated that there would be at least 10% increase in irrigation water demand, in arid and semi-arid region of Asia, with a 1°C rise in temperature. The recent report from the IPCC highlights that as one of the most densely populated regions in the world, the South Asia is among the most vulnerable to the climate change and climate variability. In the absence of adaptation, and mitigation, climate change can have major consequences on food security, and development in the decades to come.

Business-as-usual scenarios of population growth and food consumption patterns, indicates that agricultural production will need to increase by 70 percent by 2050 to meet the global demand for food. Thus climate change could result in the increased demand for irrigation water further aggravating scarcity of resources (water, nutrients, energy). The impacts of climate change will reduce the productivity, leading to greater instability in the agricultural sector (crop, livestock production, fishery and forestry) that can put the communities at high risk that already have high levels of food insecurity. Climate change can also cause environmental degradation and has limited options for coping with adverse weather conditions. In the region, the inefficient use and mismanagement of production resources especially land, water, energy and agro-chemicals has vastly impacted the health of the natural resource base, and contributing to global warming led climatic variability.

2

Major Cereal Based Systems of South Asia

Cereals are the most important staple crops worldwide including Asia. Rice, wheat and maize provide 60% of the human food globally and these three crops account for more than 90% of Asia's cereal production. In Asia, the population is expected to grow by 40% in 2050 compared to 2000. Thus, this continent is facing a tremendous challenge for meeting food production at the pace of people demand as well as the sustainability of its natural resource base. This is becoming even more challenging due to the threat of global warming and deterioration in soil health. Even though the cereal based systems in Asia are highly diverse due to contrasting eco-physical conditions in different regions, there are a few mega-systems that account for a greater share of food production in the continent. These include cropping systems such as rice-rice (RR) in the tropical climate of East and Southeast Asia, rice-wheat (RW) in the intensive agro-ecosystems of China and South Asia, cereals-legumes in South Asia and wheat-fallow and wheat-cotton (WC) in the drylands of China, India and West and Central Asia. Of the many rice-based systems, RW is the most widely grown in South Asia alone and covers more than 24 M ha. The wheat-based cropping systems exists in different countries depending on temperature, type of wheat grown (spring, facultative, winter) and water availability. WC is another widely grown system in drylands of South Asia. Recently, there has been increasing interest in expanding maize-based cropping systems in Asia. The traditional RW mega cropping system is losing a part of its area to the expansion of rice–maize (RM). Summer rice followed by winter maize is becoming important in both South and South-east Asia. This system is becoming more important due to higher yield of winter maize over wheat and other alternative winter crops, and the increasing demand of maize for animal feed and biofuel. RW followed by CW, MW, and millet-wheat are important wheat-based cropping systems grown on an area of about 22.34 M ha in SA. Other less important wheat-based cropping systems in includes; sugarcane-wheat, groundnut-wheat, rice/maize-potato-wheat, sorghum/pearl millet/pigeon pea-wheat in South Asia. Area under different major cereal based cropping systems are given in Table 1. The RW and MW systems are highly intensive in the NW and parts of central IGP. The RW system in western IGP are becoming more and more unsustainable due to increasing production cost, depletion / degradation of natural resources (water, soil, biodiversity), high cost of inputs (land, labor, chemical), low input use efficiency (fertilizers, pesticides, labor) coupled with changing climate and socioeconomic conditions. On the contrary, in the eastern IGP, population density and pressure on land are very high and farms are small and scattered, and the wheat-based systems are more or less traditional with lower productivity and income due to poor or no adoption of improved crop and resource management technologies.

Table 1. Estimated Area under Major Wheat-Based Cropping Systems in South Asia (Mha)

Cropping system	Nepal	Bangladesh	India	Pakistan	South Asia
Rice-wheat	0.57	0.40	9.20	2.20	12.37
Maize-wheat	0.04	-	1.86	1.00	2.90
Millet-wheat	-	-	2.44	-	2.44
Cotton-wheat	-	-	1.09	3.10	4.19
Fallow-wheat	-	-	2.08	-	2.08
Sugarcane-ratoon-wheat	-	-	0.97	-	0.97

3

Climate Smart Agriculture (CSA)

CSA initially proposed by FAO in 2010 at "The Hague Conference on Agriculture, Food Security and Climate Change (CC)", to address the need for a strategy to manage agriculture and food systems, under climate change. The CSA by its original proponents describes the three objectives; i) sustainably increasing agricultural productivity, to support equitable increases in income, food security and development; ii) adapting and building resilience to climate change, from the farm to national levels; and iii) developing opportunities to reduce GHG emissions, from agriculture compared with past trends. Since then, these three objectives (in short - food security, adaptation and mitigation) are designated as the three "pillars" (or criteria) of CSA, within the agricultural science and development communities.

Climate SMART (Sustainable Management of Agricultural Resources and Techniques) Agriculture is an approach of crop production, which deals with the management of available agricultural resources, with latest management practices and farm machinery, under a particular set of edaphic and environmental conditions. It works to enhance the achievement of national food security and Sustainable Development Goals (SDGs). CSA is location specific, and tailored to fit the agro-ecological and socio-economic conditions, of a location. CSA may be defined as, "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals." Therefore, if CSA will be implemented at right time, with required resources, techniques and knowledge in a particular typological domain, will lead towards food security, while improving adaptive capacity and mitigating potential for sustainable agriculture production.

3.1 Pillars of CSA

CSA is a holistic concept and it unites numerous issues related to global agricultural and other developmental objectives. It addresses the issues -- related to environmental (energy and water), social (gender and economic), food security (availability and access of food, utilization of food for adequate nutrition, and stability of food supply), and agro-ecological stability. The CSA has three pillars i.e. food security; adaptive capacity; and mitigation potential (Fig.1). Various agricultural practices might help in increasing the farm productivity, adapt to climatic variability, sequester atmospheric carbon into the soil, and/or minimize emission of GHGs from agro-ecosystem to atmosphere.

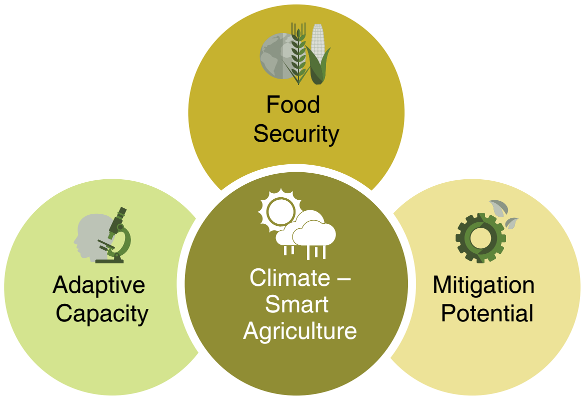


Fig. 1: Pillars of Climate Smart Agriculture (CSA)

3.1.1 Food Security: Availability and access to food for every individual

CSA is an approach to farming that seeks to -- increase food security, alleviate poverty, conserve bio-diversity, and safeguard ecosystem services. Negative impacts from climate change are likely to be greatest in the developing economies that are currently food insecure, and may even be significant in those regions that have made large gains in reducing food insecurity over the past half-century. These notable achievements of Green Revolution in South Asia were largely due to both vertical and horizontal increase in food production, owing to use of external inputs, such as high-yielding varieties, chemical fertilizers and irrigation. However recently (at the dawn of 21st century), the problem of food security with added challenges of natural resource degradation has further been surfaced, and intensified with indiscriminate use of resources, sharp rise in the cost of production inputs, diversion of human capital from agriculture and shrinking farm size. In South Asia, the ever increasing population growth is interlinked with these challenges and the natural resources in the region are 3-5 times more stressed, due to population, economic and political pressures compared to the rest of the world.

3.1.2 Adaptation: Increase resilience in farming system for sustainability

CSA practices can contribute to making agricultural systems more resilient to expected climate change effects. It has been proven to reduce the farming systems' GHG emissions, and enhance its role as carbon sinks. Adaptation in the agricultural sector is been given a high priority within this effort because of the inherent sensitivity of food production to climate and the strong inter-linkages that exist between climate, agriculture, and economic growth and development. Increase in resilience of the production systems to climatic risks is mostly achieved by increasing soil moisture, and crop diversity, modifying microclimate, improving input (nutrient, water) use efficiencies, and soil carbon storage.

3.1.3 Mitigation: Reduce emissions of GHGs, or to increase soil carbon storage

The problem of food security with added challenges of natural resource degradation, sharp rise in the cost of production inputs, diversion of human capital from agriculture and shrinking farm size are some of the issues faced by agriculture at present. Moreover, while maintaining a steady pace of development, the region will also have to reduce its environmental footprint from agriculture. In CSA, besides adaptation measures, we need to have a look on mitigation strategies. The effectiveness of these CSA measures depends on factors such as -- climate, soil type, input resources and farming system. About 90% of the total mitigation arises from sink enhancement (soil C sequestration), and about 10% from emission reduction. Reduction in CH_4 emission from agriculture can, to a large extent, be accomplished by growing rice aerobically by wetting and drying, planting rice on beds, increasing water percolation and DSR. This not only reduces amounts of water application, but also reduces CH_4 emissions.

3.1.4 Portfolio for CSA Interventions

The CSA adopts a portfolio of smart interventions that cover the full spectrum of farm household activities. These include **water smart practices**-- rainwater harvesting, Laser Land Levelling, micro-irrigation, raised bed planting, crop diversification, alternate wetting and drying in rice, direct seeded rice; **weather smart activities** -- ICT-based agromet services, index-based insurance, stress tolerant crops and varieties; **nutrient smart practices**-- precision fertilizer application using Nutrient Expert decision support tools, Green Seeker and Leaf Color Chart (LCC), residue management, legume catch-cropping; **carbon smart practices**-- Legume integration, agroforestry, zero tillage, residue management, land use system, livestock management; **energy smart practices --** zero tillage, residue management, legumes integration, DSR, precision water management; and **knowledge smart activities --** farmer-farmer learning, capacity enhancement on climate-smart agriculture, community seed banks and cooperatives. These interventions work together to increase a community's resilience to climatic stresses, while ensuring household food and livelihood security. The idea is to integrate CSA into village development plans using local knowledge and expertise to develop climate smart villages (CSVs). CSVs are sites where researchers from national and international organisations, farmers' cooperatives, local government leaders, private sector organisations, and key policy planners all come together to identify which climate-smart agriculture interventions are most appropriate to tackle the climate and agriculture challenges focused in those particular villages. In South Asia, CSVs were initiated in 2011, first in Haryana and Bihar in India.

Picture 1. Portfolio of smart interventions in Climate Smart Agriculture (CSA)

For participatory adaptation, and scaling-up of CSA based production management approach, was used in CSVs are as below:

- Avoidance of intensive tillage to minimize fossil fuel burning and reduce soil degradation;
- Retaining crop residues to buffer soil temperature, water, encourage soil carbon build-up;
- Precision nutrient and irrigation management;
- Cropping system optimization for sustainable intensification;
- Multi-stakeholder, participatory and local adaptation;
- Focus on youth, women and socially disadvantaged groups; and
- Innovation systems: farmer cooperatives & service windows.

3.1.5 Drivers of change and opportunities

Since *Green Revolution*, RW system has played a significant role, and is fundamental to India's food security. However, recent years have witnessed a significant slowdown in the yield growth rate 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 on the concept of CSA 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. Drivers of RW system intensification/ diversification for the eastern, as well as western IGP along with opportunities and challenges are presented in Table 1.

The concerns relating to diversification with CSA practices (CSAPs) came to force when net profit accruals showed diminishing trend in RW

Table 1. Drivers of change and sustainable crop production opportunities in IGP

	Eastern IGP	Eastern IGP	Western IGP
Intensification Drivers	Maize for *kharif* rice; Rice-Mustard-Spring maize; and Integrated farming system (IFS) for small holders	Maize for *rabi* wheat; Maize+Potato; and IFS for small holders	Maize for *kharif* rice; Rice-wheat-mungbean; Relay cropping of wheat in cotton; Sugarcane intercropping; and IFS for small holders
Drivers of change (Climate)	Erratic monsoons; and drought in upland landscapes	Terminal heat stress for wheat	Declining water tables; and variable rainfall pattern

	Eastern IGP	Eastern IGP	Western IGP
Drivers of change (Non-Climate)	Stress tolerant hybrids; improved management; and competitive profits	High yield/profits over wheat; factor productivity; and high yielding genotypes	Internal demand; enabling policies; new and innovative cropping systems; factor productivity; and high yielding genotypes
Opportunities	Coping mechanism for weak monsoon	Income generation; and substitution of market-risks for bio-physical risks	Resource conservation; conservation agriculture; and climate smart agriculture
Challenges	Value chain development in new maize areas; and crop performance in wet years	Resource requirements for optimal maize production among smallholders; and variations in market prices for maize	Soil salinity management; and potential consumptive water savings enough to make diversification a core policy priority

system of IGP. CSA-based system production intensification can be achieved through: (i) promotion of CSA production technologies, for alternate crops to diversifying rice; (ii) restoration of soil health through less nutrient intake crops which has residual effect on succeeding crops; (iii) adoption of integrated crop, and resource management (ICRM)/ integrated farming system (IFS).

3.1.6 Scalability/ targeting CSA

Present agricultural systems need a paradigm shift in management practices to make them productive and resilient, to emerging frequent climatic variability, and reduce environmental footprints of crop production systems. Multiple components contribute to food security, and adapting food systems to climate change involves a diversity of approaches and resources. A better use by CSA may help focus on trade-offs, and synergies between the three objectives/pillars. CSA responds to site-specificity, and potential for adoption by farmers because it is strongly based on local practices and a strong align with policies, institutions and financing. CSA concepts may be used complementarily when observing the spatial scales at which they regularly operate (Fig. 2).

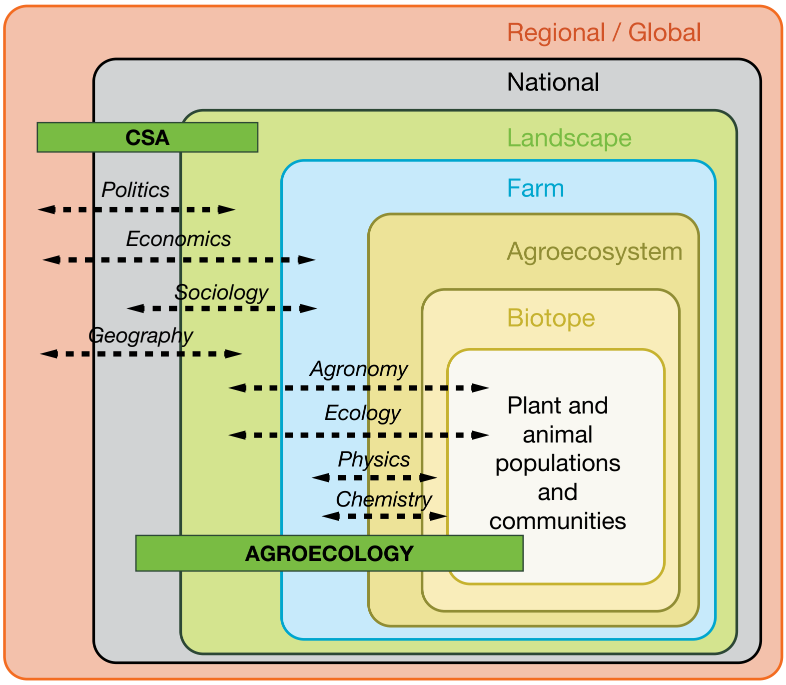


Fig. 2. Scales and scientific domains at which Climate Smart Agriculture (CSA) can (co)operate

In fact CSA is targeted on the strategies needed to manage agriculture and food systems under climate change. More specifically, CSA tenants claim that -- scientific, political and social will power are needed to disseminate information, and to help farmers make the transition to CSA (i.e. to work towards the achievement of the three criteria of CSA).

3.2 CSA for India: CSTs under irrigated system, food bowl of the country

The sustainability of rice-wheat (RW) system in NW India is crucial to meet out the National Food Security Act, 2013. Sustaining and increasing the production of cereal systems in the Indian states of Punjab, Haryana, and western Uttar Pradesh in the northwest (NW) IGP, popularly known as the "breadbasket" of the country, is essential to meet the food requirement of India's burgeoning population which is likely to increase from 1.38 billion in 2020 to 1.6 billion by 2050. The sustainability of this system is at high risk because of resource degradation, declining factor productivity, and shrinking farm profitability under current farming practices. Therefore, CSA based approach was developed, refined and implemented. Looking at the 2nd generation problems of RW system and future drivers of agricultural change, there was a need to develop and test the technologies as per the defined domain and socioeconomic situation, while taking in account the issues of food security, resource efficiency, soil health, biodiversity and environmental quality in NW India.

In NW India, a Research Platform (RP), and a Delivery Hub was established at Karnal, in Haryana, Ludhiana in Punjab and in Bihar. In this project, three-tier research with a mechanism to feed back and forth was carried out i.e. i) Strategic research at Research Platforms (RPs), for technology generation and development under intensive monitoring atmosphere; ii) Participatory research at Haryana and Bihar for evaluating and testing the technologies, and practices developed at RPs; iii) Field trials at farmers' field, to see the impact of out scalable technologies and practices. Major technologies were zero-tillage (ZT), direct seeded rice (DSR), residue management using Happy Seeder, adoption of new diagnostic tools for nutrient -- (Green Seeker and Nutrient Expert Software Tool); and water management -- (Soil matric potential based irrigation, bed planting, sub surface drip irrigation); and crop diversification for addressing emerging issues of rice/maize based cropping system. At all the stages of planning, technology generation, evaluation, refinement, and scaling, researchers from CCAFS project (both ICAR and CGIAR system) were involved. We mainly focused on maximizing annual profit and production gains, high levels of input use efficiencies (water, energy, fertilizer, labor), balanced nutrient budgets, good soil health, ecological resilience, and low environmental footprints. Experimental platforms also provided an excellent training grounds for young researchers (including several students, interns and research fellows), for both NARS and CGIAR scientists.

3.3 CSA Pathway

In India the era of green revolution have led increasing food grain production for achieving food security of the region, but these gains were accompanied by problems of resource degradation (soil, water & energy). These problems now pose a serious challenge to the continued ability to meet the quality food demand of an increasing population, and lifting the people above the poverty line. The current approaches are ecologically intrusive, economically and environmentally unsustainable; the problems which seems to be aggravated by the changing climate in the region. CSA-based sustainable intensification acquires special significance because of the ecological and environmental problems, and strains on the natural resources in the post-Green Revolution era, and difficulty in sustaining growth in output and income. The study on CSA with the aim of devising strategies to reorient cropping system keeping in mind the declining yields, deteriorating natural resources, climatic changes besides water, labor and energy shortages, being faced by the present-day agriculture. The approach is to:

- Design next generation of cereal systems, that are highly productive, resource efficient, sustainable, and adapted to the expected changes in environmental, and socioeconomic drivers;

- Assess the performance of different agricultural systems (scenarios), with respect to crop productivity, water and energy use, economic returns and environmental footprints; Evaluate the impact of CSA based scalable technologies, at farmers' fields.

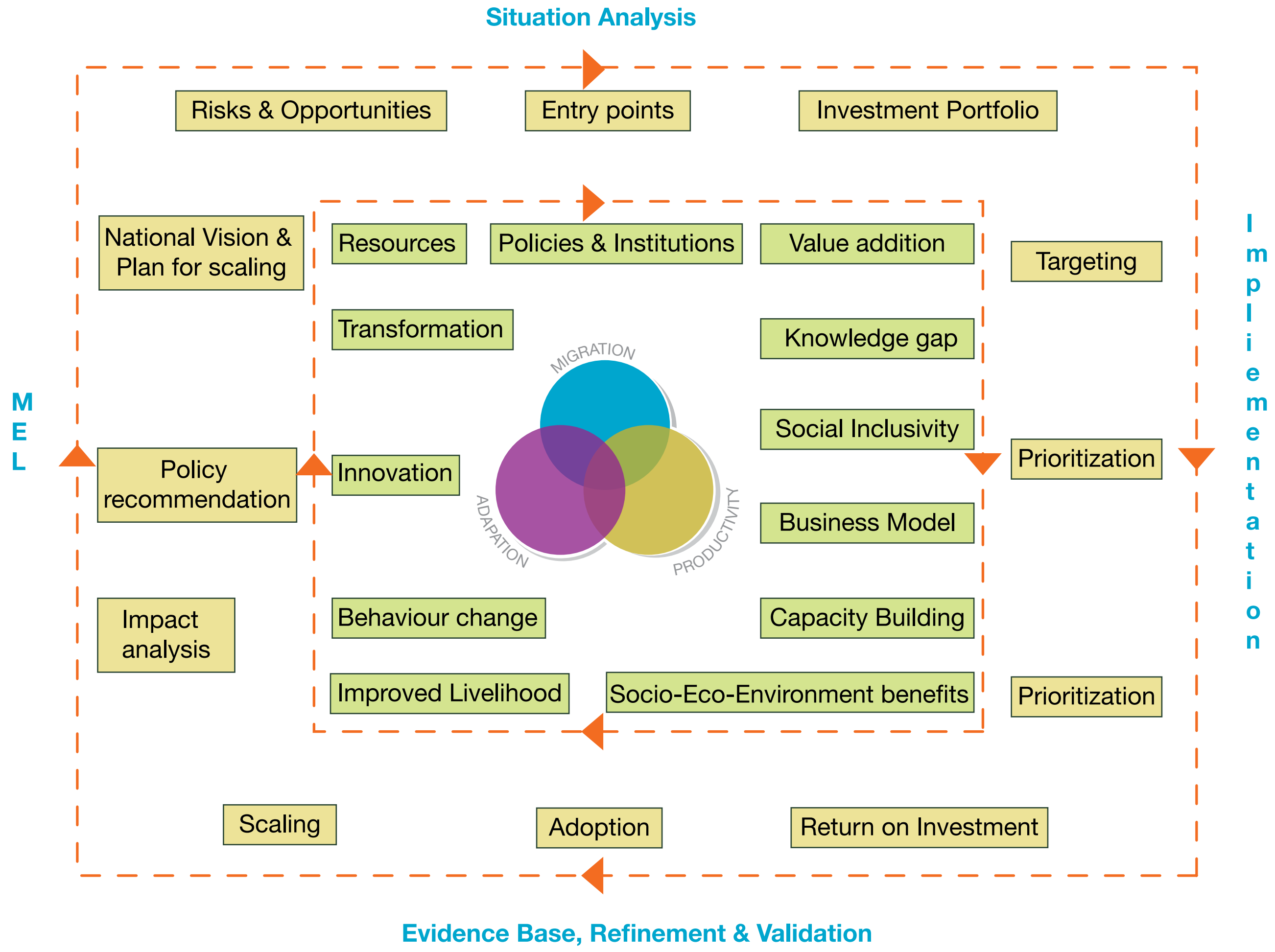
Importance of food security, mitigation and adaptation depends on location. India having diverse climatic and typological features, there is need for site-specific CSA frameworks in response to local challenges. Thus CSA pathway is illustrated defining the participatory action for innovation, implementation and validation, leading to increased adoption and scaling of CSA across sites, which needs to be further strengthened with policy support.

3.3.1 Situation Analysis

For better implementation the risks and opportunities are analysed defining indicators, like climate, socio-economic scenario, and agro-ecological conditions. Resources available & required ensuring optimizations to mitigate risk are planned as per the scope of work involving human, physical and capital. Strategic entry points are analysed under the existing policy and institutions framework, to make needful interventions based on demand and feasibility. Effective planning for investment portfolio involving CSA technologies and practices to be promoted is done for generating value addition to integrated farming systems.

3.3.2 Implementation

With the framework developed for the list of activities to be undertaken with laid outputs and objectives, the implementation phase starts. Understanding the value addition from practices in terms of improved income, yield and livelihoods, target is done on the criteria's of knowledge gap, social inclusiveness and impact at scale. Location and target group are prioritized given maximum societal benefit that can be brought and scaled. Business models are developed for scaling adoption and promoting CSA. Multi-stakeholder capacity enhancement is performed for generating knowledge base ensuring effective implementation of activities.



3.3.3 Evidence base, Refinement and Validation

Positive implementation is mapped to return on investment in terms of socio-eco-environmental benefits. This refers to climate smart indicators being addressed, increased profits to farmers, social inclusivity and reduced mitigations. The results on improved livelihoods are used as evidence base for adoption and further scaling of CSA. Learnings and improvements support refinement in technologies/practices and validated over time to successfully achieve pillars of CSA.

3.3.4 Monitoring, Evaluation, and Learning

Behavioural change is the key for any technology/ practice to reach scale-up. For sustainable change bringing impact at scaling-up, there is need for favourable policy support. Merging innovations with national vision is deemed essential to create policy recommendations, and bringing transformation in agriculture. Thus, monitoring, evaluation and learning is required to assess the planned and achieved outcomes.

3.3.6 Partners

Advancing adoption and scaling of CSA stands on the pillars of mutual interest of stakeholders. Stepping together for holistic realization of social wellbeing, partners stand collectively and individually accountable for their responsibilities. Scaling risks are better mitigated working closely and complementing the demand-supply of CSA technologies/practices. Enabling environment promoting scaling of CSA is created while strengthening capacity of partners.

SCALING CSA

Government	• Policy support • Investment
Private Sector	• Investment • Social responsibility
Researchers	• Innovation & Refinement • Capacity Building • Science based Evidence
Extension Agents	• Scaling CSA adoption • Awareness & Knowledge generation
Farmers & Cooperatives	• Participatory support • Adoption • Implementation

ENABLING CSA

3.3.5 Technologies

Technologies rating on Adaptation and mitigation (star rating)

Technology	Food security	Adaptation	Mitigation
Laser Land Levelling	2	2	3
Happy Seeder with SMS	2	2	3
Spatial Zero-till drill	2	3	2
Direct Seeded Rice	1	3	2
Permanent Beds			
Farm Design and Integrated Farming systems			
Crop diversification	3	1	1
Sub-surface drip Irrigation			
Green seeker	3	1	3
Nutrient Expert Tool	3	1	3
Leaf Color chart	3	1	3
Tensiometer/AWD	2	3	3
Intercropping			
Solar power pumps			

4 Laser Land Levelling (LLL)

4.1 Background

In arid and semi-arid regions of Asia, the challenges of water in agriculture will be intensified with climate change. The irrigation water demand will be increased by at least 10% with each 1 ºC rise in temperature, whereas the availability is expected to decline. Therefore, precision water management technologies have to play critical role in future food security. Traditional methods of levelling land are cumbersome, time consuming and expensive. Therefore, modern methods to levelthe cultivated land through Laser Land Leveller at zero gradient is getting popularity all across the IGP.

Picture 2. Use of Laser Land Levelling (LLL) Technology in field

4.2 About technology/practice

Laser Land Levelling (LLL) is a process of smoothing the land surface (± 2 cm) from its average elevation using laser-equipped drag buckets. This practice uses large horsepower tractors and soil movers that are equipped with global positioning systems (GPS) and/or laser-guided instrumentation, so that the soil can be moved either by cutting or filling to create the desired slope/level. Laser Assisted Precision Land Leveling is one of the key climate smart intervention in the intensively cropped flood irrigated systems in North-west India.

4.3. Benefits of technology

↑

Water use and weed control efficiency.

Cultivable area by 3 to 5% approx.

Fertilizer use efficiency

Crop establishment

Farm productivity by ~5-20% depending upon soil type and cropping system.

Farm profitability by USD 150-200/ha in rice-wheat system.

↓

GHG Emissions

Duration of irrigation. Patchy growth under salt affected soils.Irrigation water by 20-30% in rice-wheat system.Irrigation duration

- 10-12 h/ha in wheat season
- 47-69 h/ha in rice season

4.4 Implementation domain

The LLL can be implemented across the region, cropping system, soil type and environmental conditions. The LLL technology has been implemented in both irrigated and rainfed ecosystems. This technology has domain of 13.5 million hectares in the IGP where rice-wheat sequence dominates under irrigated ecosystems. This technology has untapped potential in rainfed ecologies of India, as well as where water scarcity and soil moisture are major concerns, to get good crop production. In the western IGP, future food security is severely threatened by unsustainable and inappropriate groundwater use. This technology is more beneficial in rice-wheat system, as rice requires ~200 cm of irrigation water. Thus, water saving measures are must as there is more need of water at rice growing season in the RW system.

4.5 Complementary practices

As LLL is a precursor to good agronomic, soil and crop management practices, therefore it can be complemented by all other management practices related to tillage, and crop establishment, fertilizer and weed management in general, and water management practices in particular.

4.6 Gender and Youth Dimension

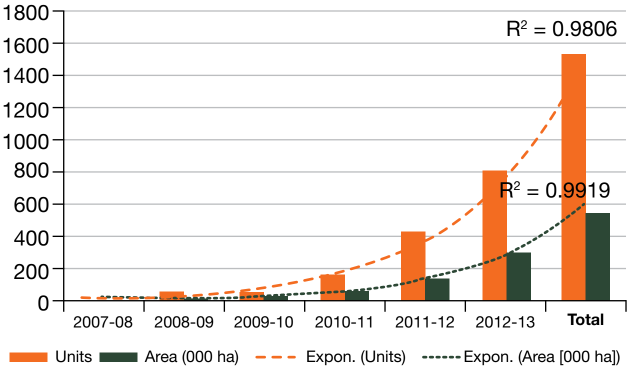
The savings from LLL in terms of water, fertilizers, energy and labor time for irrigation can be potentially used in alternate livelihood activities involving women and youth. There are results of reduced weeds in laser levelled fields, reducing drudgery of women. However, in order to increase its uptake, socio-cultural barriers, especially gender inequalities need to be addressed for access of machinery by women farmers. It also facilitates crop diversification into vegetables, which is important for food security and additional income source for women, who are often hired to do farming activities. In the out-scaling of this technology, youth played an important role by acting as service provider and opening the Custom Hiring Centers (CHCs) in the region. To motivate the women farmers and educated youth, proper design of promotional incentives is required to address the constraints/ issues for its proper utilization in newer areas.

4.7 Business case

As LLL is a scale neutral technology, not biased towards large farmers, is becoming increasingly popular among service providers, as possible business opportunities. The LLL is a fast spreading technology all across the region, and covers sizeable area within a span of 16 years since its inception in 2003. It is providing business to LLL owners or service providers, to custom hiring centres, to the manufacturing industries. There are subsidies provided by government directly to the farmers for buying the machines. The operators of LLL are paid more, as compared to other machine operators, making its usage more popular.

4.8 Statistics of adoption

This technology is practiced almost in 75% area of the NW- IGP which accounts to 5 million hectare of rice-wheat system. Now it is spreading its legs in other cropping systems of the region. But still it is a new technology in rainfed ecosystem of South India, in all the cereal, oilseed and pulse based crops and cropping systems. Till date ~25,000 machines are available in the northern region of the country. This LLL works almost 100 days in a year. LLL can level 20 acres of land area in a day (8-working hours). It is a scale neutral technology, and can be adapted anywhere, under any soil type.



ADOPTION

Enabling factors	Reinforcing/Need factors
Policy support in terms of subsidy during the initial stage of adoption	Subsidy to make purchase of equipments affordable for small and marginal farmers
Policy on preventing farmers to refrain from rice transplanting/sowing before 15th June to save ground water	Need for skilled operators to set/adjust laser leveler settings and to operate the tractor in the new areas
Technical knowledge to farmers through various capacity building programmes at village, block and district levels by the Govt. departments	Access of 2 wheel tractors for its operation in undulated terrain, irregular and small sized fields
Formation of machine banks and PACS by the respective state agencies. Custom Hiring Services (CHCs) by the progressive farmers and small scale centres at village level	Socio-cultural barriers, especially gender inequalities in the domain

5 Happy Seeder with SMS

5.1 Background

Rice-wheat is the most popular cropping system, extending across the whole IGP of India, and in north-west IGP where combine harvesting of rice and wheat is now a common practice, leaving large amount (> 6.0 t) of crop residues in the fields. Due to limited window for the planting of subsequent wheat crop, and poor residue management options, open-field burning of about 30 million tonnes of rice and wheat residues is done, causing increased concerns over public and soil health issues, and environmental problems such as the greenhouse gases effect and ozone layer depletion. Managing 8-10 t/ha residues efficiently and economically is very difficult for the farmers to plant their wheat crop on time which has been a daunting task with conventional implements. Zero-till technology for wheat seeding have been found beneficial in terms of economics and timeliness of wheat sowing however, there are problems with direct drilling of wheat into combine-harvested rice fields using the standard ZT seed drill.

Picture 3. Use of Happy Seeder with SMS Technology in Field

5.2 About technology/practice

The Happy Seeder, a key innovative planter, is capable of direct drilling of wheat seeds after rice harvest with surface retention of residues as mulch, and without any preparatory tillage. One of the challenges was uniform spread of loose residue over the soil surface. Manual spreading of residues is cumbersome as neither labor is available nor it is economical, leading to poor performance of Happy Seeder. The Super Straw Management System (Super SMS), attached at rear of the combine harvesters, are able to chop and spread straw uniformly.

5.3 Benefits of technology

↑

Productivity & Profitability

- 0.3-1.0 t/ha of wheat in rice-wheat system

Carbon sequestration

Better crop establishment

Capacity and performance of Happy Seeder

Central sponsored scheme: 'In-situ Management of Crop Residues' in the NW India

↓

Cost of tillage

- USD 100/ha
- Herbicide and energy use

Fertilizers: After 4 years of continuous cultivation

- N by 20-30% and K by 50%
- Govt. burden for fertilizer subsidy

Irrigation water

- 10-30% in rice-wheat system

Weed menace

- Rice-wheat system by ~70%

GHG Emissions: Reducing N dose

- Fuel consumption and water use

Climate change effects

- Moderating soil moisture and temperature

5.4 Implementation domain

In South East Asia, *Green revolution* facilitated the expansion of area under RW rotation, and now estimated to ~14 million ha, which mostly confined all across the Indo-Gangetic Plains (IGP). The whole of the IGP which covers nearly one-fifth of the total geographical area in the four countries *viz*. India, Pakistan, Nepal and

Bangladesh of South Asia, which occupies by 10.5, 2.2, 0.5 and 0.8 million ha, respectively is the domain of this technology. In north-west Indian states, *viz*. Punjab, Haryana and Western Uttar Pradesh, 80-90% of rice area is followed by wheat. In north-west IGP it is spreading at a faster rate than any other domain areas.

5.5 Complementary practices

In South Asia, RW rotation ensures employment, livelihood and income to small holder farmers and country's food security. This technology is complemented by simple zero-till and spatial ZT machine in the manual harvested area of Basmati rice. To improve the water and nutrient use efficiency, Happy Seeder is complemented with precision water (drip irrigation, soil matric potential based), nutrient (NE software tool, Green Seeker based) and other residue management strategies like chopper, mulcher, and shredder.

5.6 Gender and Youth Dimension

Provision of higher subsidies or incentives to women, to open the Machine Banks in the area, can mainstream women in technology adoption and upscale. Lower infestation of weeds and less water application, reduced the drudgery of women. The higher productivity and profitability, ensures household food & nutrition security. In the scaling out of this technology youth played an important role, by acting as owner cum service provider, and opening the machine banks and custom hiring centers in the region. To motivate the women farmers and educated youth, they should be provided with the timely technical capacity building trainings to prepare them for the backstopping arrangements in case of urgent requirement to address the social constraints/ issues for its uptake in domain area.

5.7 Business case

Happy Seeder technology is "environmental as well as farmer friendly" option for residue management. This technology would usher a new policy paradigm, by moving from subsidy to efficiency. It promotes environmental services for sustainability of agriculture, and public welfare. This technology will complement the Government Schemes on -- soil health, water saving, climate risk reduction, 'Nutrition and Food Security',

ADOPTION

Enabling factors	Reinforcing/Need factors
Attachment of Super SMS (Straw Management Systems) made mandatory for registration of all new combine harvesters in Punjab	Better availability of good quality machines, gives small window of operations (25 days)
Promotion of manufacturing of good quality Happy Seeders to cover all the combine harvested rice acreage where residue is burnt	Strengthened policies for SMS attached to combine harvester
Implementation of policy, banning in-field straw burning and direct drilling sowing of wheat into rice residues Farmers will be fined for crop residue burning in the form of environmental compensation (Reside burning in < 2 acres- INR 2,500; 2-5 acres- INR 5,000; >5 acres- INR 15,000 per incidence)	Modification to operate in wet straw specially during early morning hours
Awareness programmes at village level, and training and capacity development of service providers	Removal of subsidies for diesel and electricity (to reduce pumping of groundwater)
Convergence of relevant Government schemes and pooling resources	Improve technical knowledge and ability in newer areas for up-scaling
Concurrent use of SMS-fitted combines and Happy Seeder for harvesting of rice, and sowing of wheat in one time	Need to strengthen Agro Service Centres in all co-operative societies (PACS), co-operative societies, co-farmers and other private agencies

'Doubling of Farmers Income', and the 'One Health' programs. The potential advantage that farmers serving as service providers can create higher operational efficiencies, by connecting Primary Agriculture Cooperative Societies (PACS) and Machine Banks. With support from Govt. Schemes the farmer cum service provider can act as an entrepreneur, creating employment and income opportunities.

5.8 Statistics of adoption

The rapid adoption of Happy Seeder technology needs a major government push, to publicize and popularize the technology. Currently the area covered under Happy Seeder is 0.2 Mha by around only 5000 Happy Seeders and 1000 super SMS fitted combines. It is estimated that to cover 50% (5.0 million ha) of the total acreage under RWCS in India, about 60,000 Happy Seeders and 30,000 super SMS fitted combines will be required.

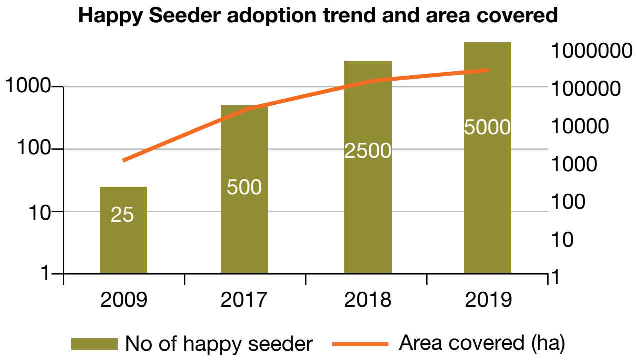


Figure 3: Graph representing (log scale data) adoption of Happy Seeder and area covered since 2009

6 Direct Seeded Rice (DSR)

6.1 Background

In the IGP, manual transplanting of rice in puddled fields is a common practice in rice-wheat cropping system. In the recent past, timely availability of labor during transplanting is a big constraint throughout NW India. Low wages and adequate availability of water favour rice trans-planting in the past scenario, whereas, high wages and low water availability favours DSR in the current scenario. In Indian IGP, increasing shortages of water, energy and labour, forced the farmers to adopt conventional till/ zero till direct seeded rice (CT/ZT-DSR).

Picture 4. Display of Direct Seeded Rice Technology

6.2 About technology/practice

DSR is a practice of direct sowing of rice, just like other grain crops in dry/wet field using Multi-Crop Planter / Turbo seeder in unpuddled condition after wheat/ summer mungbean harvesting. In the IGP, depending on water and labor scarcity, farmers are changing either their rice establishment methods only or both tillage and rice establishment methods. Planting of DSR should be completed 10-15 days in advance, before onset of monsoon to get better crop establishment. For better germination, it is recommended that seed rate and seeding depth should be maintained at optimum level using the Multi Crop Planter fitted with inclined plate seed metering mechanism.

6.3 Benefits of technology

↑

Productivity: 15-20%

Profitability: ~25% in rice-wheat system

High yields

- Heavy and salt affected soils
- Wheat after DSR: 5-10%

Water productivity

- >25% compared to transplanting

↓

Cost of cultivation

- USD 20-30/ha
- Labour saving: USD 55-65/ha
- Nursery saving: USD 15-20/ha

Irrigation water use: ~25%

Labour: 15-30%

Methane emission:

- 50-60% in irrigated ecosystem of NW India
- Machinery maintenance

6.4 Implementation domain

- The DSR appears to be an economically viable alternative to transplanted rice, to overcome the emerging problems of labor, water scarcity and rising production cost.
- The irrigated ecosystem of Haryana and Punjab is increasing because of lower tube well discharge, whereas, in rainfed ecosystem of UP, Bihar and Orissa, it is being adopted due to the uncertainty of timely rains, and of long dry spells.
- Basmati growing areas of the country are ideal for DSR cultivation. DSR helps in restoration of medium to heavy textured soils, as deep rooted varieties perform better by extracting the water and nutrients from the deeper layers, as traditionally rice is a shallow rooted crop.

- Wet-DSR is popular in eastern IGP in which sprouted rice seeds are broadcast or sown in lines on wet/puddled soil. However, Dry-DSR is popular in NW IGP where dry rice seeds are drilled on unpuddled soil either after dry tillage or zero tillage.

6.5 Complementary practices

The DSR practice is complemented with all good agronomic, soil and crop management practices. This practice of crop establishment is well complemented by various inputs (water, nutrient, chemicals etc.) management practices, as they are directly correlated with them. Sub-surface drip irrigation and relay planting of summer pulses in DSR field is helping in boosting the system productivity and profitability while improving the soil quality and crop diversity in the domain area.

6.6 Gender and Youth Dimension

The crop production inputs like irrigation water, fertilizers, energy and labor can be saved and efficiently used in alternate farming system (crop + livestock) activities, involving women and youth. The DSR helps in reducing drudgery of women farmers compared to those of transplanted rice. However, in order to increase its uptake, the associated technologies should be embedded under defined socio-cultural settings of the region. It allows diversification into pulses and vegetables during summer, which is vital for nutritional security of households, and offers higher income for seasonal daily wager women farmers. In the scaling out of this technology youth and women plays' an important role by providing services through custom hiring centres, co-operative societies and FPOs in the region. To motivate the women farmers and educated youth, proper knowledge of promotional incentives is required, to address the constraints/ issues for its uptake in niche areas.

6.7 Business case

The DSR is a practice which integrates all the management components of rice production system across IGP. DSR is directly related to ground water depletion rate in NW IGP, and uncertainty of onset and withdrawal of monsoon in eastern IGP. The Central and State Govt. schemes should be aligned with this practice, for its wide acceptability and adaptability to generate new atmosphere of business cases, by making timely availability of multi crop planters, herbicide sprayers, moisture measurement tools etc. It can also promote the multiple services for the service providers, machine banks and co-operative societies.

6.8 Statistics of adoption

Direct seeded rice, a common practice before green revolution in India, is becoming popular

ADOPTION

Enabling factors	Reinforcing/Need factors
Policy support in terms of incentives and free supply of inputs to DSR growers in the region	Better crop establishment due to variable rainfall pattern during crop establishment stage
Central Government Promotional Schemes for the crop diversification programme of Rashtriya Kisan Vikas Yojana (RKVY).	Efficient management of mixed weed flora including nonpaddy weeds like Leptochloa, Eragrostis, Dactyloctenium
Ban on transplanting of rice before 15th June in Punjab and Haryana	Availability of broad spectrum herbicides
Formation of farmers' producer organization (FPOs) for supplying of inputs and knowledge sharing with farmers	Availability of suitable varieties for direct seeding of rice (DSR) in the country
Custom hiring services, machine banks, self-help groups, co-operative societies presence at village level	To provide the complete package of technical knowledge practices on DSR
Policy and it's strong implementation on banning of crop residue burning in NW IGP	Treat iron deficiency in sandy soils

once again because of its potential to save water and labour. Currently, direct seeded rice in Asia occupies about 29 Mha, which is approximately 21 per cent of the total rice area in the region (Pandey and Velasco, 2002). In South Asia, rice was cultivated on 60 Mha of which India's share is 70%. The area under DSR is increasing over the years, but with a slow pace in the NW IGP. The area is spreading only in Punjab and Haryana being agrarian states where groundwater depletion currently is a major concern. Timely application of pre-emergence and post-emergence herbicides is very essential for its wider adoption and scalability in the region.

An area of 30,000 hectare has been covered under DSR during 2015-16 and about 30,000 hectare area covered during 2016-17 in Haryana. The targeted area in Punjab and Haryana is 1.0 Mha for the year 2020. The area under DSR in other eastern and southern states of India is also increasing to save the water and for the restoration of natural resources.

7 Raised Bed Planting

7.1 Background

In the Indo-Gangetic Plains (IGP) of South Asia heavy rainfall in the monsoon season, create situation of inundation/waterlogging under flat sowing, prevails chances of crop failure . The cultivation of crops on permanent raised beds reduces the adverse impact of excess water on crop production, and reduces the need to irrigate crops in semi-arid and arid regions.

Picture 5. Display of Bed Planting Technology

7.2 About technology/practice

Bed planting is a method of crop establishment, where crops are cultivated on raised beds. The bed planter has adjustable blades for making raised beds of different widths and heights that can be adjusted by the shifting of blades on the frame and roller on the rear. The sowing on raised beds is done with the help of the Multi Crop Bed Planter fitted with inclined seed metering mechanism system. The permanent raised beds with only superficial reshaping in the furrows between the raised beds is needed, before planting of each succeeding crop, to reduce cultivation costs and increase sustainability of systems. Moreover, it controls machine traffic, limiting compaction to furrow bottoms, allows the use of lower seeding rates than with conventional planting systems and reduces crop lodging.

7.3 Benefits of technology

↑

Productivity & Profitability
- 10-20%

Water use efficiency

Crop establishment
- Less lodging
- Less water logging

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Cost of cultivation
- 25% less seeds
- 25% less fertilizers
- 35% less water

Reduced use of herbicides
- Less weed problem
- Controlled irrigation water in furrows

GHG Emissions

7.4 Implementation domain

- Widespread in America and Europe in most of the crops since 1970s
- Increasing acceptability in South Asia under row crops
- Maize, soybean, cotton, sunflower, pigeonpea, mustard and wheat planted on beds
- Irrigated and rainfed ecosystem to control weeds, as bed planting provides opportunity for mechanical weed control
- Eastern and western IGP for addressing crop lodging problem
- Rice-wheat systems with declining water table

7.5 Complementary practices

Bed planting is directly related with good soil and crop management practices in any cropping system. This practice of crop establishment is well complemented by crop inputs (water, nutrient, energy, chemicals etc.), management practices in the defined agro-ecological region. Intercropping with micro-irrigation helps in boosting the system productivity and profitability in maize based systems.

7.6. Gender and Youth Dimension

- Inputs like seeds, water, fertilizers, energy and labor are saved and can be used for growing other horticulture/vegetable crops, and by engaging women here to earn extra income.
- Family women can catch the early market by selling green cobs for higher benefits.
- Reduces burden on women for intercultural operations as it can be done mechanically.
- Allows intercropping/relay cropping of pulses and vegetables which helps in nutritional and financial security of households and can provide an income source for women.
- In the scaling out of this technology, youth are the major drivers to provide bed planting services through custom hiring center, co-operatives societies and FPOs in the region.

7.7 Business case

- Maize bed planting can promote installation of community driers, as maize contains 25% moisture in the grain at the time of harvesting.
- Mechanical weeding and spraying of herbicides and pesticides can be undertaken by co-operative societies.
- Value addition of crops like maize for improved income.

7.8 Statistics of adoption

Maize-wheat cropping system (~2.0 m ha) area can be brought out to bed planting in India. The area under eastern IGP has potential to grow the maize on beds for intercropping of pulses and vegetables. Some other crops like pigeonpea in eastern India, soybean and cotton in North-West and Central India can be grown on beds under limited water supply or rainfed ecologies.

ADOPTION

Enabling factors	Reinforcing/Need factors
Awareness on the root cause (second generation problems of rice-wheat system in IGP) of groundwater depletion, soil health deterioration, environmental pollution	Technical knowledge on bed planting and spraying machinery to farmers
Krishi Kiosks imparting information to farmers about Central and State Government schemes focused on Agriculture and FPOs to supply all inputs under one roof.	Increased awareness and interest amongst the farmers for new crop establishment methods, like growing wheat crops on beds in IGP
Access of multi crop bed planter from custom hiring centers, machine banks and co-operative societies	Timely availability of bed planters to small farmers

8 Spatial Zero-Till Machine

8.1 Background

Rice-Wheat rotation is the dominating cropping system in South Asia and it extends all across the Indo-Gangetic Plains. In North-West IGP, especially in Haryana state of India almost 50% (0.5-0.6 mha) of the rice area is occupied by Basmati Rice (scented rice). To maintain its fragrance and quality, it is mostly hand harvested, leaving small amount of anchored rice residues in the fields. In this condition simple ZT machine works very well.

Picture 6. Spatial Zero-Till Machine

But in combine harvesting (without), anchored residue (20-25cm height) along with some loose rice residue (after removing the loose residues) hamper wheat seed placement at desired depth by using simple ZT machine. Due to the limited window for planting of subsequent wheat crop, rice crop is harvested by combines and residues are being burned *in-situ*. Zero-till machine works well for wheat sowing where rice is harvested near the soil surface manually and in the fields where loose straw from combines is completely removed. However, there are problems with direct drilling of wheat into combine-harvested rice fields using the simple ZT seed machine due to: (1) dragging of loose rice straw; (2) poor traction of the seed metering drive wheel due to the presence of loose straw; and (3) frequent lifting of the implement under heavy residue conditions, resulting in uneven seed depth and thus crop establishment.

8.2 About technology/practice

The Spatial Zero-Till Machine is a new innovative drill which is capable of direct drilling of wheat after rice harvest, with limited residue conditions. It is similar to Zero Till machine but is especially modified. The furrow openers are mounted on frame in three rows and having a clearance of almost 2 feet. This machine is able to sow wheat in standing stubbles in combine harvested paddy field.

8.3 Benefits of Technology

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Improved productivity
- 0.1-0.3 t/ha of higher wheat yield in rice-wheat system

Systems' resilience
- Maintaining crop residues on soil surface

Nutrient use efficiency

Soil quality improvement

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Input cost
- USD 50/ha: saving of tillage operations

GHG emission and energy use
- Reduced fuel consumption

Weeds

Air pollution

8.4 Implementation domain

This technology has limited domain and extends mostly in the Basmati growing areas of the country, where combines are in operation and also in those areas, where combine harvester is not equipped with SMS, and loose residue are collected by the farmers to feed the cattle. It has more scope in eastern IGP and southern India where small land holdings prevails, and rice straw is used for cattle feeding. It can be implemented in Nepal and Bangladesh as well.

8.5 Complementary practices

Spatial ZT machine may be complemented by simple zero-till and *Happy Seeder* in the rice-wheat domain of South Asia. Crop management practices like precise water and nutrient management are very much required to get more benefits from this technology. Residue management options using the machines like chopper, mulcher, shredder might be complemented to scale out in larger area.

8.6 Gender and Youth Dimension

Similar to Happy Seeder business in the Rice-Wheat domain, it can be potentially used as a new start-up by youth. In increased adoption of this technology, youth and progressive women can play an important role, by creating machine banks and custom hiring centers in the region. Also they can create a knowledge hub/centre to impart knowledge on machines, along with other crop production management technologies. For the fast implementation, provision of higher subsidies or incentives to women and youth should be offered, to have new start-ups in the region. Invariably higher profitability ensures the good living standards of households.

8.7 Business case

Spatial ZT technology is a socially acceptable, and environment friendly technology in the domain. This technology can generate a strong business case throughout the Indian IGP. Central and State Govt. schemes related to agriculture should be complemented for its wider acceptability and adaptability. By this technology, localized nature of the business can be made through strong local linkages with farmers groups. Custom hiring of machines through PCAS and machine banks is required to customise its advantages to the society.

8.8 Statistics of adoption

This machine is very new in the Rice-Wheat domain area to manage the anchored and some loose residues effectively. At present its adoption is limited to two districts (Karnal and Kurukshetra) of Haryana state. The area under this technology is around 2000 ha by 2018. It is estimated that to cover 40% (0.5 million ha) of basmati area in Haryana, about 6000 Spatial ZT machines will be required.

ADOPTION

Enabling factors	Reinforcing/Need factors
Efforts to cover all the combine harvested rice acreage where residues are being used as cattle feed	Address small window of operation in Rice-Wheat system (15-30 days per year).
Establishment of machine banks and Agriculture Service Centres to ensure timely availability of machine	Removal of subsidies for diesel and electricity (for pumping groundwater)
Effective implementation of the policy banning in-field straw burning, and ZT direct drilling wheat into rice residues.	Generate awareness on technical know-how in newer areas for its rapid adoption
Convergence of relevant government schemes (soil health, water saving, climate risk reduction, food security, doubling farmer income, etc.), pooling resources and effective monitoring at village level	Need to strengthen machine banks in all co-operative societies
Promotion for manufacturing of good quality machines	Better availability of machine, and awareness and complete training to farmers for this machine

9 Crop Diversification

9.1 Background

In South Asia, stressed natural resources for agriculture with increase demand for food due to rising population are the major cause of concern, where the present cropping pattern is no more economically viable option. The dominance of the wheat-paddy system has led to serious economic, social and ecological problems such as deceleration in productivity of ground water resources, and decline in soil fertility. Therefore, there is need to critically redesign alternative cropping patterns based on available resources.

Picture 7. Crop Diversification model in the field

9.2 About technology/practice

Crop diversification is an approach which aims at altering the cropping sequence, with a focus to reduce the mono-cropping pattern or saving precious resources like water and energy. Diversification means growing alternate than routine crops, for the purpose of replenishing soil nutrients. Crop diversification is the product of action, reaction and interaction among the physical and non-physical environment as it gives wider choices on selection of crops and their varieties in a given area to expand production related activities of various crops and also to lessen the risk. Crop diversification is generally viewed as a shift from traditionally grown less remunerative crops to more remunerative crops with the advent of modern agricultural technology especially during the period of green revolution.

9.3 Benefits of technology

↑

- Productivity: 15-20%
- Profitability: ~25% in rice-wheat system
- Labour employment
- Water& Nitrogen use efficiency
- Food and nutritional security

↓

- GHG Emissions
- Natural resources degradation
- Crop failure
- Market price variations
- Soil erosion, weeds and disease

9.4 Implementation domain

- Crop diversification can be practiced across the region, cropping systems, soil type and under varied environmental conditions.
- This technology has domain of ~10 Mha in rice-wheat sequence of IGP both in irrigated and rainfed conditions.
- In the western IGP, due to lowering down of groundwater levels, wheat and maize are the best available remunerative option for rice.
- In eastern IGP, inclusion of pulses after rice harvest (*Utera* cropping) is required for improving the farm profitability and soil quality.
- Also in other arid and semi-arid regions of India, where resource degradation, moisture shortages and more climatic variability prevails, this technology can be an excellent option for making the system resilient.

9.5 Complementary practices

The agriculture practices contributing to boost system productivity and farm profitability while improving the soil and environmental quality complements the crop diversification and soil and crop management practices for better crop production.

9.6 Gender and Youth Dimension

Crop diversification opens the plethora of opportunities for both youth and women. Youth can be engaged in providing the services on new modern tools, and techniques for crop production related precise input management. Women may have better options for horticulture/vegetable cultivation to improve the farm profitability. Women can be engaged in value addition of crops in the small scale industries related to processing, packing, and marketing etc. Both youth and women may utilize all the resources very effectively and timely to capture the early markets. Nutritional security of households can be met through women, through new initiatives like bee keeping, mushroom cultivation, baby corn, vegetable, fruits etc. Custom hiring centre, co-operative societies and FPOs has wider application in the particular region.

9.7 Business case

- New start-ups and entrepreneurs can be created for value addition of crops like maize, soybean, pigeonpea, mustard etc. in NW India.
- New industrial growth in the villages for drying, processing and value addition of high value crops.
- Installation of community driers will help to boost the society by making more profit.
- Inclusion of pulses in major cropping systems, inclusion of cattle based enterprises in farming system etc. in NW India may be a productive way to build resilience into agricultural systems for national food security, and creating additional employment opportunities.
- Business related to custom hiring services, FPOs, co-operative societies, local service providers will expand at the localized places.

9.8 Statistics of adoption

Crop diversification exists as per the agro-climatic conditions, but focus should be given to those areas in the region where problems of groundwater depletion, soil quality, environmental pollution and low farm profitability prevail. In western IGP, groundwater depletion is a major concern in almost 5.0 Mha area and thus, it is the best site for adoption of crop diversification to maintain the ecological balance in the region. In eastern IGP, declining farm profitability is a major concern and crop diversification provides the opportunities for rice-wheat system for higher profit.

ADOPTION

Enabling factors	Reinforcing/Need factors
In NW India, policy initiatives for crop diversification to divert 5% area of rice to other alternative crops	Supportive policies for crop diversification as done for maize and DSR
Policy on incentives, free supply of inputs and free insurance of maize crop under crop diversification of rice-wheat scheme in NW India	Better marketing opportunities for the new crops adopted
Promotional schemes to save groundwater for future generations through 'More Crop per Drop'.	Better infrastructure for value addition services
Minimum support price based assured procurement of maize in Haryana	Knowledge and availability of good quality seeds, chemical etc. for situation specific needs
Convergence of private-public market institutions to promote farmers towards crop diversification	Availability of driers for maize drying in north-west India in grain markets
Krishi Kiosks for information dissemination to farmers about Central and State Government schemes and FPOs	Very low interest of farmers towards diverting to new crops

10 Intercropping

10.1 Background

In South Asia, monotonous cropping system of rice-wheat production has led to second generation problems in the IGP related to soil, water, weeds, insects, pests and diseases, contributing to global warming led climatic variability. Therefore, to maintain the natural resource base there is a need to diversify the cropping system through changing cropping system and/or intercropping/ relay cropping. The aim of intercropping in any system is to increase the productivity, by utilizing the available resources effectively.

Picture 8. Demonstration of Intercropping in the field

10.2 About technology/practice

Intercropping is the practice of growing more than one crop on the same field at the same time, in a definite row pattern, to increase the productivity per unit area. After one row of the main crop, three rows of intercrops can be grown. Here, component crops are arranged in alternate rows (row intercropping), in wide strips (strip cropping) and in standing crop when the existing crop has flowered but not harvested (relay cropping).

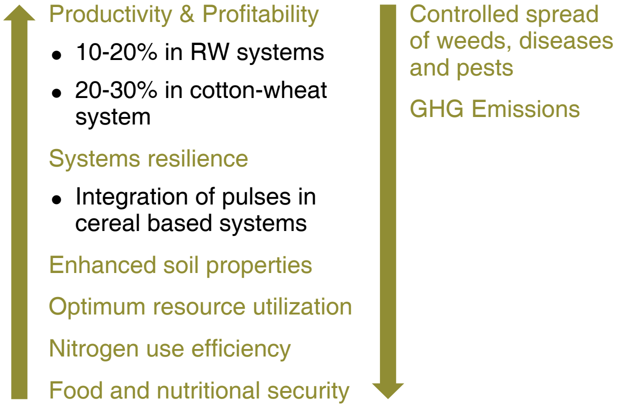
In eastern IGP, vegetables like potato, cauliflower, cabbage, pea, lentil and flowers like gladiolus, marigold, chrysanthemum etc. can be grown during winter season, as an intercrop with maize.

In western IGP, relay planting of mungbean in standing wheat crop in rice-wheat system and wheat in standing cotton in cotton-wheat (CW) rotation are feasible to break the monotony of system.

In rice-wheat system, the window period (around 65 days) after wheat harvest can be effectively utilized through relay mungbean in standing wheat crop. Intercropping of pigeon pea with mungbean is also one of the options to replace the rice from rice-wheat system in western IGP.

In cotton-wheat system, sowing wheat after 20th November reduces the productivity at the rate of 1.0-1.5% per day reducing average yield after cotton by > 0.5 t ha^{-1}. Wheat sown after cotton harvest in general faces an unfavourable temperature regime, and smaller window for growth and development, leading to lower yield.

10.3 Benefits



Productivity & Profitability
- 10-20% in RW systems
- 20-30% in cotton-wheat system

Systems resilience
- Integration of pulses in cereal based systems

Enhanced soil properties

Optimum resource utilization

Nitrogen use efficiency

Food and nutritional security

Controlled spread of weeds, diseases and pests

GHG Emissions

10.4 Implementation domain

Intercropping is suitable for both irrigated and rainfed ecologies of South Asia. This technology has domain of ~10 Mha in rice-wheat sequence of IGP. In India, rice-fallow areas constitute 11.7 Mha spread over Tamil Nadu, Andhra Pradesh, Odisha, Karnataka, West Bengal, Assam, Bihar, Jharkhand and Chhattisgarh. These areas are suitable for pulse catch cropping after rice harvest, as they have excess moisture at sowing, and terminal drought at flowering. In eastern IGP, inclusion of pulses as intercrop in maize boosts farm profitability and soil quality. Though, in rice-maize cropping systems of eastern IGP pulses, vegetables and floriculture are the intercropping options with *Rabi* maize. The timely planting of wheat without any penalty on cotton crop can be achieved through relay planting in standing cotton using innovative planters in ~4.5 Mha of South Asia.

10.5 Complementary practices

Selection of crops and their varieties as per the site specific and climatic conditions, precise fertilizer and water management, and intercultural management practices complement intercropping under the expected climate change effects. Intercropping systems work in space and time dimensions with the main crops, therefore all the management practices of main crops are complementary to the intercrop crops.

10.6 Gender and Youth Dimension

Women may have better options for growing vegetable and floriculture crops with the main cereal crops and thus enhancing the farm profitability. Cultivation of flowers and vegetables improve opportunities to reach market and better role in small scale industries related to processing, packing, and marketing etc. Youth can be attracted towards new crops, for making timely availability of technical knowledge on inputs, machinery, selling locations and new modern tools and techniques for precise management of intercrops. Financial and nutritional security of households can be achieved by adopting intercropping.

10.7 Business case

Intercropping creates avenues for new industrial growth in the villages for drying, processing and value addition of high value crops. New start-ups can be created to increase the profits through value addition and post-harvest processing of intercrops like soybean, pigeonpea, mungbean, lentil, uradbean, mustard etc. in western IGP. Intercropping helps in boosting the activities related to custom hiring services, FPOs, co-operative societies, local service providers will be the new avenues for the villagers to increase the status of the society.

10.8 Statistics of adoption

Diversity of agro-ecologies and cropping systems coupled with versatile habits, and short duration of pulses provides opportunities to increase acreage through intensification of cropping systems, in addition to diversification in some areas. Bringing new niche areas under pulse cultivation may play an important role in increasing the pulse grain production in the country. There is a potential of bringing 2.7 Mha under intercropping, 1.0 Mha under catch cropping and 2.5 Mha in intensification of rice fallow in addition to substantial acreage (4.0 Mha) under sequential cropping through intensification. For example in intensification of rice-wheat and maize-wheat systems, altogether 10.0 Mha additional acreage can be brought under pulses with improved agronomic management.

ADOPTION

Enabling factors	Reinforcing/Need factors
Policy support in the form of free supply of seeds for mungbean and sesbania to utilize time between wheat harvesting and rice sowing in Haryana under crop diversification programme	Development of infrastructure for marketing and post harvesting processing units
Significant hike in minimum support prices for pulses to attract farmers for pulse and oilseed cultivation	Integrated policies for crop diversification through intercropping system in the domains of different cropping system
Mission like ‘More Crop per Drop’ and ‘Soil Health’ to bring more area under low water requiring crop	Availability of knowledge and inputs for newly introduced crops
Krishi Kiosk created for information dissemination to farmers about government schemes and FPOs to supply all inputs under one roof.	Provide facilities for sowing, harvesting and threshing of different crops

11

Nutrient Expert® (NE)

Nutrient Manager for Wheat - Start

Nutrient Expert for Wheat

Version 1.0

First time user? Working in a new location? Make sure to have the 'Settings' right!

Nutrient Expert for wheat helps you to:

- evaluate current nutrient management practices
- determine a meaningful yield goal based on attainable yield
- estimate fertilizer NPK rates required for the selected yield goal
- translate fertilizer NPK rates into fertilizer sources
- develop an application strategy for fertilizers (right rate, right source, right location, right time), and
- compare the expected or actual benefit of current and improved practices.

To start, click a button

Nutrient Expert for Hybrid Maize - Start

Nutrient Expert for Hybrid Maize

South Asia – Beta Version (April 2011)

First time user? Working in a new location? Make sure to have the Settings' right!

Nutrient Expert for Hybrid Maize helps you to:

- develop an optimal planting density for your location
- evaluate current nutrient management practices
- determine a meaningful yield goal based on attainable yield
- estimate fertilizer NPK rates required for the selected yield goal
- translate fertilizer NPK rates into fertilizer sources
- develop an application strategy for fertilizers (right rate, right source, right location, right time), and
- compare the expected or actual benefit of current and improved practices.

To start, click a button

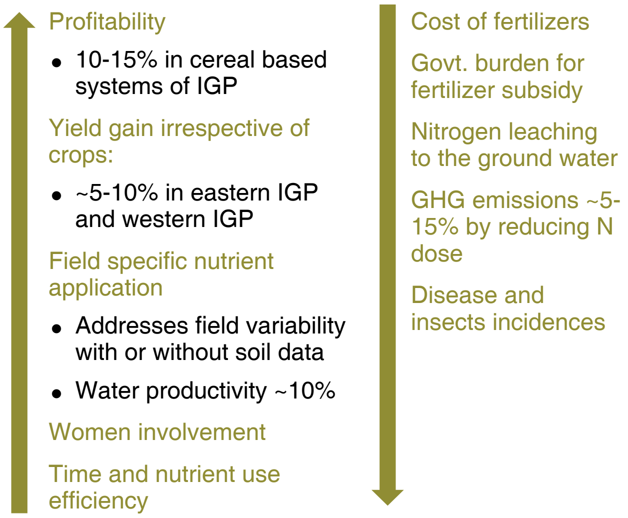
11.1 Background

India is the third largest producer and consumer of fertilizers in the world after the United States and China. Urea, DAP, MOP and other complexes are the major fertilizers used in agriculture crops to meet the crop nutrient requirement. The nutrient recommendation for cereal crops in South Asia 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. The approach of 'more inputs- more output' is now known to be ecologically intrusive, economically unsustainable and environmentally unsafe, and leads to sub-optimal factor productivities and yield levels that are difficult and expensive to maintain over time. Blanket fertilizer application, therefore, results into under-fertilization in some cases and over-fertilization in others. Although fertilizer consumption is increasing quantitatively, the corresponding yield increase per unit of nutrient has diminished over the years. Inappropriate and imbalanced use of nutrients has led to multiple nutrient deficiencies and low nutrient-use efficiency resulted in soil degradation. India is losing soil 30 to 40 times faster than its natural replenishment rate. Therefore, solution lies in part in having a precise, site-specific nutrient management approach that will build sustainable and profitable agriculture production. Nutrient expert (NE)E is a nutrient decision support software (DSS) that uses the principles of site-specific nutrient management (SSNM) and enables farm advisors to develop fertilizer recommendations tailored to a specific field or growing environment. The Nutrient Expert DSS modules for wheat and hybrid maize for South Asia were developed by IPNI and CIMMYT; validated in close partnership with National Agricultural Research System (NARS) and released in 2013 for public use.

11.2 About Technology

Nutrient Expert® is an easy-to-use, interactive computer based decision support tool that provides nutrient recommendation for individual farmers' individual fields with or without soil test data. NE takes into account the most important factors affecting nutrient management recommendations and uses a systematic approach of capturing information, which is important for developing a location-specific recommendation. It synthesized the on-farm research data into a simple delivery system that enables farmers to rapidly implement SSNM for their individual fields. The software estimates the nutrient requirement based on attainable yield by combining informations like fertilizer/manure applied, crop residue retained in the previous crop, crop growing conditions etc. with expected N, P and K responses in target fields to generate location-specific nutrient recommendations for crops (rice, wheat, maize etc.). The software also does a simple profit analysis comparing costs and benefits between farmers' current practice and recommended alternative practices. The algorithm for calculating fertilizer requirements was developed from on-farm research data and validated over 5 years of testing. The software is currently available without charge for wheat, rice & maize in South Asia (http://software.ipni.net/article/nutrient-expert).

11.3 Benefits of technology



Profitability
- 10-15% in cereal based systems of IGP

Yield gain irrespective of crops:
- ~5-10% in eastern IGP and western IGP

Field specific nutrient application
- Addresses field variability with or without soil data
- Water productivity ~10%

Women involvement

Time and nutrient use efficiency

Cost of fertilizers

Govt. burden for fertilizer subsidy

Nitrogen leaching to the ground water

GHG emissions ~5-15% by reducing N dose

Disease and insects incidences

11.4 Implementation domain

In the high-yielding rice-wheat production systems of western IGP, intensive tillage operations and blanket fertilizer recommendations have led to high production costs, decreased nutrient use efficiency, lower profits and significant environmental externalities. Therefore, IGP are the best sites to implement nutrient recommendations based on NE to reduce fertilizer costs and to increase input use efficiency in rice-wheat and maize-wheat system. The algorithms for NE is available for rice, wheat and maize so it can be implemented in theses crop area all over the South Asia.

11.5 Complementary practices

NE management practices considers economic, social, and environmental dimensions of fertilizer management and is essential to complement the sustainability of agricultural systems. The 4R- nutrient stewardship principles (right source; right rate; right time; and right place) complements these fertilizer application decisions to scientific principles and guides the application decisions specific to crops, soils and local site to increase the nutrient use efficiency. This technology can also be complemented with management practices related to tillage, residue management, crop establishment practices in general and fertilizer management in practices in particular.

11.6 Gender and Youth Dimension

Nutrient Expert provides opportunities for both youth and educated women. Women can play a role in decision making on input supplies to the crops as per the NE recommendation. The non-governmental organizations, farmers' and women's self-help groups can create a centre for calculating the exact dose of fertilizer based on the inputs given by the farmers. Gender-sensitive participatory approaches are used to ensure active participation and learning among women, who represent the majority of farmers involved. In the out-scaling of this technology youth played an important role because maximum youth having the laptops and smart phones. This type on new spicy technologies can attract both women and youth in agriculture.

11.7 Business case

This technology can create the new business opportunities for cooperative societies and local fertilizer suppliers through getting information from farmers which is required by NE and on the basis of that they can provide different type of fertilizer to farmers which is earlier limited to sell of urea only and some extent to DAP. NE can be used by decision makers to develop national agricultural strategies, or by agri-business providers to effectively develop markets in favor of prevailing cropping systems.

11.8 Statistics of adoption

This technology is being adopted by the farmers of IGP at demonstration level but it can out-scale not only in IGP but all the rice, wheat and maize growing areas of South Asia. Adoption of NE-based fertilizer management practices in all rice and wheat area in India and would translate into 13.92 million tonne (Mt) more grain production with 1.44 Mt less fertilizer N use and 5.34 47 Mt CO2e GHG reduction per year over current farmers' practice.

ADOPTION

Enabling factors	Reinforcing/Need factors
Crop lodging due to over dose of fertilizers in cereal crops	Capacity building/ Training schemes (e.g. vocational trainings) to create skilled personnel
Higher prices of fertilizers	Generate awareness among farmers
Community groups supporting purchase of NE tools and their availability in co-operative societies and FPOs	Uncontrollable variables (rainfall, planting date, temperature etc.) from planting to harvesting that adversely affect the relationships between estimate yield and potential yield.
Timely availability of full dose of N fertilizer in wheat crop in western IGP during urea shortages	Support to make decision support tools affordable for the small holders in the IGP
Feminization of agriculture complemented its adoption by women farmers	Capacity Building of female farmers of the women-friendly technology and tools can be developed accordingly for women farmers.

12 Green Seeker

12.1 Background

Traditionally, farmers in the Indo-Gangetic plains of South Asia and elsewhere apply nitrogen uniformly as a blanket application based on the University recommendation for most of the crops. Such broad-based 'blanket' recommendations of fertilizer Nitrogen (N) restrict efficient N use, and recovery of N fertilizer. Therefore, under and over application of N is a common phenomenon, which limits the crop yields in agriculture system. Current fertilizer N recommendations (amounts and timings) are based on large agro-ecological regions of rice and wheat growing tracts in IGP and does not account for spatial and temporal variability of the field. It is important to know about the amounts and variations in the indigenous N supply during crop season, to determine the optimal timing and amount of fertilizer N applications in any crops and cropping system. Since indigenous N supply is highly variable over time, in same as well as different fields, in any given agro ecological region it is not easy to precisely manage N requirements of the crop plants. Innovative fertilizer management practices aimed at managing N efficiently, must integrate both preventive and corrective strategies, to sustain the soil resource base and increase the profitability of irrigated rice and wheat crops grown in the IGP.

Picture 9. Practising Green Seeker in the field

12.2 About technology

Green Seeker is an integrated optical sensing and application system, that offers more efficient and precise way of instant fertilizer application. Green Seeker is an affordable and innovative diagnostic tool that can be used to assess the heath or vigor of a crop. Green Seeker is based on the measurements of reflectance in the red (defined by chlorophyll content) and near infrared (defined by living vegetation) region of the electro-magnetic spectrum for estimating N requirement of crops using early season estimates of N uptake and potential yield. In this technology the yield potential for a crop is identified using a vegetative index known as NDVI (Normalized Difference Vegetative Index), and an environmental factor. Nitrogen (N) is then recommended based on yield potential, and the responsiveness of the crop to additional nitrogen. Fertilizer N use efficiency can be improved through Site Specific Nutrient Management (SSNM) using Green Seeker, as it takes care of both spatial and temporal variability in soil N supply. Urea Calculator android app (available in English, Hindi and Punjabi language) on a smart phone or tablet are used to calculate N fertiliser application rates from crop readings taken with the Green Seeker.

12.3 Benefits

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Profitability
- 5-10% in cereal based systems of IGP

Yield gain irrespective of crops
- ~5% in eastern IGP and ~2% in western IGP

Field specific N application
- Addresses field variability

Women involvement

Time efficiency

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Cost of fertilizers

Govt. burden for fertilizer subsidy

Nitrogen leaching to the ground water

GHG emissions by reducing N dose

Disease and insect incidences

12.4 Implementation domain

In IGP of India, rice-wheat and maize-wheat cropping system occupy 10 Mha and ~2.0 Mha area respectively, which are biggest consumer of fertilizer urea. The area under conservation agriculture in these cropping systems are increasing, but overdose of chemical fertilizer (urea) is being applied by farmers, without considering the indigenous supply of nutrient through crop residue. The green seeker guided nitrogen recommendation can be implemented in these cropping systems to optimize the doses of the N fertilizers.

12.5 Complementary practices

Urea calculator app and N-enrich plot are very much required to complement the actual dose of N application at right time. For initial doses of N, scheduling and amount of N fertilizer should be complemented to target the last dose of urea on green seeker readings basis. Apart from this, the green seeker guided nitrogen management practices, are complement in zero till system coupled with precise water management technologies, for harnessing the best benefits. Good agronomic, soil and crop management practices always have synergistic effect on saving of precious inputs.

12.6 Gender and Youth Dimension

Realization of the full potential of this technology, however, will require significant improvement in the supporting infrastructure and in capacity building particularly for small women farmers, effective use of information and accurate dissemination. Women in the male-headed households also feel that their participation in family agriculture has improved with increased flow of information and their access & trainings of new technologies. In the scaling out of this technology, youth played an important role by creating the awareness among young farmers and creating new business opportunities.

12.7 Business case

This technology can create new business opportunities for service providers, custom hiring centres and village co-operative societies, by giving these tools to farmers on the rent. Progressive farmers can provide services to others farmers in the society. Site specific nutrient management with other precise management technology, and input uses in cereal crops is a good opportunity for them.

12.8 Statistics of adoption

Green seeker, the site specific nutrient management tool, can have wider applicability in rice, wheat and maize growing areas of South Asia. It is suitable for all IGP ~14 Mha and areas where important cereal crops are grown. This technology has gained popularity in NW IGP of India, after intensive farmers field demonstration trials by National Agricultural Research and Extension Systems (NARES), State Agricultural University and International organization (CIMMYT).

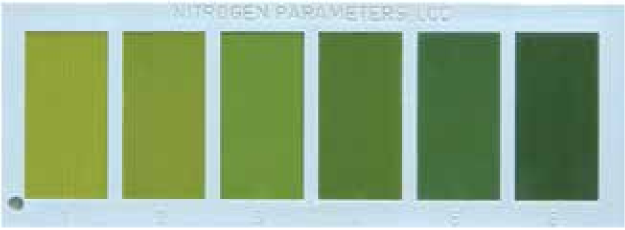
ADOPTION

Enabling factors	Reinforcing/Need factors
Crop lodging due to over dose of N fertilizer in rice and wheat crop	Capacity building/ Training schemes (e.g. vocational trainings) to create skilled personnel
Higher prices of N fertilizers	Generate awareness among farmers
Community groups supporting purchase of equipment and their availability in co-operative societies and FPOs	Uncontrollable variables (rainfall, planting date, temperature etc.) from planting to harvesting that adversely affect the relationships between in-season estimate of yield (INSEY) and yield potential (YPO).
Timely availability of full dose of N fertilizer in wheat crop in western IGP during urea shortages	Support to make agricultural equipments affordable for the small holders in the IGP
Feminization of agriculture complemented its adoption by women farmers	Capacity Building of female farmers of the women-friendly technology and tools can be developed accordingly for women farmers.

13 Leaf Colour Chart

13.1 Background

In South Asia, 90 percent of smallholder farmers are not accessible to soil testing services. In major cereal dominant cropping systems, excessive, non-judicious and imbalanced use of chemical fertilizers can result in the deterioration of soil quality and its factor productivity. Also, especially N fertilizer is applied by farmers inefficiently in IGP leading to sub-optimal yields. Blanket fertilizer recommendations given for a large area does not match the nutrient requirement of crop under the changing agriculture scenario. As demand for fertilizers rises, it is important to ensure that they are applied at the right amounts, at the right time, and in the right locations to enhance productivity and crop yields. The Leaf Color Chart (LCC) is inexpensive and simple alternative to Soil Plant Analysis Development (SPAD) and can quickly and reliably monitor relative greenness of leaf as an indicator of leaf N status.



Picture 10. Demonstration of Leaf Colour Chart

13.2 About technology/practice

Leaf Colour Chart (LCC) is a tool to rapidly assess leaf N status, and thereby guide the application of fertilizer N to maintain optimal leaf N content, which is vital for achieving higher crop yields. It is an inexpensive and easy-to-use tool consisting of four colour-shades from yellowish green to dark green. The middle part of topmost fully expanded leaf is compared with the colour panels of the LCC. This tool have provided an excellent opportunity in terms of developing real-time N management strategies for rice, but it does not take into account photosynthetic rates or the biomass production, and expected yields for working out fertilizer N requirements.

13.3 Benefits of technology

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Improved productivity and quality
- Tailored N supply

Precise N application
- Spatial and temporal variability

Yield gains
- 2-5% in IGP in cereal crops

Women inclusiveness
- Easy to use

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Nitrogen stress in crop

Nitrogen leaching to groundwater

GHG Emissions
- Reduced N dose

Subsidy burden on government
- Fertilizer cost

Disease and insect incidences

13.4 Implementation domain

The technique is more relevant for cereal crops such as wheat, rice, maize and sugarcane growing tracts of South Asia. In India, rice and wheat are grown in ~42 and 27 Mha area. The LCC guided nitrogen recommendations can be implemented in cereal based cropping systems, to optimize the doses of the N fertilizers, and to overcome environmental externalities along with decreased Nutrient Use Efficiency (NUE) and farm profitability.

13.5 Complementary practices

Good agronomic, soil and crop management practices always complement to precise site specific N management practices. Right dose and timely application of fertilizers is the key for higher farm profitability. Technical know-how on color strips and dose of N at every color strips is of great importance to apply as per demand of the crop. Apart from this, the LCC guided nitrogen management practices are complement to tillage and crop establishment practices.

13.6 Gender and Youth Dimension

LCC is easy to use and women friendly tool for N management in cereal crops. This type of instrument invokes interest among women and youth farmers, not previously engaged in agriculture business/ practices. Women farmers should be promoted by giving incentives for adopting new tools and techniques to enhance their role in society. LCC can reduce the drudgery of women by applying the fertilizer as per the need of crops rather than applying excessive fertilizer based on blanket recommendation.

13.7 Business case

This technology can create new business opportunities for service providers, custom hiring centres and village co-operative societies through providing agro-advisory and capacity development/training of the producers as well as to the manufacturers of the LCC.

13.8 Statistics of adoption

The LCC is a precise N management device and it has wider scalability in rice, wheat, maize and sugarcane crops. It is suitable for all across the agro-ecologies of South Asia.

ADOPTION

Enabling factors	Reinforcing/Need factors
Higher prices and low subsidy of urea	More systematic training schemes (e.g. vocational training) at village level
Crop lodging due to excessive dose of N and under dose of potassium in rice-wheat based systems	Awareness among farmers regarding LCC
LCC is cheap, easily available and less technical	Address social barriers for women farmers to adopt LCC guided N application

14 Subsurface Drip Irrigation (SDI) Technology

14.1 Background

Rice-wheat is highly productive and dominant cereal based system in South Asia and furnishes the staple grain supply for a huge fraction of the world's population and is necessary for global food security. The ubiquitous practice of annual rice-wheat cropping comes with a huge cost on natural resources; especially on ground water table. Farmers tend to believe that rice prefers continuous pond water conditions during the growing season for maximum yields. Such a practice results in very low irrigation water use efficiency.

Picture 11. Subsurface Drip Irrigation (SDI) Technology

The extended pumping of groundwater over the years to meet the immense requirement for water by transplanted rice has emerged in a radical drop (~91 cm year-1) in groundwater tables in NW India contributing to the possible cutback in water availability for future cultivation. Due to over-exploitation of groundwater in NW- IGP, there is an immense pressure on the agricultural sector to reduce its water consumption. Therefore, use of micro-irrigation systems (sprinkler, surface drip and sub-surface drip) is one option in RW system except its diversification with other crops like maize, soybean, pigeonpea etc. Recently, the introduction of smart water management technology (Subsurface drip irrigation) was developed for sustainable use of water and nutrients in different crops.

14.2 About technology

Micro-irrigation is a co-ordinated and controlled water management system where water is made to flow under pressure through a network of pipes of varying diameters, the main-line, the sub-main lines and the lateral lines with appropriately placed emitters along the length of the latter through which water is discharged to the root zone. Irrigation technique in which narrow tubes delivers water directly through emitters to the base of the plant near soil surface called surface drip irrigation and / or ~15 cm below the soil surface near root zone called Subsurface Drip Irrigation (SDI) and spraying water in different directions at 360o through water jets called Sprinkler Irrigation. Micro-irrigation systems are capable of applying small amounts of water and N directly to the plant root zone, where the water and N is needed, and these small amounts can be applied frequently to maintain favourable moisture conditions, and nutrient availability in the root zone. The drip laterals are buried with tractor mounted sub surface drip laying machine to a desired depth depending on soil, crop and tillage practices.

SDI technology is used to remove the hurdles of surface drip irrigation such as i) disrupted mechanical inter-culture operations, ii) after harvesting of crops lateral take it out from the field, and after sowing again put it back, this is a laborious job which incurs an extra cost, and iii) life of laterals gets reduced due to the direct contact from sun light, strong winds, human activities etc.

14.3 Benefits of technology

Fertigation

- Saves 20-25% of nitrogenous fertilizer

Productivity

- 5-15% in rice/maize-wheat system

Profitablity

- USD 100-150/ha in rice-wheat system
- USD 50-100/ha in maize-wheat system

Water use efficiency

- Systems' intensification
- Opportunities of adjusting the third crop in rice/maize-wheat system

Irrigation water

- ~50% in cereal (rice, wheat and maize) crops

Nitrogen leaching and volatilization

Cost of cultivation in long run

- Enhanced durability of the system
- increased life expectancy of laterals

Occurrences of soil borne diseases

Weed infestations

Salinity problems in the root zone under salt affected areas

14.4 Implementation domain

The SDI can be implemented anywhere in the world for better crop production where water availability is limited for agriculture purposes. The SDI can be implemented in all regions, where deep tillage (>15cm) are not performed, and it is more popular under zero till practices. It is practically feasible with shallow tillage operation (<10 cm deep) in all types of soil across the different agro-ecologies. In whole IGP where water and energy crisis has already taken place SDI can be a viable option for producing more grain with less (~50%) water and energy. This system also promotes No-till farming so ultimately in this region the harm full effect of tillage on soil can be avoided. The SDI have huge potential in both arid and semi-arid areas of South Asia where water is a scare resource, high water evaporative demand and limited water supply for crop production.

14.5 Complementary practices

The SDI technology can be complemented with zero-tillage, solar driven irrigation pumps, irrigation scheduling equipment and with irrigation water application practices. The SDI system is well suited with zero tillage based cropping systems, which enables the wider applicability of the system. As a fact that in SDI less water is required per irrigation which enables the use of green energy through solar powered operated based ground water pumping. The irrigation scheduling must be followed through appropriate soil moisture sensor in SDI to identify the actual time of irrigation.

14.6 Gender and Youth Dimension

The SDI system under ZT management definitely attracts women for farming due to the fact that it is less laborious and free from drudgery. The SDI reduces the women farmers' drudgery, as in most of the arid and semi-arid areas irrigation water is applied by them through SDI technology during the crop season. Youth today have more exposure to technology, than previous generations and can start small business and act as entrepreneurs in this new area.

ADOPTION

Enabling factors	Reinforcing/Need factors
Promotion of zero tillage in the rice/maize-wheat system in the IGP	Need for skilled machinery operator for installing the drip line in the field.
Policy support in terms of giving subsidy (up to 90%) directly to farmers' for drip irrigation	Training for depth and lateral spacing for drip under different soils and cropping systems
Crop diversification and agriculture technology mission for sustainable agriculture (ATMSA) for effective and sustainable use of natural resources for crop production	Making availability of sub surface drip laying machine at custom hiring centre at village level
'More Crop per Drop' policy initiatives by the central and respective state governments through different schemes	Imparting technical knowledge to farmers through various agencies involved with SDI technology

14.7 Business case

The machinery required for the placement of the drip line, will create additional business opportunity for the custom hiring centres. With the implementation of SDI, the liquid fertilizer industry will get the new business opportunities, all across the domains.

14.8 Statistics of adoption

Among the micro-irrigation methods, drip irrigation is being practiced over 3 percent of total net cultivable area of the country under different agriculture and horticulture crops. However the adoption of SDI was earlier limited to sugarcane in central and south India. But now it's being popularized among the farmers of Punjab after the complete package of practices on SDI in conservation agriculture based rice-wheat and maize-wheat system released by State Agricultural University. For 2019, Government of India has set a target of irrigating 0.15 Mha through micro-irrigation in Punjab State, in all the crops (vegetable, fruits and others). In this, 900 acres will have surface –based drip irrigation and remaining (100 acres) under SDI system in maize crop.

15 Tensiometer/ Water Meters

15.1 Background

In south Asia blanket application of irrigation water is followed through flood irrigation in most of the crops without considering plant, soil and climatic factors. More than 70% of good quality water is used for agriculture purposes in South Asia. But in the current scenario of global warming, the irrigation water availability is decreasing and that foster the scientists, bureaucrats, policy makers to think on. To increase the irrigation water use efficiency and its productivity, number of simulations based on plant, soil and climatic factors has been developed, but all are out of reach due to poor knowledge of farmers of South Asia. For that a hand held instrument called tensiometer, easy to operate has been developed, for scheduling the irrigation water in crops. Irrigation scheduling on the basis of soil matric potential to rice, wheat and maize has been shown to save precious irrigation water and increase water productivity compared to conventional irrigation practices in IGP.

Picture 12. Tensiometer/Water Meter in the field

15.2 About technology/practice

A tensiometer is a device for measuring the soil matric potential (SMP; kPa) or soil moisture tension. It consists of a porous cup and connected to a vacuum gauge through a water-filled tube. The porous cup is placed in good contact with the surrounding soil at the depth of measurement ranging from 15-45 cm depth in most of the cereal crops. When the matric potential of the soil is lower (more negative) than inside the tensiometer, water moves from the tensiometer along a potential energy gradient to the soil through the saturated porous cup, thereby creating suction sensed by the gauge. Water flow into the soil continues until equilibrium is reached and the suction inside the tensiometer equals the soil matric potential. When the soil is wetted, flow may occur in the reverse direction, i.e. soil water enters the tensiometer until a new equilibrium is attained. In ZT rice plots, the first 2-3 irrigations were applied at 3-4 days intervals and thereafter at soil matric potential of −20 kPa. Maize and wheat irrigations based on SMP, were applied at -50 to -60 and -40 to -50 kPa SMP, respectively and depend on the soil type.

15.3 Benefits of technology

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Timely field irrigations & Water table level

Hydraulic gradient is also determined from measurements using two tensiometers.

Profitability & Water use efficiency

- Timely water availability to plants

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Irrigation water

- 10-20% in cereal crops

Cost of cultivation

GHG emission

Reducing energy use in pumping the ground Water for irrigation. GHG Emissions

Nutrient use efficiency

Suitable moisture under crop root zone Water use and weed control efficiency

Cultivable area by 3 to 5% approx

Fertilizer use efficiency

Crop establishment

Farm productivity by ~5-20% depending upon soil type and cropping system

Farm profitability by USD 150-200/ha in rice-wheat system

Duration of irrigation. Patchy growth under salt affected soils. Irrigation water by 20-30% in rice-wheat system. Irrigation duration

- 10-12 h/ha in wheat season
- 47-69 h/ha in rice season

15.4 Implementation domain

Tensiometer can be used anywhere in any crop, but its soil matric potential reading varies from soil type and crops. It works very well with -90kPa in any agro-ecosystem. It should be used in high water requiring crops like rice, so that ample irrigation water can be saved for other crops and used, as rice requires almost 200 cm of irrigation water with blanket application/ farmers' practice in South Asia.

15.5 Complementary practices

Tillage and crop establishment practices in rice-wheat system with tensiometer based irrigation can generate synergy to optimize the use of resources. Crop management practices should also be applied together for higher input, water, and nutrient use efficiencies.

15.6 Gender and Youth Dimension

Tensiometer is a gender-neutral device, and it can be used by both men and women for deciding the time of irrigation in crops under irrigated ecosystem. Small and smart devices attract youth in agriculture to make it different from the conventional farmers. These can make the big difference in increasing the productivity, by applying irrigation water at right time, right amount and at right place. It reduces the drudgery of women and saves money, by checking the unnecessary irrigation to crops.

15.7 Business case

The tensiometer for timely application of irrigation water can create small scale manufacturing units in the nearby towns. Imparting technical knowledge on tensiometer by FPOs and other co-operatives will boost the other precise irrigation water application measures like drip irrigation, sprinkler irrigation, bed and furrow irrigation etc.

15.8 Statistics of adoption

Tensiometer based irrigation can be adopted in all the crops. It is mostly used in irrigated ecosystem, where irrigation facilities are available. The cereal crops of IGP are best fit case for its implementation, which covers almost 10 Mha in India and 13.6 Mha in South Asia.

ADOPTION

Enabling factors	Reinforcing/Need factors
Government focus on precise water management under crops to achieve mission of 'More Crop per Drop'	Improved knowledge on soil matric potential values of different crops under varied soil conditions. Availability of good quality tensiometer
Development of farmer' friendly tensiometer by putting the color strips instead of gauge	Capacity building programmes/trainings on technical know-how of the extension workers and at village level to increase awareness of water use efficiency
Providing information on its use in Kisan Mela and at ATIC (Agriculture Technology Information Centre) throughout the year	Incentives for applying irrigation based on the tensiometer values to the farmers. Better convergence between irrigation systems and time of irrigation

16 Solar Pumps

16.1 Background

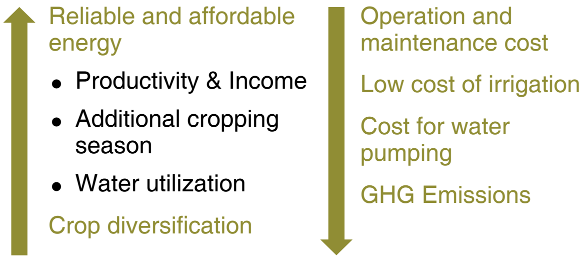
Due to shortage of canal water supplies, use of groundwater for irrigation approached to 67% that caused rapid expansion of tube well development. Pumping of groundwater for irrigation through tube well is totally dependent on electric and diesel sources of energy. Therefore, the agricultural sector in India is one of the major consumers of both diesel and electricity. Out of nearly 30 million irrigation pumps in the country, 70% are run on grid electricity and 30% are powered by diesel. In the various studies, it is reported that roughly 6% of India's total GHG emissions come from groundwater pumping for irrigation which account almost 62 billion kilogram equivalent of carbon dioxide (kg CO2e). In the current context of climate change, solar energy (renewable source) is the most viable alternate energy option to run the tube well pumps.

Picture13. Solar Pumps in the field

16.2 About technology

A solar-powered pump is a pump running on electricity generated by photovoltaic panels or the radiated thermal energy available from collected sunlight, as opposed to grid electricity or diesel run water pumps. The operation of solar powered pumps is more economical, mainly due to the lower operational and maintenance costs, and has less environmental impact than pumps powered by an internal combustion engine (ICE). Solar pumps are useful where grid electricity is unavailable and alternative sources do not provide sufficient energy, to meet the pumping requirement of tube wells. The solar power operated tube well compliments the drip irrigation as this method requires less water per irrigation and is easily met by solar system.

16.3 Benefits of technology



Reliable and affordable energy

- Productivity & Income
- Additional cropping season
- Water utilization

Crop diversification

Operation and maintenance cost

Low cost of irrigation

Cost for water pumping

GHG Emissions

16.4 Implementation domain

- Solar pump works well in dry land (water scarcity region) to irrigated (ample supply of irrigation water) ecologies throughout the South Asia.
- These solar powered pumps work efficiently at relatively moderate ground water level, where low head favours high discharge of tube wells.
- The possible water sources for the solar systems are pits; open dug wells, medium tube wells, diggi, tanks, farm ponds and surface water from canals and rivers.
- The solar powered tube wells with drip irrigation can be implemented in diversified cropping systems to minimize water requirement and optimal utilization of water in crops, vegetables and in fruit trees.
- With the increasing energy prices of diesel and electricity, this technology will be adopted at wider scale.

16.5 Complementary practices

Introduction of solar pumps might be coupled with varied irrigation management based measures to improve the efficiency of irrigation and on-farm water management methods (e.g. drip or sprinkler irrigation, rainwater harvesting) or agricultural practices (e.g. change of crops, conservation agriculture etc.) to increase overall efficiency and viability of the system. Micro-irrigation system linked with solar tube well is providing a long term solution for water and energy crises, in the south Asian agriculture paradigms. The water requirement of crops and cropping system in a given area is directly correlated with solar pump units and discharge rate. At farm level, an integrated approach to water, soil, nutrient and energy management complements to resource use efficiency and systems' sustainability.

16.6 Gender and Youth Dimension

Solar tube well (with low-pressure drip irrigation), were installed in vegetable fields and even in cereal crops, that were formerly irrigated by flood method which is laborious and time consuming. This allowed the women farmers to become net producers of vegetables, and grain to generate income from market sales and this substantially increased their household nutrition intake and food security. Being the case in the deployment of many rural energy solutions, gender characteristics play an important role in terms of energy decision-making. In the scaling out of this technology youth played an important role by creating the awareness among young farmers. The selling, maintenance and repair of solar pumps can be a start-up opportunity for the village level youth and this technology will also create the business opportunities and rural employment through mobile solar based irrigation systems. Solar pumps are eco-friendly and gender neutral and it gives equal opportunities for both youth and women in promotion of individual solar pumps, community pumps etc.

16.7 Business case

Solar energy can become a source of income generation especially for the small holders.
For mono crops irrigation for 70 to 120 days is necessary. For two cropping seasons per year approximately 200 days are necessary. This means that there are times when energy is produced but not needed for irrigation and this energy may feedback into the grids for selling and future use.

16.8 Statistics

It has been reported that the solar water pumping systems market in the country has recorded a substantial growth in the last few years. Indeed, the support from the Government of India to encourage use of new and renewable energy has created a positive effect on the market. In 2014-15 the total number of solar pump sets in India were around 11,626 and which is increased to 1,77,011 in 2017-18.

ADOPTION

Enabling factors	Reinforcing/Need factors
Policy support in terms of subsidy for solar tube well and micro-irrigation system (drip and sprinkler)	Support to farmers to meet high initial investment costs for solar pumps and provide systematic training schemes (e.g. vocational training) to have access of skilled personnel
Department of soil and water conservation, Punjab launched a scheme for "Matching irrigation water availability and demand for improved productivity through efficient on-farm water management" to promote the micro-irrigation, solar pump sets and on-farm water storage tanks	Existing energy subsidies for fossil fuels and electricity that distort market; legislation and regulation of energy and agricultural markets may hinder the uptake and scaling-up of solar energy systems
Promoting solar tube well installation in the framework of national action plans regarding climate change, as a way to reduce emissions from agriculture	Improved knowledge on Solar tube well management that can lead to waste water use, over-abstraction of groundwater, and low field application. Improve targeting of the prevailing subsidy programmes for the promotion of 'More Crop per Drop'
Ease of banking and loan disbursal process for farmers and developing Solar Powered Irrigation System (SPIS) financing products	Encourage SPIS deployment under enterprise model (water/irrigation as-a-service)
	Convergence of promotion schemes (subsidies, incentives, input supply) for agriculture need to be strategically designed to support change in water management, agricultural practices and even gender equity

17 Integrated Farming System

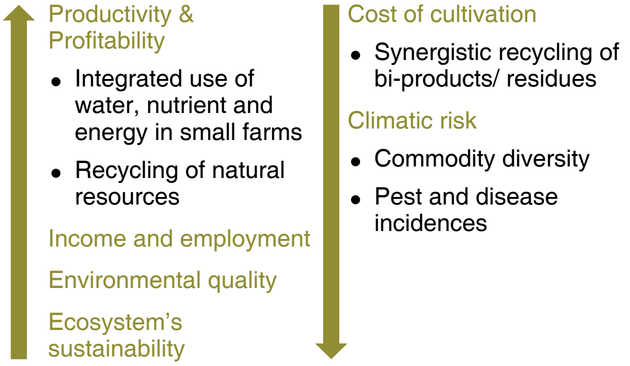
17.1 Background

Continuous cultivation of rice-wheat cropping system for over four decades in IGP has set in the processes of degradation, in the natural resources and biodiversity. Depletion of underground water, declining fertility status associated with multiple nutrient deficiencies, increased concentration of Green-House Gases in the atmosphere, demands sustainability of system. Nearly 50 percent farmers in India cultivate less than one ha land holding, and ~70% farmers are small land holders (<2 ha). A farmer with a family of 5-6 persons and almost equal number of cattle is unable to cope-up with his daily expenditure from rice-wheat system. Integrated farming system with multi-components, may pave the way for realizing increased productivity and profitability.

Picture 14. Practice of Farming Systems at CSSRI experimental farm

17.2 About technology/practice

Farming system is a mix of farm enterprises such as crop, livestock, aquaculture, agro forestry, and fruit crops to which farm family allocates its resources based on bio-physical and socio-economic conditions for optimum utilization of resources. Instead of crop components, the farmers may choose the subsidiary components like dairy, fishery, poultry, duckery, piggery, bee-keeping, mushroom production, agroforestry and energy plantation etc. based on their resources and household needs. Understanding the diversity of farming systems is required to delimit the recommendation domains of different farming components and management portfolios options relevant to diverse farm typologies.



Productivity & Profitability

- Integrated use of water, nutrient and energy in small farms
- Recycling of natural resources

Income and employment

Environmental quality

Ecosystem's sustainability

Cost of cultivation

- Synergistic recycling of bi-products/ residues

Climatic risk

- Commodity diversity
- Pest and disease incidences

17.3 Implementation domain

- Regions across South Asia having majority farmers as marginal (<1 ha land holding) and smallholders (<2 ha land holding) engaged in agriculture for sustaining their livelihood.
- Bio-physical resources, economic condition and social settings define combination of farm enterprises.
- Both irrigated and rainfed ecologies to break the autonomy of monotonous cropping systems.
- It is not prescriptive but is a dynamic concept, and it must have the flexibility to be relevant on any farm, in any conditions, and it must always be receptive to change and technological developments in the domain.

17.4 Complementary practices

Farming System is a farm management approach that combines the ecological care of diverse and healthy environment with the economic demands of agriculture to ensure continuous supply of wholesome affordable food. Therefore, it is complemented by all the resources, technologies and knowledge used for crop and animal production throughout the year. The by-product of one component may be used for the productive purposes in another component. All the agriculture activities are inter-related with the interaction of atmosphere. Farming system interacts adequately with environment without dislocating the ecological and socio-economic balance on one hand, and attempts to meet the farmer's requirement to attain the national goals on the other.

17.5 Gender and Youth Dimension

Farming system approach opens the plethora of opportunities for social inclusion. It empowers both youth and women by harnessing their potential like crop husbandry for youth and animal husbandry for women. Women may also have better options for horticulture/vegetable cultivation to improve the farm profitability and to get involved in crops value addition and also ensured household nutritional security by taking initiatives like bee keeping, mushroom cultivation, baby corn, vegetable, fruits etc.

17.6 Business case

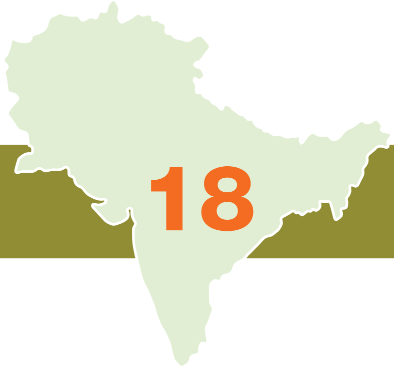
Farming system creates the business for small scale industries at village level on dairy, poultry, plywood, bee keeping, machinery etc. It promotes the start-up processing industries related to crops and animals in the IGP. It creates avenues for new Micro, Small and Medium Enterprises (MSME), industrial growth in the villages for drying, processing and value addition of high value crops. Farming system creates the business for service providers, custom hiring services, FPOs, co-operative societies, local service providers on different aspect of farming system.

17.7 Statistics of adoption

Farming system approach prevails all over the world, but it is more prevalent under South Asia because of significant (>50%) marginal and small land holders. It is adopted in almost 70% of total cultivated area (143 M ha) in India. Around 70 million farmers are adopting farming system approach instead of cropping system approach. With the increase in human population, the area under integrated farming system is required to expand to approx. 100 million farmers.

ADOPTION

Enabling factors	Reinforcing/Need factors
Integration of farming system components with many of the governmental scheme e.g. RKVY sub scheme RADP, MNREGA, Food Security Mission, National Horticulture Mission, Watershed projects etc. besides rural developmental schemes, other governmental programmes related to fisheries, poultry, non-conventional energy, rural electrification, rural sanitation etc.	Lack of improved knowledge on different components of farming system
Subsidy on most of its components ranging from 25-75%.	Market development and linkages for commodities basket
Minimize the adverse impact of possible crop failure due to climatic hazards.	Technical know-how on different components of farming system
Marginal and small land holdings favours farming system approach	Attracting large farmers towards farming system
Reduced market dependence for household food, feed and nutritional requirement	



18 Conclusions and Way Forward

South Asia is not only most populous but also a highly vulnerable regions of the world facing challenges of natural resource degradation with projected serious implications of climate change on the future food security. It is a paradox that though the region enjoys high economic growth, at the same time suffers from extreme poverty, undernourishment, and the deterioration of its natural resources. The natural resources in the region specially under intensive cereal-based systems in, '*The Green Revolution Corridors*' are severely constrained due to mounting pressure to produce more food for growing population. Under such scenario, the classical conventional farming practices are neither economical nor sustainable.

Business-as-usual scenarios of population growth and food consumption patterns indicate that agricultural production will need to increase by 70 percent by 2050 to meet global demand for food. Thus, climate change could result in the increased demand for irrigation water, further aggravating resource (water, nutrients, energy) scarcity. The impacts of climate change will reduce productivity and lead to greater instability in production in the agricultural sector (crop and livestock production, fisheries and forestry) in communities that already have high levels of food insecurity and environmental degradation and limited options for coping with adverse weather conditions. In the region, the inefficient use and mismanagement of production resources, especially land, water, energy and agro-chemicals, has vastly impacted the health of the natural resource base and contributing to global warming led climatic variability.

To respond the challenges of climate change, several climate-smart agriculture (CSA) practices has been developed, refined and tested by several research organizations and farmers which have demonstrated improved productivity, resilience and adaptive capacity for different commodities and agro-ecological zones within the region. However, due to knowledge gaps and piecemeal information to the extension agents, policy planner and farmers, the perceptions on climate vulnerability and responses of the CSA practices vary with bio-physical and socio-economic diversity of farm households. The lack of integration of bio-physical and socio-economic knowledge in technology targeting limits the large-scale adoption by diversity of farmers specially marginalized and women farmers. Therefore, this compendium on key climate smart agriculture (CSA) practices in intensive cereal-based systems will serve as 'one-stop-shop' for the extension agents and planners to help them in targeting portfolios of CSA practices under diversity of farming practices for improved adaptive capacity of farming community, ensuring food security while minimizing agriculture's environmental footprints.

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