BISA Report Series 1

Major Accomplishments 2012 - 2014

BISA Borlaug Institute for South Asia
New Delhi

Citation: Borlaug Institute for South Asia. 2015. *Major Accomplishments 2012-2014*. BISA Report Series 1, New Delhi, India: Borlaug Institute for South Asia. **38 p.**

The Initial support from CIMMYT, Mexico, the Government of India, Indian Council of Agricultural Research and the State Governments of Bihar, Madhya Pradesh and Punjab provided the ground work for establishment of the Borlaug Institute for South Asia on October 5, 2011. The strategic ecoregional research initiatives with financial support of the ICAR/DARE, Government of India and from the convening centre CIMMYT has gradually helped BISA in developing a dynamic agenda of genetic enhancement based resource conservation technologies appropriate to South Asia.

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BISA Executive Committee

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Preface

Launched on October 05, 2011 with three farms at Ladhowal in Ludhiana, Manegaon in Jabalpur and Pusa in Samastipur, the Borlaug Institute for South Asia (BISA) has come of age. Thanks to the visionary leaderships of CIMMYT and ICAR, and the dedication of BISA staff, the institute has made steady progress in infrastructure development conducive for good research on these farms.

On my joining BISA in August 2014, I was given to understand by many peers that BISA was moving at a snail's pace in terms of R4D and development of the infrastructure for conducting strategic and other meaningful research. Some of them believed that BISA was using its three large farms mainly for seed production. As a new comer to BISA family, I too struggled with this perspective, more influenced by others' opinions than the facts on the ground. Visits to the centres helped me change my understanding of the BISA developments.

The three research centres of BISA at Ladhowal, Manegaon and Pusa are very different from each other in terms of natural resource endowments of local farmers, soils, agro-ecology and production system constraints and strategic entry points for resolution of the NRM problems. Research has shown that the chosen cropping systems have responded very favourably to soil and crop management practices developed and tested on conservation agriculture platforms. BISA centres are today the flag bearers for conservation agriculture. Research at the BISA centres has addressed the critical issues of suitable implements for conservation agriculture, innovating on water-wise technologies, climate change, greenhouse gas emissions as well as sustainable intensification, and contributed to the technical knowhow for reducing the acreage of *'Kharif Fallows'* in the Vertisol belt of Central Plateau region. The strategic genomic research at BISA centres has pointed out that the yearly variations in wheat production can be minimised by developing weakly vernalised wheat cultivars for early sowing. Our research efforts have exploded the myth that 'SRI-SWI' is more profitable. I am glad that BISA has already generated research products and technical know-how that are being exchanged freely with researchers, extension agents and farmers. The technical contents presented in this document will confirm that BISA has been '*seeding innovations and nourishing hopes*' for a better tomorrow.

I express my sincere gratitude to Dr Thomas A. Lumpkin, Director General, CIMMYT, Mexico and Dr S. Ayyappan, Secretary, Department of Agricultural Research and Education (DARE) & Director General, Indian Council of Agricultural Research (ICAR), New Delhi for making the BISA dream a reality. Thanks are also due to the Governments of Bihar, Madhya Pradesh and Punjab for helping BISA live up to the expectations of the people. I thank and compliment all, whose love for the legacy of Dr Norman E. Borlaug, helped BISA reach this stage.

January 03, 2015
New Delhi

Hari Shanker Gupta
Director General

1. Introduction

The Government of India (GOI) and the CIMMYT signed an agreement on October 5, 2011 to set up a new research institute named after the renowned agricultural scientist and Nobel Laureate, Dr. Norman E. Borlaug. The new institute known as Borlaug Institute for South Asia (BISA) has three Regional Research Centres located at Ladhowal (Ludhiana, Punjab), Pusa (Samastipur, Bihar) and Manegaon (Jabalpur, Madhya Pradesh). These centres are located in 3 agro-ecologically different regions, namely, the semi-arid northwest Indo-Gangetic plains in Ludhiana (Punjab), the sub-humid middle Gangetic plains of Samastipur, Bihar and the humid central plateau of Jabalpur (Madhya Pradesh). The BISA research centre at Ladhowal is located on the bank of Sutlej River at 30°59'28.74" N latitude and 75°44'10.87" E longitude at an elevation of 229 m. The research Centre at Manegaon is located between 23°13'13.45 and 23°14'37.21" N latitude and between 80°04'2.77" and 80°04'59.64" E longitude at an elevation of 407 m above mean sea level. The research Centre at Pusa is located between 25°57'08" and 25°57' 44" N latitude and between 85°40'13" and 85°40'57" E longitude, and the soils belong to Dholi soil series, a member of the fine loamy, mixed, hyperthermic (calcareous) family of *Fluventic Haplustepts*. Typically soils of the Dholi series are very calcareous, deep, and moderately well drained on very gently sloping recent alluvial plain. The annual rainfall at Ladhowal, Manegaon and Pusa is about 680, 1700 and 1200 mm respectively. Whereas soils of the Ladhowal and Pusa centres are of alluvial nature, soils of Manegaon belong to deep black cotton soils (Vertisols) of the Central Plateau derived from basaltic rocks.

The BISA farm at Ladhowal is representative of the agro-ecological situation of Haryana, western UP and the two Punjabs on the Indian and Pakistan sides. The BISA farm at Pusa represents large tracts of sub-Himalayan *Tarai* in India and Nepal, eastern UP, Bihar, West Bengal and Bangladesh. Agricultural situations of the Manegaon farm are typical of the large tracts of the Central Plateau region of India and the summers of the Central Asian republics.

South Asia is inhabited by 50% of the world's poor, and 75% of the South Asia's poor live in rural areas. They consume 25 and 101 million tons of maize and wheat, respectively. Climate change and terminal heat stress are expected to result in 6-23% losses in maize and 25-30% losses in wheat in South Asia. Under these pressing circumstances, BISA is expected to serves as an agricultural research hub for the region and will strive to:

- Ensure access to the latest in research and technologies that are currently not available in the region
- Strategize research aimed at doubling food production in South Asia while using less water, land and energy
- Strengthen cutting-edge research that validates and tests new technologies to significantly increase yield potential
- Develop technologies for higher productivity in rice, maize and wheat based farming systems
- Design research outputs targeted to small and marginal farmers across the region
- Build on CIMMYT's vast germplasm resources, and make research products and know-how developed by BISA freely available to stakeholders
- Create a new generation of scientists to work with new technologies through training programs that will retain them in South Asia
- Enable researchers to pursue multiple strategies and research possibilities while simultaneously allowing for more meaningful collaboration with national institutions
- Build a forum with partners from all sectors – research centres, governments, science community, businesses and farmers – to

transform farmers' lives and improve food security in the region

- Develop a policy environment that embraces new technologies and encourages investments in agricultural research
- Develop and utilize BISA as a regional platform that focuses on agricultural research in the whole of South Asia

During the last three years, the dedicated staff of BISA, extremely limited in number, toiled hard to make farm lay-outs for research at all three Centres, and initiated focused strategic research. This compilation provides an idea of how BISA is advancing in science to offer solutions to the second generation problems of the first Green Revolution (GR). It also looks at the possibility for a new revolution in lesser endowed regions bypassed by the first GR in India.

2. Sustainable Intensification for Enhancing System Productivity

Sustainable intensification is a process wherein agricultural yields are increased without adverse impact on the environment and without conversion of additional non-agricultural lands to agricultural lands. Agricultural intensification can be accomplished in one of the three ways:

- Increasing yields per hectare (e.g., through timely sowing and with increased inputs of water and fertilizer nutrients),
- Increasing cropping intensity per unit of land (e.g., use of short season crop cultivars, relay and mixed cropping so as to grow an additional crop), and
- Changing land use from low value crops to that receive higher market prices and/ or that serves as a continuous source of income (e.g., tree-crop-livestock systems, agri-horticulture).

The concept of sustainable intensification does not articulate any particular vision or method of agricultural production. It emphasizes ends rather than means, and does not pre-determine technologies, species mix or particular design components (Pretty and Bharucha 2014[1]). We, however, believe that a pre-requisite vision for sustainable intensification is that agricultural technologies deployed in each context must be environmentally sustainable.

2.1 Enhancing system productivity of rice-wheat and cotton-wheat systems

The challenge for farmers in the Indo-Gangetic plains is to combine a legume into the cereal-cereal system that can "*close the window*" of the dry season with the soil covered with crop residues to maintain aggregate stability, modulate soil temperature to favour plant/root growth, sequester carbon and mop up the residual NO_3-N from the surface soil layers before it is leached to aquifers (ground water pollution). Relay seeding of a pulse crop breaks the monotony of the cereal-cereal R-W system, enables the build-up of soil carbon pool and overcomes terminal heat stress in wheat.

Therefore, efforts were initiated for seeding of green gram (mung bean) through

(i) adjustments in planting dates and choice of rice and wheat cultivars to facilitate early seeding of green gram, and

(ii) relay seeding of green gram crop into standing wheat crop.

This latter strategy also helps in tackling the terminal heat problem in wheat which resulted in 10-26% yield losses in Punjab in 2010 and also resulted in shrivelled grains in the Indo-Gangetic plains. The former strategy was tried on BISA farms at Pusa, Bihar and the results are presented graphically in figure 1. At BISA Manegaon (Jabalpur), efforts were made to increase the cropping intensity by reducing the acreage of *Kharif* fallows.

At Pusa, three rice cultivars of varying durations (*Rajendra Bhagwati*, Arize Hybrid and *Rajendra Mahasuri*) were planted in combinations with 3 wheat cultivars to enable planting of mung bean (green gram) crop. Results presented in figure 1 indicate that green gram crop can be incorporated into RW system through an appropriate choice of cultivar like *Rajendra Bhagwati* (short duration, high yielding cultivar). Productivity of green gram in (*Rajendra Bhagwati* - early wheat) system was close to one ton/ha. Inclusion of green gram significantly enhanced the system productivity to the equivalent ~ 16 t/ha yield of R-W system.

In order to pursue the relay cropping strategy for intensification of RW or cotton-wheat (C-W) systems, the BISA scientists at Ludhiana developed a high clearance-narrow wheel tractor and a relay planter for seeding green gram into a standing wheat crop or a wheat crop into a standing cotton crop (to avoid yield losses in wheat due to late planting).

[1]Pretty, J. and Z.P. Bharucha. 2014. Sustainable intensification in agricultural systems. Annals of Botany. doi:10.1093/aob/mcu205, http://www.aob.oxfordjournals.org/ at Albert Sloman Library, University of Essex on October 29, 2014.

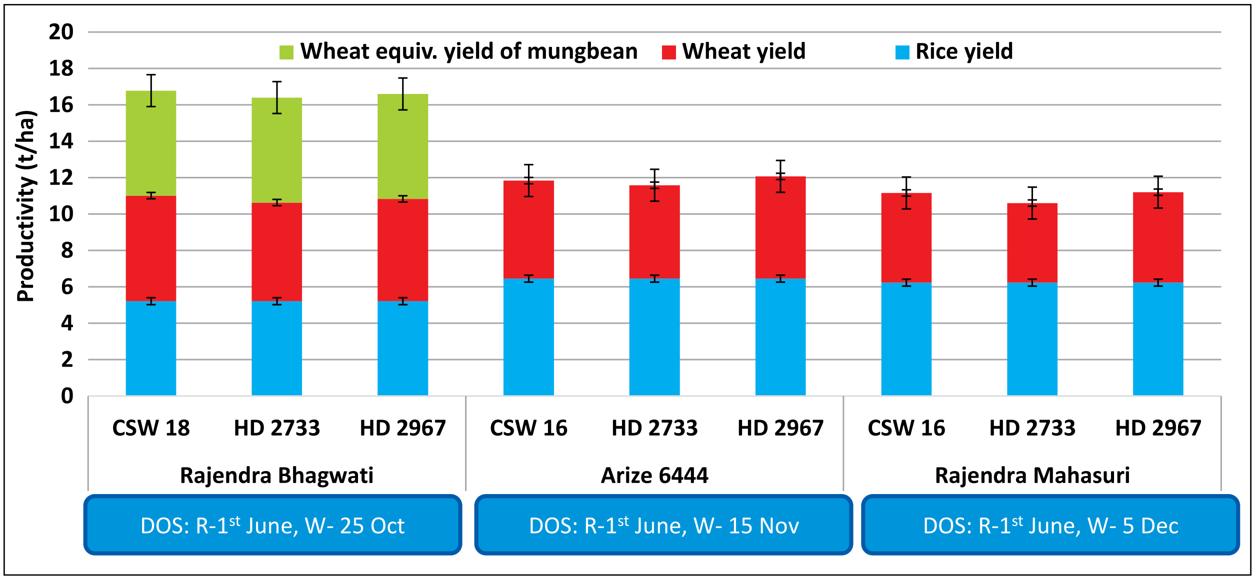


Fig. 1. *Sustainable intensification of R-W system with green gram in eastern Gangetic plains at BISA farms, Pusa, Samastipur, Bihar*

Mung bean planted after early wheat harvest in Pusa (LHS) and relay planted in standing wheat by using a high clearance tractor and a relay seeder (RHS)

Relay planting of mung bean in wheat, and wheat in cotton at BISA farms, Ludhiana

With planting of mung bean, besides ecological benefits enumerated previously, farmers got a mung bean grain yield ranging between 0.6 and 1.0 t/ha, as a bonus crop. The practice also encouraged farmers to practice last watering in wheat to prevent terminal heat stress and to facilitate germination of mung bean crop in the furrows.

Another system intensification option through relay cropping was tested at BISA Ludhiana, with relay seeding of wheat in cotton-wheat system using a high clearance tractor and seeder. It was observed that timely wheat planting improved wheat yields by 1.5 t/ha and also improved cotton productivity by about 10-15% through facilitation of last picking of the cotton balls. The technology has the potential of benefitting many Indian and Pakistani farmers in about 3 Mha.

2.2 Reducing acreage of *kharif* fallow lands (black cotton soils, Vertisols)

In the Central plateau region of India, many farmers during *Kharif* season grow rice, maize, soybean, sorghum, and pigeon pea crops, etc., in black soils (Vertisols). Here, southwest monsoons generally start in the first fortnight of June. The common practice is that farmers wait for the first few rain showers so that hard dry soils become soft for preparatory tillage and seeding of *Kharif* crops. Farmers generally transplant rice after the start of the rainy season. However, in the case of other crops, if the rains start before seeding and continue intermittently and not stop for an extended period, farmers either try to plant in too wet a condition and end up making a mess in deep Vertisols or leave the field fallow. Given the uncertainty in timing and the amount of initial monsoon rainfall, conditions change very quickly in black soil region from the highly cloddy dry soils with wide and deep cracks to extremely plastic, slippery, muddy soils when wet. Such situations disrupt preparatory tillage and sowing operations. As a consequence, large tracts of lands remain fallow in *Kharif* (in spite of > 1000 mm rainfall) or farmers are forced to grow puddled/unpuddled transplanted rice in the low lying fields. Geo-spatial multi-temporal analysis of the remotely sensed satellite data (ICRISAT, 2006[2]) has suggested that nearly 2.02 million ha (6.57% of the total area of the state) remained fallow in the state of Madhya Pradesh alone (total fallow area is ~11 mha in India and 14 mha in South Asia). This is in spite of a strong recommendation for dry sowing of crops before the onset of the rainy season (ICRISAT, 2006).

Farmers do not practice dry seeding in tilled fields for fear of:

- Seed loss through picking by birds,
- Loss of seed viability due to extended exposure of seed to peak summer temperatures ranging between 38 and 47°C for more than 40 days, and
- Mortality of young seedlings in alternate wetting-drying cycles, commonly observed in most of the Central Plateau region.

It was hypothesized that all the three reasons advanced by farmers are not valid for “closed window” of dry season when soils are covered with residues in conservation agriculture (CA). We have found pre-monsoon direct dry seeding better than waiting for the rains to actually start and then get caught with continuous rains and making a mess by trying to seed in wet conditions. With the onset of monsoons, black soils soon become water saturated, adversely affecting the germination of most crops. We have observed that most crops fail to germinate in water saturated black soils after the heavy rains. Thus it appears that heavy rainfall events make it difficult for the seed to germinate at low oxygen contents in crops such as pigonpea, maize, mung bean, soybean, sorghum, pearl-millet and cluster beans. This is a very compelling reason for direct dry seeding and circumventing the current land fallowing practice. In order to promote CA, reduce *Kharif* fallows and promote direct dry seeding before

[2]ICRISAT 2006. Spatial Distribution of Rainy Season Fallows in Madhya Pradesh: Potential for Increasing Productivity and Minimizing Land Degradation. Dwivedi *et al.* 2002). ejournal.icrisat.org August 2006, Volume 2, Issue 1, 40 p.

the onset of monsoons, seeding operations on the 541 - acre BISA farms at Manegaon were initiated on April 28 and completed by June 16, 2014.

Rice, maize and sorghum crops were planted using the Turbo-Happy seeders and Double disc openers attached to Multi-crop zero till planters. The seed rate was increased by 10% in rice. The seed rate of maize planted in rolling topo-sequences was increased by 50% to offer effective competition to germinating weeds and to reduce crop damage by wild life and birds. Seeding was carried out in the presence of 5-8 t/ha of residues of the previous wheat crop as surface mulch. It may also be mentioned that all the crops (maize, rice, sorghum, pearl millet, soybean, and cluster bean) were direct dry-seeded on the conservation agriculture platforms (flat and raised beds).

Between April 28 and June 16, 2014, there were four rainfall events (5-20 mm) interspersed with several windy and sunny days. It was observed that in the first four rainfall events, seed placed under the surface mulch, imbibed some moisture (but insufficient to trigger germination). During the alternate wetting-drying cycles experienced by seeds, the imbibed water contents never reached threshold moisture contents required to trigger the seed to initiate germination, preparatory to the emergence of seedlings. For this reason, we did not observe germinated seeds even after 4 rainfall events except in some low-lying spots. After the first few showers and onset of monsoons (on June 14 & 17, 2014), when it rained 20 & 25 mm respectively, (fig. 2), additional water through sprinkler irrigation was supplied to facilitate and ensure successful germination events.

Germination counts of the dry seeded crops were recorded several weeks after rain events. Data on germination counts are presented in figure 3. From

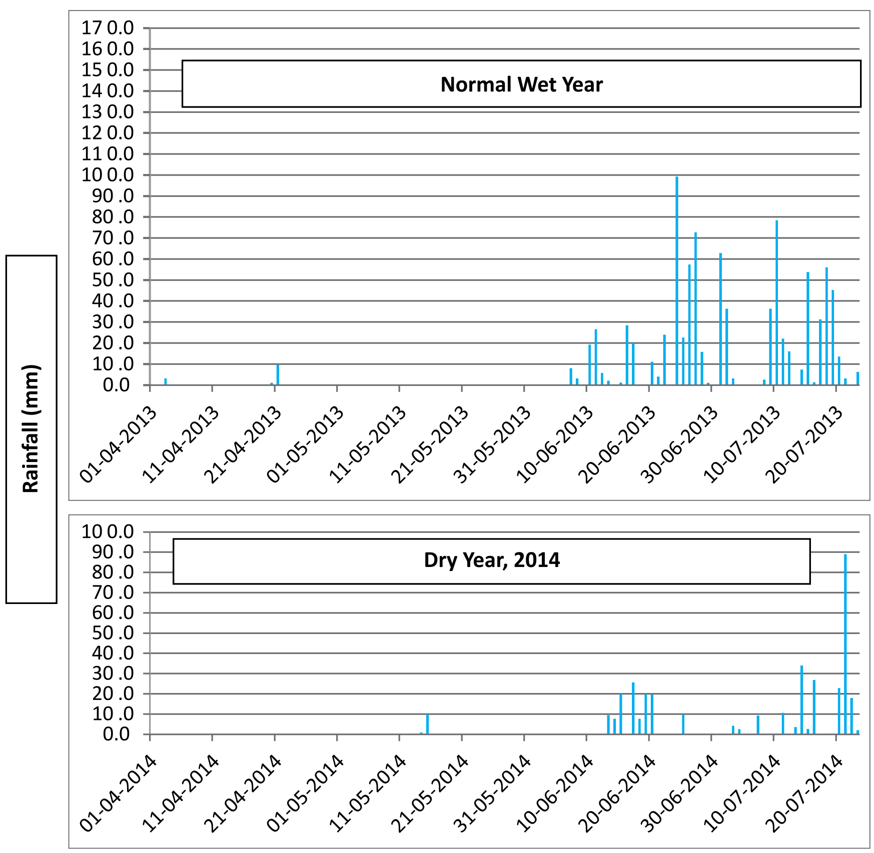
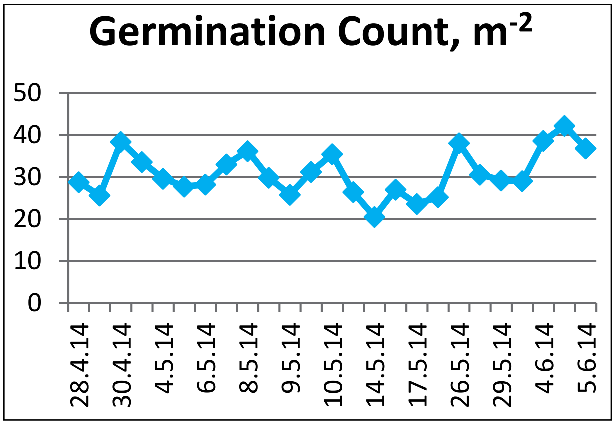


Fig. 2. *Pre-monsoon dry seeding opportunities of Kharif crops in the Central Plateau: Rainfall patterns in normal wet and dry years*



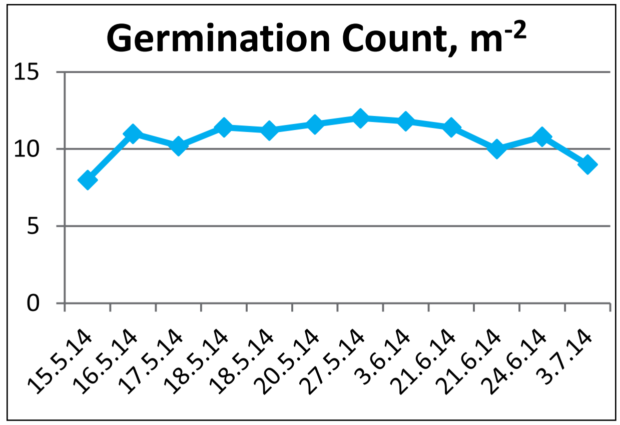


Fig. 3. *Germination count in rice (cultivars: Pusa 1121, Pusa 1509 and Kranti) and of maize hybrids (DKC9133, NRI Shiva, NK 6850, NK 6240, Bio 7707, Bio 9544, Bio 9720, CSB1) seeded between April 28 and June 5, 2014*

the observed data on plant population/m^2, it is evident that extended periods of seed exposure to high temperature and alternate wetting-drying of the seed during pre-monsoon showers did not adversely affect the seed quality (fig. 3). Rice population was around 30 seedlings/m^2. Maize population was around 10 plants/m^2. The germination counts are average of 100 and 50 sites counted, spread over 150 acres of rice and maize, respectively. Normal population/m^2 in farmers' fields vary around 25-30 seedlings in rice and 6-8 seedlings in maize. Results of the large field trials bring out that direct dry seeding in zero-till black soils, is a safe recommendation in the presence of surface mulches. It is because surface mulching mediates the genotype-temperature-moisture interactions in conservation agriculture to prevent any loss of seed or viability of the seed.

It appears that direct dry seeding (DDS) practice recommended earlier has a huge potential *only if practiced and popularised through conservation agriculture*. This technology has a major potential to reduce the acreage of *Kharif* fallows, reduce soil erosion by providing vegetation cover, increase cropping intensity, rainwater use efficiency and thus improving the livelihoods of the people in the Central Plateau region. In other areas, crop yields will improve through direct dry seeding before the onset of monsoons by way of efficient rain water use and better crop stand and the crop becoming more competitive to rainy season weeds.

The relationship between plant population and yield of 5 rice cultivars as observed in large sized field plots (~ 150 acres) on the BISA Research Centre, Manegaon, Jabalpur is given in figure 4. Productivity of the fine grained aromatic rice cultivar Pusa 1121 varied between 30 and 55 q/ha. For Kranti rice cultivar, the maximum productivity was 75 q/ha. The average productivity with sprinkler irrigation under non-ponded water conditions was nearly 32 q/ha. Maize productivity has not been included here because of heavy damage to the cobs by monkeys and parrots.

2.3 Futuristic cropping systems for the eastern Gangetic Plains

In this experiment, combinations of 3 tillage and crop establishment (conventional, zero-till flat and raised beds) were combined with 5 cropping systems (maize-wheat, maize-mustard, maize-chickpea, soybean-wheat and soybean-maize) considered to have a significant potential in near future for diversification of eastern Gangetic plains of India in particular and South Asia in general. Crops were established and managed following better-bet management practices of the cropping

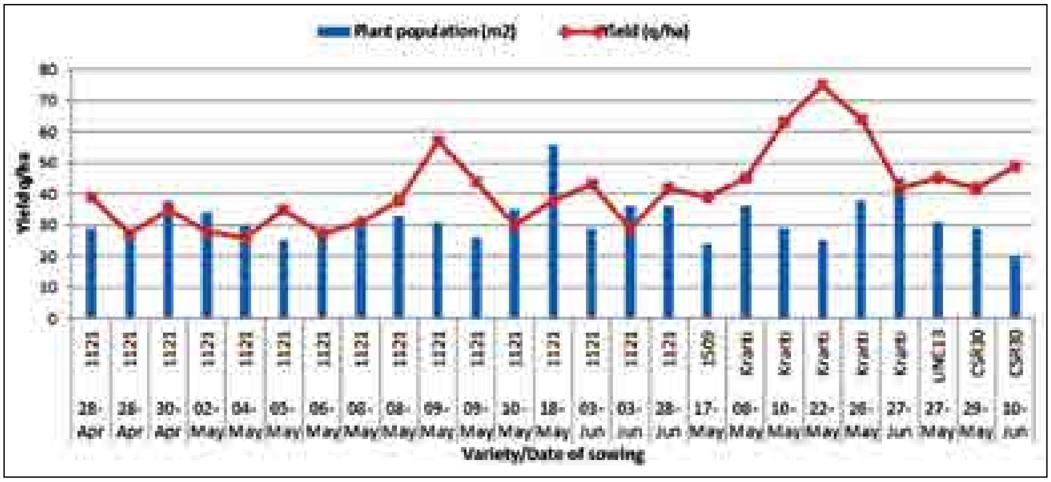


Fig. 4. Plant population and yield of pre-monsoon dry seeded rice crop cultivars at BISA farms, Manegaon, Jabalpur during Kharif 2014

systems. *In all the treatments, except the soybean-maize cropping system, mung-bean crop was planted after harvest of the winter crop.*

Treatments details:

(i) PTR-CTW (Puddled transplanted rice-conventional till wheat-farmer practice)

(ii) ZTDSR-ZTW (Zero till direct seeded rice-zero till wheat)

(iii) PBM-PBW (Maize and wheat planted on permanent beds)

(iv) PBS-PBW (Soybean and wheat planted on permanent beds)

(v) PBM-PBC (Maize and chickpea planted on permanent beds)

(vi) PBS-PBM (Soybean and maize planted on permanent beds)

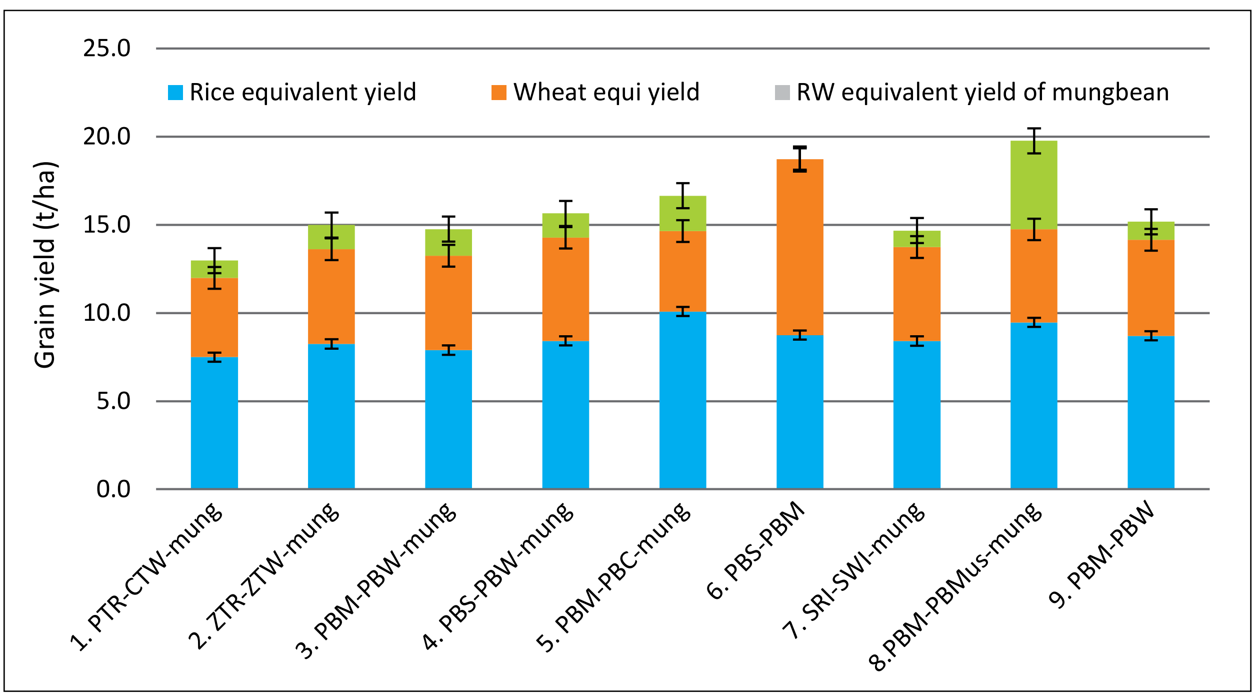


Fig. 5. Wheat equivalent yields of different cropping systems at BISA, Pusa, Bihar (since 2012)

(vii) SRI-SWI (System of rice and wheat intensification on flat)

(viii) PBM-PBMus (Maize and Indian mustard on permanent beds)

It was observed that maize-mustard-mungbean cropping system performed best among all the 8 cropping systems, followed by soybean-maize system. The maximum wheat equivalent yield of the maize-mustard-mungbean cropping system was 19.5 t/ha (fig. 5). In maize-mustard system, early harvesting of mustard allowed early planting of mungbean (so as to escape yellow mosaic virus), which gave 1.13 t/ha of mungbean, (equivalent to 5 t/ha of wheat crop). Delayed planting of mungbean crop after harvesting of chickpea and wheat yielded much less grains. Performance of soybean-maize cropping system was very close to the maize-mustard-mungbean system. Results of the field study brought out that rice based cropping systems including the SRI-SWI proved relatively less efficient in terms of water use and biomass production compared with soybean-maize and the maize-mustard-mung bean systems.

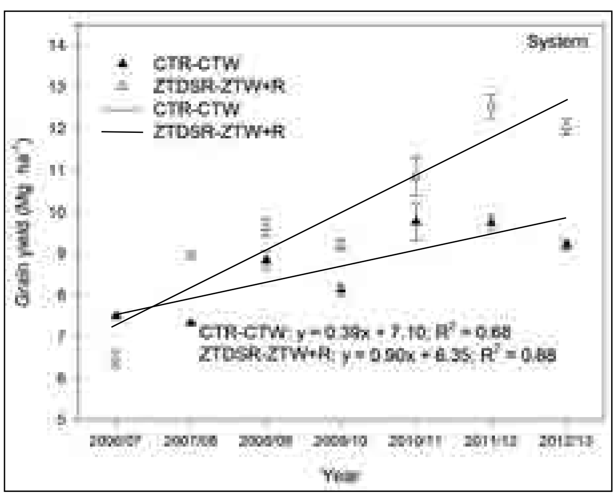
3. Conservation Agriculture and Adaptation to Climate Change

3.1 Evaluating the long-term effects of conservation agriculture in wheat based cropping systems of eastern Gangetic Plains

Conventionally, rice is transplanted in puddled soils and wheat is sown after fields are tilled to a fine tilth. The rice-wheat system is practiced in more than 13 Mha in South Asia. It is widely practiced in the Indo-Gangetic Plains, but is now showing signs of natural resource fatigue, and is no more sustainable. Uncertain weather events further add to the challenge and make it difficult to keep pushing the productivity of the RW systems. To address the issues related with natural resource fatigue and make agriculture climate resilient, conservation agriculture (CA) based crop management practices were developed for the irrigated systems, adapted and promoted in the region. Long term field trials on rice-wheat and maize-wheat systems were initiated in 2006 at the Research farms of the Rajendra Agricultural University, Pusa, Samastipur, managed jointly by RWC/CIMMYT (2006-2007) and subsequently by CIMMYT and RAU (2007-2010). Presently this long term trial is managed by RAU-CIMMYT-BISA scientists. The major objectives of the trial were to study short, medium and long-term effects of tillage and residue management practices on soil health and to study the carbon footprint in the RW system. There were 8 treatments, as under, which were randomised thrice in large plots:

1. Puddled transplanted rice (PuTR) - Conventional till wheat (CTW),
2. PuTR - Zero till wheat (ZTW),
3. Direct seeded rice on permanent beds (PBDSR) - Direct drilling of wheat on permanent beds (PBDDW),
4. Zero - till direct seeded rice (ZTDSR)-CTW,
5. ZTDSR - ZTW without residue (ZTW-R),
6. ZTDSR - ZTW with residue retention (ZTW+R),
7. Unpuddled transplanted rice (UPTR) – ZTW,
8. Wet DSR (WDSR) - ZTW (Changed to ZTR+ *Sesbania* brown manure - ZTW in 2011).

Long term data were analysed for productivity and profitability of the two systems as presented in figures 6 & 7. In the initial stages, rice productivity in the conventional system was a little more than the no-till system but the loss in rice productivity was compensated by the enhanced wheat productivity in zero-till CA systems. The results of the best bet ZTDSR-ZTW + Residue. management practice have been compared with the conventional till system (CTR-CTW) in figure 6. Results bring out



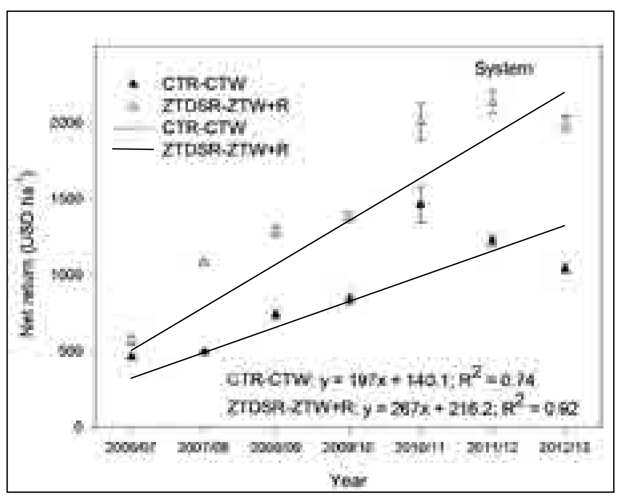


Fig. 6. *Equivalent total productivity and net returns in R-W system from the conventional and double zero-till systems in Pusa, Samastipur, Bihar (RAU-RWC-CIMMYT collaboration in association with BISA since 2012)*

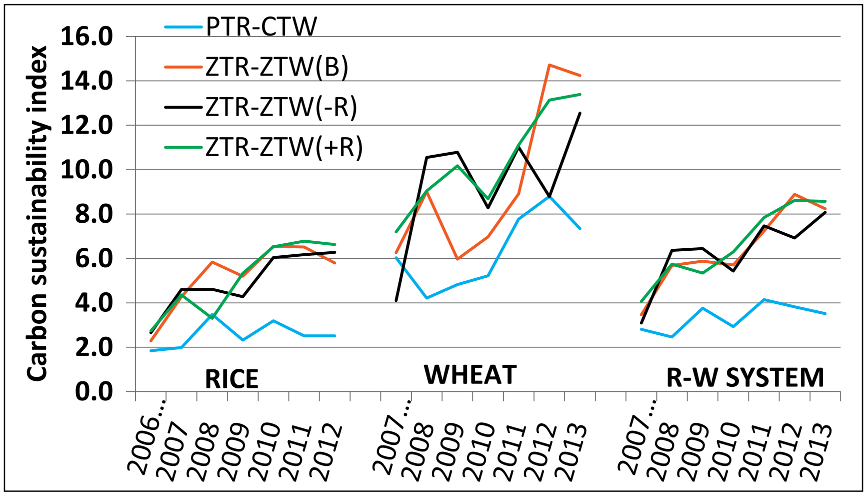


Fig. 7. *Carbon foot prints of the R-W system practiced traditionally and with zero-till options (flats/raised beds and with ± crop residues), at Pusa, Samastipur, Bihar (2006-2013)*

that after CA has been practiced for 2-3 seasons continuously *in the presence of residues*, it begins to reflect on improved soil health, and enhanced and more yield gains and net benefits which could be as high as about US$ 2 K/ha from the R-W system.

It is well established that the practice of puddling in transplanted rice system adversely affects the productivity of wheat, the crop following rice. With 'better bet management' practices (ZTDSR-ZTW + Residue; double zero-till), total productivity of the RW system continued to improve each season which was significantly more perceptible in the *residue based double zero-till based system*. It may be mentioned here that RW system productivity was higher in all CA based systems than in conventionally tilled (CT) and CT-CA conglomerate systems. It has been observed that net returns followed suit with productivity and were higher in CA based systems than in the CT system, although the differences became obviously significant only after the second year.

3.2 Carbon foot prints of rice-wheat system

Reducing energy use/greenhouse gas emissions, improving efficiency, eliminating waste and reducing resource usage along industry value chains improve the environment and sustainability of the agricultural systems.

Carbon sustainability index is a measure of the improvement in C-production efficiency defined as C_{output} as percentage of C-based inputs and expressed by equation following (Lal, 2004) as under:

$$\text{Carbon sustainability index} = \{(C_{output} - C_{input}) / C_{input}\} . 100$$

Carbon sustainability index of agricultural systems determines the C footprints vis-a-vis relative sustainability of agronomic production systems. Dynamics of the C-sustainability index for conventional and double zero-till (ZTDSR-ZTW+ Residue) rice-wheat systems are presented in Fig. 7.

No-till farming involves drastic reduction/ elimination of plowing, retention of crop residue mulch, and judicious use of chemicals. In conventional R-W production system, crop residues are removed or burned, and fields excessively ploughed/puddled resulting in loss of C from the soil organic carbon pool. The results presented in fig. 7 suggest that the C-sustainability of the rice system (irrespective of the tillage system) was lower than that of the wheat production system. Tillage systems and residue management practices just attempt to improve C foot prints of the R-W system. Hence the higher values of C-foot prints for ZTR-ZTW + Residue on the flat or on the raised beds suggest to the superior performance of R-W grown in specific tillage system.

3.3 Comparative performance of System of rice-wheat intensification (SRI-SWI) *vis-a-vis* other crop establishment methods

In this study, we compared 3 establishment methods, *viz.,* (i) Puddled transplanted rice followed by conventional till wheat (PTR-CTW), (ii) Zero till rice and wheat (ZTDSR-ZTW) and (iii) System of rice-wheat intensification (SRI-SWI) in two ecologies (low land and upland ecologies) representative of Bihar. The trial was conducted at BISA farm, Pusa, Samastipur, Bihar.

Results very clearly show that in lowland ecology the zero-till-direct seeded rice (ZTDSR-ZTW) is likely to out-yield the puddled transplanted rice as well as the rice established with the SRI method. However, under the upland ecology, SRI system produced slightly more rice grain than the ZTDSR (fig. 8).

The production costs were disaggregated into labour, tillage, irrigation, agri-inputs and harvesting/threshing costs. Results have indicated that SRI is very labour intensive and its cost was more (USD$ 391 & 376 USD/ha) as compared to ZTDSR, in low-land and mid-land ecologies, respectively (fig. 9).

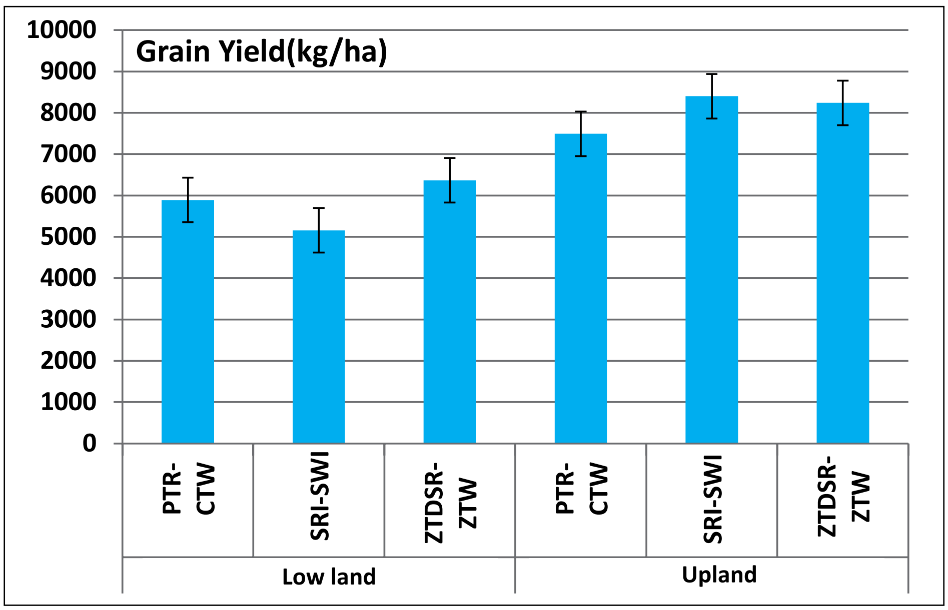


Fig. 8. *Rice yields with three crop establishment methods in two rice ecologies (2013-14)*

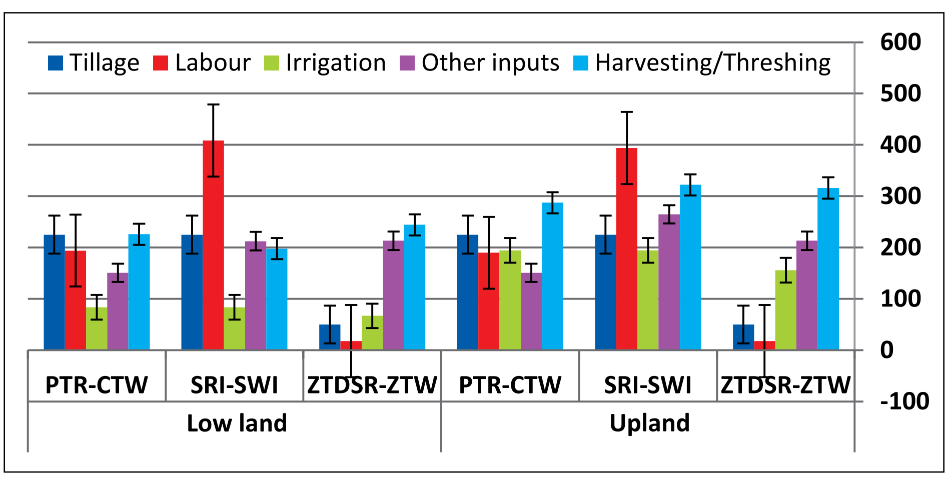


Fig. 9. *Disaggregated production costs in three rice establishment methods (2013-14)*

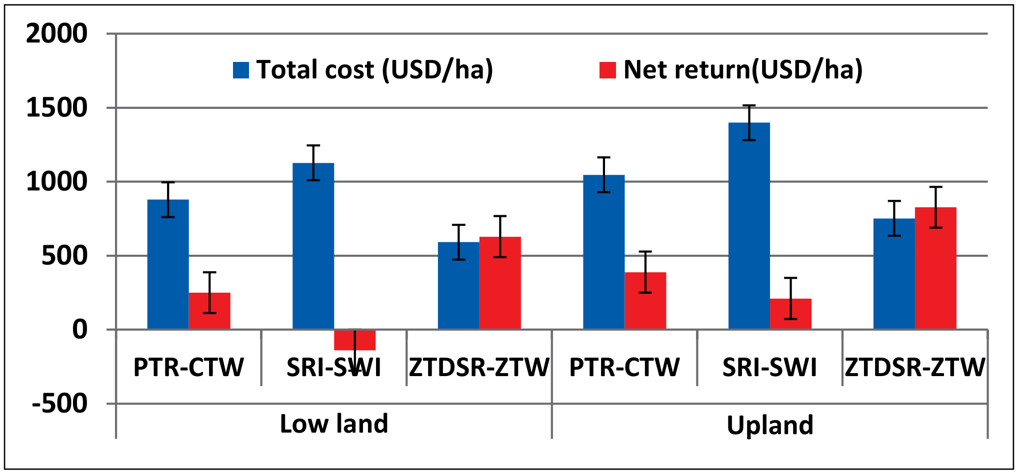


Fig. 10. *Production costs and net profit in rice established with 3 crop establishment methods (2013-14)*

Farmers, and a researcher indicating their preference for zero till dry-seeded system vis-a-vis SRI-SWI system (2013)

Total cost of cultivation of SRI rice was higher by USD$ 536 & 648 (equivalent to ₹ 32.2-38.8 K)(fig. 10) over ZTDSR under low-land and mid-land ecologies, respectively. Excessive labour requirements make the SRI system of rice production really uneconomical.

3.4 Crop yield and water productivity: water-wise technologies for permanent raised bed planted spring maize in north-west India

Maize is the third most important cereal crop (after wheat and rice), and is grown across a wide range of climates in South Asia. Spring maize (February-June) is expanding rapidly in northwest India but high evaporative demand during the growing period as well as knowledge gap on irrigation water management leads to application of water in much higher quantity than required for physiological processes. This further adds to the growing challenge of declining water table, a major concern for agricultural sustainability in northwest (NW) India. Mulching with crop residues and using drip irrigation are the obvious ways to reduce evaporation and increase water productivity (WP) in spring maize. Our study focuses on the interactions of residue mulching × irrigation water management in spring maize in relation to crop yield and irrigation water productivity.

A two-year field experiment was conducted during spring 2013 and 2014 seasons at BISA farms, Ladhowal (Ludhiana), under the aegis of Cereal Systems Initiative for South Asia (CSISA), managed by CIMMYT with support of USAID and BMGF. Treatments to maize grown on 67.5 cm wide raised beds included two levels of mulch (no mulch and 5 Mg ha^{-1} straw mulch) as main plot treatments and irrigation methods (surface drip, flood irrigation each furrow and flood irrigation alternate furrow each applied at 45 and 60 kPa Soil Metric Potential and farmer practice, FP) as sub-plot treatments.

Grain yield and irrigation water use were significantly affected by mulch and irrigation treatments (figs. 11 and 12). Mulching caused significant increase in yield over no mulch, irrespective of irrigation treatments, except FP. On an average, drip irrigation saved up to 66% water compared to that in farmers practice. Applying drip irrigation at 45 kPa SMP along with residue mulch produced maize yield similar to that under flood irrigation but with a saving of 4232 m^3 ha^{-1} of water and thereby increasing irrigation WP by 175%.

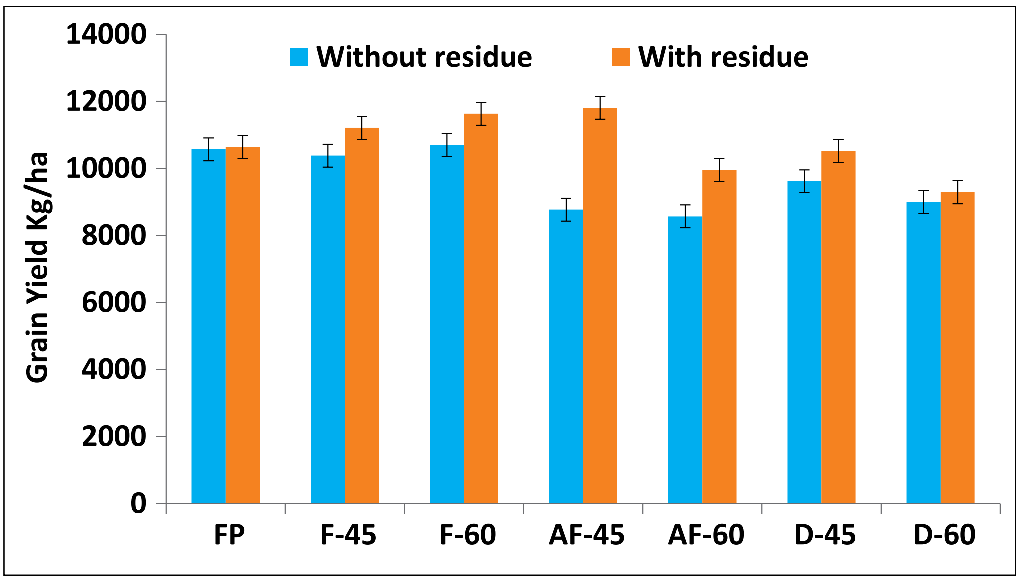


Fig. 11. *Grain yield (kg ha^{-1}) of spring maize (2013) irrigated through furrows, skip furrows and with drip system at 45 and 60 kPa soil moisture regimes with two residue mulch regimes*

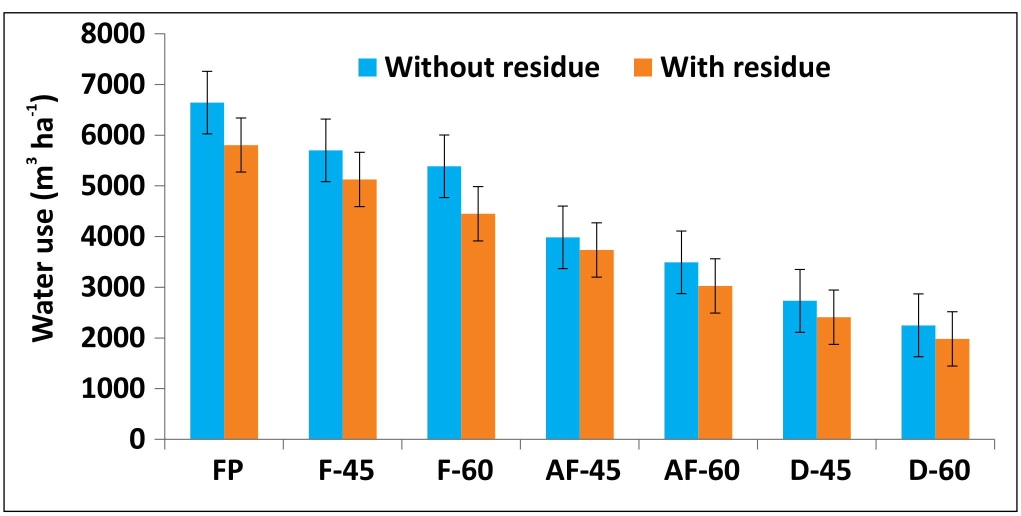


Fig. 12. *Irrigation water use (m^3 ha^{-1}) in spring maize (2013) irrigated through furrows, skip furrows and with drip system at 45 and 60 kPa soil moisture regimes with two residue mulch regimes*

Results of the water management studies bring out that mulching and irrigation water management methods had additive effects both on yield as well as water productivity. It is important to note here that mulching with Skip furrow irrigation was as effective as drip irrigation in terms of water productivity.

3.5 Nutrient and precision irrigation water options in rice-wheat systems

Rice consumes about 50% of total irrigation water in Asia and accounts for about 24-30% of the withdrawal of world's total freshwater. The seasonal water input to rice fields is the combination of water used in land preparation and to compensate for evaporation, transpiration, seepage, and percolation losses during crop growth. Most of the water applied during crop growth is not used directly for transpiration, and is, therefore, considered lost from fields. The water productivity of rice in terms of evapotranspiration (ET) is not different from other C3 cereals such as wheat. The higher water application in rice is also due to water requirements for puddling and losses associated with continuous flooding such as seepage and deep percolation losses to groundwater. Our study focuses on the interactions of establishment methods × irrigation water management in rice-wheat system in relation to crop yield and irrigation water productivity.

Direct seeded rice crop was grown with three water management regimes in the presence/absence of crop residues of the previous crop as under:

1. DSR - Surface drip
2. DSR - Subsurface drip
3. DSR - Flooded
4. Puddled transplanted rice (TPR, Conventional - Farmer practice)

Preliminary results as presented in table 1 for one season, indicate that compared to conventional practice (flooded puddled transplanted rice), drip irrigation system saves almost 57% of irrigation water without any serious implications on crop productivity. Rice crop raised as DSR crop and subsequently managed like a flood irrigated crop can still save 20 cm of precious irrigation water. The presence of crop residues generally enabled additional water saving. Drip irrigation system is also seen to improve partial factor productivity of Nitrogen. Initial results are very encouraging.

With similar grain yields, water productivity increased more than 100% under drip irrigation system. Fertigation significantly increased N-use efficiency in RW system. Through fertigation in surface/subsurface drip systems, partial factor productivity of applied nitrogen (the ratio of output value to the cost of specific input) increased by 6-18% compared to puddled transplanted rice and flood irrigated direct seeded rice.

3.6 Integrating fertilizer application management with three elements of conservation agriculture

N-use efficiency in irrigated crops can be significantly improved by replacing area general ad-hoc recommendations with dynamic real time recommendations. Now a days soil test based recommendations are being supplemented with

Table 1. Effect of water management options on the grain yield of rice (*Kharif* 2014) and saving in irrigation water

Crop establishment & irrigation methods	Grain yield (kg/ha)		Irrigation water use (M3/ha)	
	Without residues	With residues	Without residues	With residues
DSR-surface drip	5,010	4,620	5,590	5,570
DSR-sub-surface drip	4,710	4,713	5,737	5,393
DSR-flooded	5,160	4,930	10,460	10,120
TPR-flooded	4,560	5,000	12,660	12,040

real time N recommendations based on 'Nutrient Manager'; 'Nutrient Expert' and 'Green Seeker' optical sensor-based N management strategies. The last strategy consists of applying moderate amount of fertilizer N at planting and crown root initiation stages and sensor-guided fertilizer N dose at later growth stages. Sensor-guided fertilizer N applications resulted in high yield levels and high N-use efficiency.

In the Indian context, canal water and power supplies are not demand driven. Even in tubewell irrigated areas, farmers have to depend for irrigation water on the power supplies. Thus it is not always easy for the farmers to synchronize water and fertilizer application timings for optimum results. In a rice-maize system field trial conducted by BISA scientists at RAU farms, Pusa, Bihar, it was earlier observed that a small amount of rice residues retained on the soil surface significantly improved early growth and vigor of maize. Vanlauwea *et al.* (2014)[3] has very recently demonstrated that fertilizer response improved significantly when a minimal 3-ton residue provided the initial soil cover for initiating CA.

The above description suggests that we must integrate the CA elements (residue cover, diversification and drastically reduced tillage) with the fertilizer application methods, and timing, etc., for best results. In order to assess this hypothesis, a maize trial was conducted in raised-bed system and the results are presented in table 2.

Above results bring out that area-general ad-hoc N recommendations must be replaced by more specific recommendations based on Green Seeker, Nutrient Manager and Nutrient Expert. Maize yields improved when N was drilled, and application rates were based on Green Seeker or Nutrient Expert, the latter a little better.

In the Indian context, several studies (Bijay-Singh *et al.*, 2011) have earlier shown that application

New guide mounted 'Inverted T opener' to space urea from seed

Table 2. Effect of N application method, rate and splits on Maize yield in BISA farm, Pusa, Samastipur, Bihar

Nutrient application method and # of splits	Appln method	# of N splits	Maize yield (t/ha)
FFP	FFP	FFP	3.45
Ad-hoc state recommendation	Ad-hoc (Broadcast)	Ad-hoc state rec	3.89
Ad-hoc state rec (NPK)	Drilling	3 splits	4.41
Ad-hoc state rec (NPK)-80% N in 2 splits, 3rd N split based on GreenSeeker (GS)	Drilling	3 splits	4.73
NE based NPK rates	Broadcast	3 splits	3.96
Nutrient Expert (NE) based NPK rates	Drilling	3 splits	4.77
NE based NPK rates-80% N in 2 splits, 3rd N split based on (GS)	Drilling	3 splits	4.95

Note: Measurements of GHGs in progress - M.L. Jat et al. (CIMMYT-GCAP/CCAFS-BISA)*

[3]Vanlauwe, B., J. Wendt, K.E. Giller, M. Corbeeld, B. Gerard, C. Nolte *et al.* 2014. A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. Field Crops Research 155: 10-13.

of 75 - 80% of recommended N dose can be applied at planting time or whole applied in two doses at planting and crown root initiation stage. These results have been found as an appropriate prescriptive fertilizer N management.

While split applications of nitrogenous fertilizers are known to improve nutrient use efficiency, farmers often face difficulties in synchronizing N applications with watering. Also in the presence of crop residues retained on the surface as mulches, it is difficult to top dress N. Fertilizer granules often don't reach the root zone in the presence of mulch. Application of N at seeding time is an option, but it is often difficult to band place N fertilizer granules away from the seed. Whenever, N fertilizer granules are in contact with seed, it adversely affects germination.

In order to avoid seed-urea contact, and separate them, a small sharp guard plate was fixed to chisel tyne openers of the zero-till drill, and the delivery tube was slightly tilted to deliver N granules away from the seed. The newly designed tyne is a major step forward in the direction of enabling basal application of 80% N at seeding time.

3.7 Development of conservation agriculture machinery & evaluation

1. **Modified Combine Harvesters :** Most of the combines commonly used in India do not have provisions for multi crop harvesting (e.g., wheat, rice, green gram, chickpea, soybean, pigeon pea maize, etc.). These combines also suffer on account of wheel alignments (presently compact soils through 4 ruts in each pass), inability to harvest raised bed planted crops at 67 cm spacing and formation of win rows. BISA took the initiative together with Preet Combines, Sangrur, Punjab to remove these bottlenecks. The following modifications and adjustments have been made to suit the existing combine models:

   - Fitting a motor driven straw spreader to facilitate planter operations
   - Wheel alignment (270 cm axle width of rear and front wheels) to suit permanent raised bed planting system as well, and
   - Development of a 6-row maize header for harvesting maize.

Newly designed combine harvester with spreader

2. **Knife Roller :** Green manuring crops are generally incorporated into the soil by disking/ planking and ploughing. Knife roller is a front mounted hydraulically controlled roller which is used to knock down/roll-down the standing green manure crops or stubbles of maize or pigeon pea crops. It trashes/breaks them into 30 cm pieces. This equipment takes very less power and is used to mulch ground surface with maize and *Sesbania* residues, etc. Development of the

New knife roller for mulching and seeding with Turbo Happy Seeder knife roller simultaneously allows mulching and seeding of specific crops in a single tractor pass.

3. **High Clearance Tractor (HCT) :** A 100-cm high clearance platform for 4-wheel tractor was developed in collaboration with M/s Rajar Agricultural Works, Ludhiana, and the Department of Farm Machinery & Power, Punjab Agricultural University, Ludhiana. A normal tractor can be converted into HCT in four hrs and vice versa. Development of the HCT became crucial for enhancing the productivity of cotton-wheat systems in India and Pakistan. Both countries lack availability of high clearance rims, tyres and tubes, needed for relay seeding of wheat or green gram in standing cotton and wheat crops, respectively. This tractor can easily move through the tall row crops and can be used for intercultural operations, weeding, fertilizer application, spraying and relay seeding of next crop. Now we can attach a normal implement with this high clearance tractor and we are hoping that it will increase the use of this tractor in normal/high clearance mode. One can adjust the implement by using top/other links as in normal three point linkage.

High clearance tractor with seeder

4. **Mini Happy Seeder (MHS) :** First prototype of Mini Happy Seeder was developed as attachment with the walking type two-wheel tractor through support and collaboration of M/s Dasmesh Mechanical Works, Amargarh, Malerkotla, Punjab. Preliminary testing gave us very encouraging results, and detailed testing / evaluation is in progress at BISA research farm at Ludhiana. It worked very well for direct seeding of wheat in the presence of rice straw load of 5-6 t/ha when attached to a two-wheel tractor. An operator can very easily ride on its depth control wheel during farm operation and transportation.

Mini happy seeder

5. **Tractor Operated Relay Seeder :** A 12-row relay seeder was fabricated to sow wheat into 67.5 × 75 cm^2 cotton geometry. It is capable of sowing 12 wheat rows into 4 spaces of cotton in a single pass. Similarly, a 15-row relay seeder was also developed to sow wheat into 101 × 50 cm^2 cotton geometry. It is capable of sowing 15 wheat rows into 3 spaces of cotton in a single pass. The row spacing between adjacent wheat rows is 18 cm in both the seeders. Different types of furrow openers such as disc, and inverted t-type required for sowing different treatments of wheat into standing cotton were fabricated. During field testing of the relay seeder, the

High clearance relay seeder

operational parameters like forward speed of travel, fuel consumption, field capacity, etc., were also measured at BISA, Ludhiana.

6. **Bund cum Channel Maker :** The bund cum channel maker allows special arrangements of two discs mounted on the tool bar to facilitate bund cum channel making. The implement has been developed together with M/s Dasmesh Mechanical Engineering Works, Amargarh, Punjab for making irrigation water channels and the field bunds/borders. This development has enhanced the use of this equipment and made the life of farmers a little easier. It reduces a lot of spade work for farmers

Bund cum channel maker

7. **Subsurface drip laying machine :** This tractor driven machine operates with a PTO. It has two adjustable blades for opening narrow slits into surface soil for imbedding drip line at any desired depth. The depth control wheel helps in maintaining a desired uniform depth for the drip line.

Narrow ditch maker for laying down subsurface drippers at desired depth and spacing

4. Genetic Enhancement

4.1 Wheat cultivars for different planting dates in eastern Gangetic plains

A research trial was conducted on the BISA farms with ten elite wheat cultivars to identify wheat genotypes that have high yield potential, and that are stable and able to reduce aberrations in wheat productivity/production under changing climatic situations as part of CIMMYT projects supported by BMZ. These wheat cultivars were planted at weekly intervals beginning mid-October to mid-December each year with two contrasting tillage and crop management methods for enhancing crop productivity. The tillage treatment included crop establishment with CA and conventional tillage system. The ten elite cultivars/ genotypes included Munal, CSW 16, CSW 18, *Baaj*, PDW 621-50, HD 2967, GW 322, GW 366, GW 273, and JW 3288. This trial includes 7 planting dates at weekly interval, 10 genotypes of different duration and 2 tillage systems (CT and ZT).

The results of the trial conducted at Pusa showed that yield variability of different wheat genotypes was lesser when sown early in the middle of October to mid-November (fig. 13), and more with late planting of wheat. Productivity of all cultivars was higher under zero-till seeding as compared to conventional tillage (only average values have been plotted in fig. 13). The genotype CSW 18 gave higher yield at early seeding (Oct 22) situation, while HD 2967 was found relatively more stable on different planting dates. Whereas the genotypes HD 2733, HD 2824 and *Baaj* were found suitable for timely seeding (fig. 13), the cultivars such as HD 2733, and HD 2967 are likely to perform better even under late planting situations. This calls for differential seed production strategies for enhancing wheat production in the eastern Gangetic plains.

Rate of yield reduction due to late planting was nearly 45/kg/day/ha in eastern Gangetic plains compared to 32kg/day/ha in north-western parts of the IGP. Loss in yield was mainly due to sudden rise in mercury causing forced maturity. With proper selection of rice cultivars (early HYV such as Rajendra Bhagwati, results presented in earlier sections), it is possible to not only sustain but also enhance wheat productivity in the eastern Gangetic plains of India, Nepal and Bangladesh.

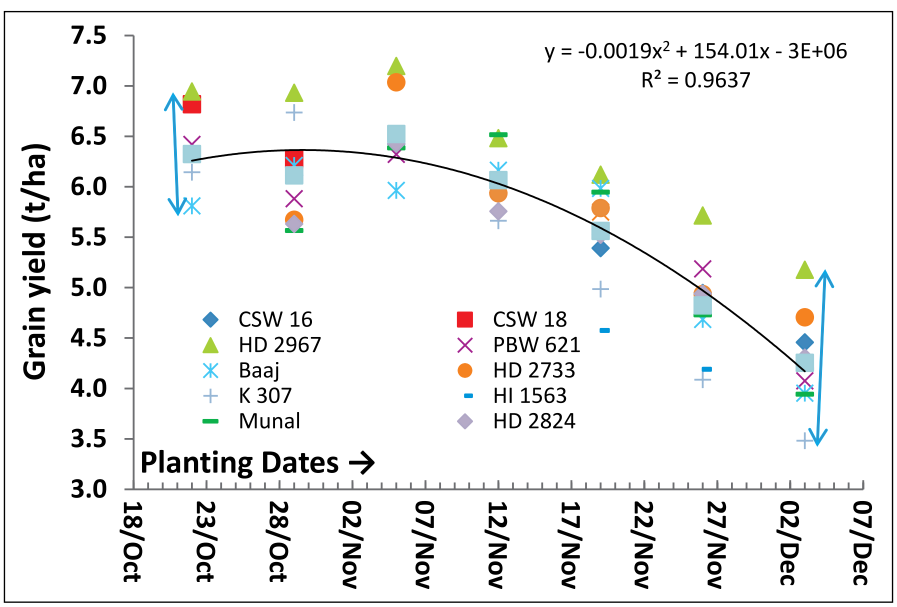


Fig. 13. *Effect of planting time on yield variability and yield of 10 different wheat genotypes*

4.2 Wheat genotypes appropriate to on-going climate changes: Bi-plot analysis

It was hypothesised that fluctuations in productivity of South Asian wheat are more when planted late than when planted early in October in the conserved residual moisture of monsoon rains (rainfed areas) and of rice fields (irrigated areas). In order to test the above hypothesis, 106 genotypes were received from CIMMYT, 2 from IARI and 30 from JNKVV for assessing their yield potential. Additional 4-5 cultivars were added at each BISA site as best possible national/ local checks. The two genotypes (CSW18 and CSW16) from IARI were specifically bred for conservation agriculture platforms for (i) early and (ii) timely planting. Results of wheat evaluation trials conducted during *Rabi* 2011 and subjected to biplot analysis are presented in fig. 14.

Results presented in the Biplot above can be summarised as follows:

- Performance of wheat genotypes was almost similar in Pusa and Jabalpur environments (even ranks are likely to be similar). Pusa has dry hot sub-humid climate and Jabalpur has hot humid climate.
- Ludhiana type environment would need a different wheat genotype. Genotypes along with positive X-axis at the farthest distance (on negative side of Y-axis) are likely to perform better at Ludhiana.
- Along the X-axis, variety at the farthest distance (on positive side of Y-axis) would perform better in these three environments.
- Some of the genotypes bred for tilled situations can perform equally well for no-till (flat) and raised bed systems. However, it's better to subject wheat lines to pass through CA plots at some point in the breeding program.

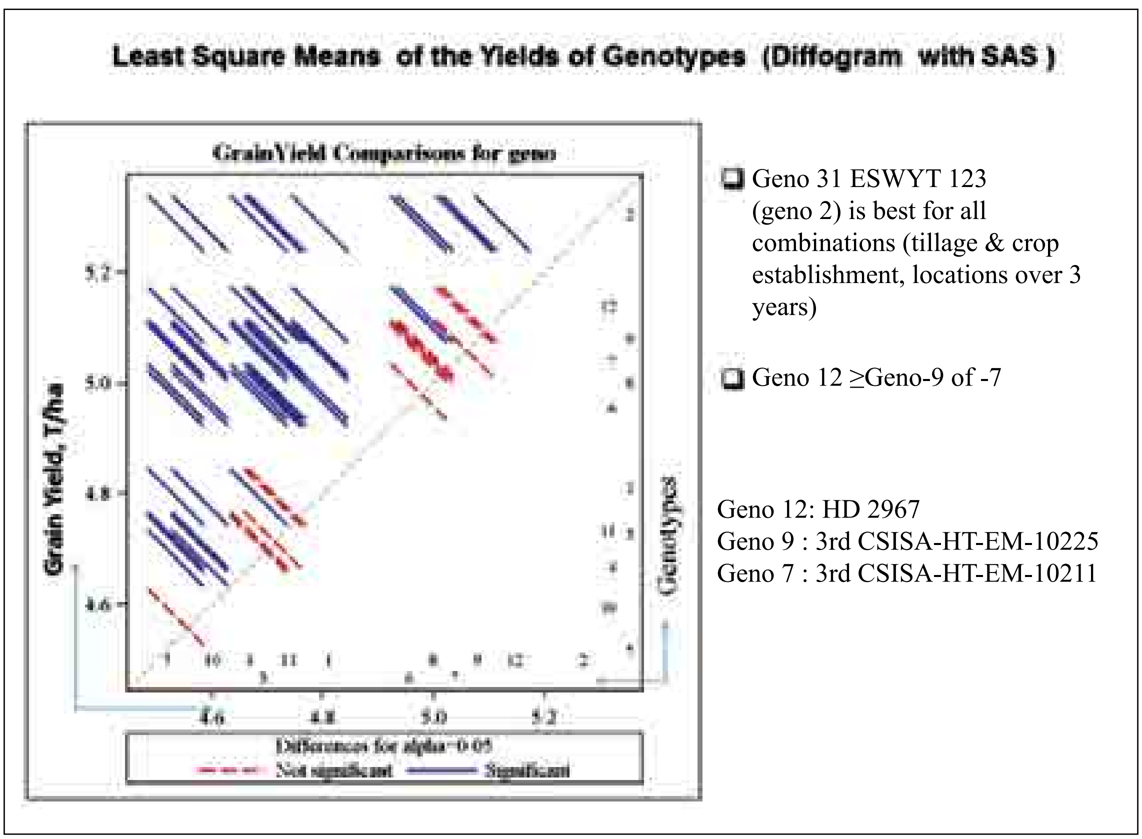


Fig. 14. *Biplot analysis of 107 genotypes evaluated with local and national checks at three BISA locations*

Top ranking genotypes in three locations in the last three seasons are shown in table 3. The shortlisted genotypes performed better than others. These genotypes seem to have a wider adaptability and stability in three different environments over the years (2011-2014).

- Top 3 wheat genotypes which out-yielded the best national/local check by at least 10% are shown in red
- For early planting weakly vernalized HD2967 and CSW 18 cultivars are the best
- GW 366 has serious black tip and no-dormancy issues; needs to be phased out from the high rainfall regions
- Seed of the best genotypes were made available to DWR, Karnal in 2013-14 season for their further evaluation.

4.3 Genotype × tillage × cropping system interactions

The G × T × E interactions are well known and have been reported and documented earlier by several workers. We studied the genotype × cropping Systems at Pusa wherein wheat genotypes were tested in the field plots continuously used under the rice-wheat and maize-wheat systems for 4 years in the past. The yields of the specific genotypes grown in plots used previously in two cropping systems (M-W and R-W) are presented in fig. 15. The yield of wheat genotypes was generally more

Table 3. Best performing wheat genotypes at BISA farms (2011-14)

Location	2011-12	2012-13	2013-14
Jabalpur (MP)	31 ESWYT123 3rd CSISA HT-EM 10225	31 ESWYT – 107 31 ESWYT - 145	3rd CSISA HT-EM 10225 3rd CSISA HT-EM 10212 CSW18, HD2967
PUSA (Bihar)	31 ESWYT-123 3rd CSISA HT-EM10212 3rd CSISA HT-EM 10211	1 ESWYT 148 3rd CSISA HT-EM 10225 31 ESWYT-123	31 ESWYT-123 31 ESWYT-125 3rd CSISA-HT-EM-10212
Ladhowal (Punjab)	31 ESWYT-142 31 ESWYT-141 31 ESWYT-137 3rd CSISA HT-EM 10225	31 ESWYT -137 31 ESWYT-141	

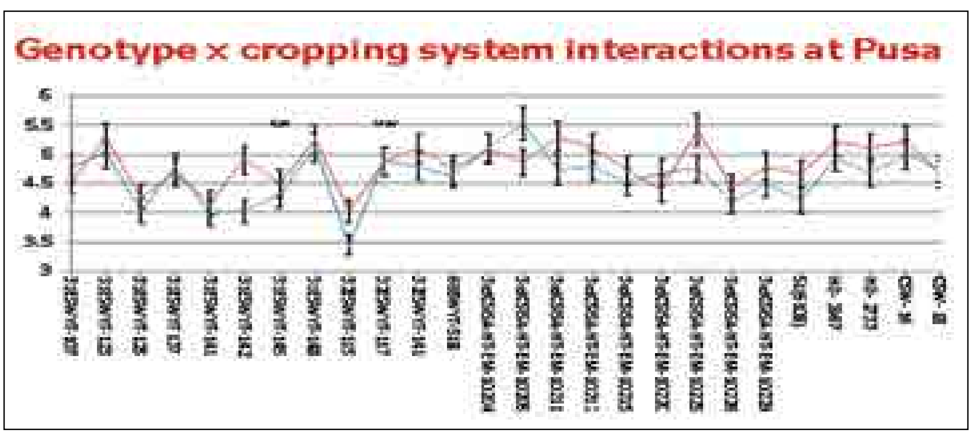


Fig. 15. *Genotype x. cropping system interactions in rice-wheat and maize-wheat systems*

when the preceding crop was maize rather than rice. This suggests the need for wheat cultivars which are better suited and adapted to the contrasting edaphology encountered in the rice-wheat system.

The cross-over of the wheat yield curves of specific genotypes grown in R-W and M-W plots clearly suggests that genotypes respond to G × T interactions manifest G × Cropping system interactions. Wheat genotype 3rd CSISA-HT-EM-10225 performed best in M-W system, but for the R-W system, wheat genotype 3rd CSISA-HT-EM-10205 was the best performer. More G x CS interactions can be seen in figure 15.

4.4 Need for weekly vernalized genotypes/ cultivars for early planting of wheat in residual soil moisture of rice crop

On the basis of the results presented earlier, it can be hypothesised that early planting of wheat in October is likely to help achieve stability in production and productivity of wheat under changing climatic situations of the Indian subcontinent. Ten wheat genotypes/cultivars were planted in BISA farms at Manegaon, Jabalpur on 10 dates at weekly intervals between October 15 to December 17 to work out the best planting time under changing climatic situations under CIMMYT-BMZ support. For need assessment of weakly vernalized wheat genotypes for early planting in black soils (Vertisols), however, only two weakly vernalized genotypes were compared with the best local check (GW366) in Jabalpur. Wheat cultivar HD 2967 and CSW 18 have been reported to be the weakly vernalized wheat genotypes developed recently (personal communication from Dr Rajbir Yadav, Principal Wheat Breeder, IARI). Results presented in figure 16 indicate that (i) genotypes and (ii) planting time play a very significant role in stabilizing wheat productivity and production.

In figure 16, the yield of wheat cultivars planted in October 22 fluctuated between 6572 and 5636 kg/ha (i.e., by 936 /kg/ha). However, when the same cultivars were planted a month after in late November/early December, yield fluctuated between 5905 and 3405 kg/ha (i.e., 2500 /kg/ ha). Since wheat yield fluctuations were observed 2.5 times of early seeding, it would be of great importance to reduce such wide fluctuations in productivity through appropriate choice of cultivars and seeding dates. Results presented in figure 16 suggest that it will be of crucial importance that breeders develop wheat genotypes for early planting in residual moisture of rice/monsoons in October to save precious water and to buffer aberrations in production/productivity due to climate changes.

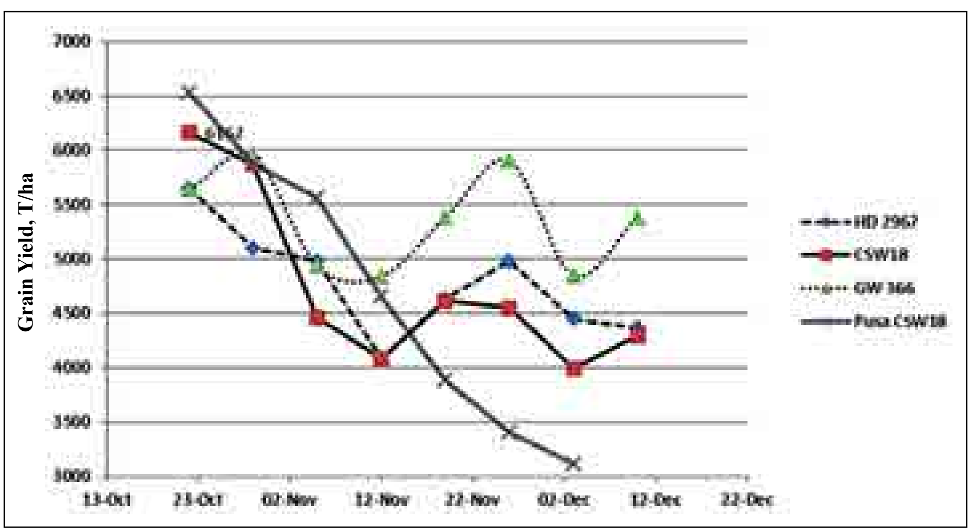


***Fig. 16**. Performance of elite wheat cultivars at different planting dates at BISA farms, Pusa and Manegaon in 2012-13*

The yields of CSW18 and HD2967 were the highest, and almost similar in Pusa when planted in October. The yields of both cultivars declined with later planting dates. At present, there is no single wheat cultivar available to farmers which can yield equally well under early and timely/late planting situations. Therefore, for early planting situations, the cultivars such as CSW 18 and HD 2967 seem to be the best choice. It is worth mentioning here that the genotype CSW 18 (early planted wheat) had a unique trait of compensating reduced tillering (early planted wheat) by extended spike length and higher test weight of the grains when it is planted early in October. These traits are possibly not switched on in early growth stages (yet to be tested) of HD 2967.

The performance of the cultivar GW 366 recommended recently for Central Plateau is interesting because its yield improved with late planting. This may be because of several rainfall events late in the season. The disadvantage of cultivar GW 366 would be that it has no seed dormancy and has a tendency to develop "black point" (~20%) and germinate in the spike (~5%) with a rainfall event of a few hours even. This suggests the need for a little dormancy in wheat under changing climatic situations. Early planting of wheat also facilitates seeding of mungbean (green gram) after wheat harvest as in results presented for Pusa, Bihar.

4.5 Evaluation of wheat genotypes for dual purpose (green fodder, and grains and *bhusa*/straws) for improving livestock productivity in Central India

Grazing of winter wheat is a common practice in many temperate regions of the world but not in India/South Asia where spring wheat types are generally grown. Cutting of wheat for green fodder or its grazing is expected to reduce canopy light interception that could potentially reduce biomass production and grain yields. This is particularly true when cutting or grazing is practiced late in the crop growth stages. However, if cutting is practiced after canopy closure, enhanced light penetration and possible radiation-use efficiency (RUE, shoot dry matter produced per unit light intercepted) may offer some opportunity to Indian farmers in meeting huge fodder shortages without diverting precious resources. Likely genotypic variations in regeneration mechanism, sufficiently developed plant root system likely to invigorate regeneration and changes in dry matter partitioning following cutting may ameliorate the expected grain yield penalties with appropriate fertility management.

Earlier in north-west IGP, trials with irrigated wheat were conducted in western Uttar Pradesh, Haryana and Punjab and in Madhya Pradesh in the central plains. These trials have indicated that widely adapted cultivar like PBW 343 can be cut 70 days

Villager's cutting 55 days old wheat for green fodder, planted on October 20, 2014 in Mr Sadari's fields located in Sahpur Bhagoni village, near Pusa, Bihar after seedling emergence in Indo-Gangetic plains and 50 days after in Central Plateau. Cutting of wheat drastically reduced leaf area and NDVI, but the crop recovered very rapidly to regain its full canopy within 2 weeks of replenishment of the N removed in green fodder. Normally 50-70 days, wheat crop cut for green fodder, has nearly 30% protein (on dry weight basis, equivalent to N removal ~40 kg N/acre). It suggested that cutting did not affect the overall total dry matter accumulation, and grain yield. This was because the cut crop had delayed phenological development, allowing increased partitioning of shoot dry matter to spikes.

In a field trial, we studied the regeneration mechanism and invigoration capacity of the cut/grazed wheat cultivars in *Typic Haplustert black soil* of the BISA research farm at Manegaon, Jabalpur. We collected regeneration data on 26 wheat genotypes. We recorded the data on regenerated tillering and spikes under the categories below:

1. Tillers regenerated from the cut culm portion of the elongated stem
2. Tiller buds initiated in the axils of the basal leaves of the main shoot from lower nodes of the elongated stem –Tillers bearing spikes
3. Tiller buds initiated but bore no spike
4. Tillers not put up by the cut culms
5. Total number of plants

Regeneration data of dual purpose wheat cut 50 days after seedling emergence indicated that there are wide variations in 29 genotypes in their potential to regenerate (table 4).

Results presented in table 4 indicate that except the four genotypes, cutting resulted in yield penalties in most of the genotypes. Four wheat genotypes, namely, 3rd CSISA-HT-EM-10211; 3rd CSISA-HT-EM-10212; 3rd CSISA-HT-EM-10215; and 31 ESWYT-125 successfully mitigated the potential yield penalties caused by defoliation/cutting at 50 DAS stage.

4.6 Genome-Wide Single Nucleotide Polymorphisms (GS) - A variant of Marker- Assisted Selection (MAS)

Plant selection through genome-wide single nucleotide polymorphisms (GS) - a variant of marker-assisted selection (MAS) – enables crop breeders to accurately and cost-effectively, estimate a genome EBV (GEBV), even at seedling stage to rank best parents. Paving the way towards a high-throughput approach, genotyping-by-sequencing (GBS), researchers, Jesse Poland, a geneticist with the Kansas State University (KSU), and Ravi P. Singh, Head of Bread Wheat Improvement Program of the CIMMYT teamed up with the Cornell University to develop GBS-assisted climate-resilient and high-yielding wheat for South Asia. This project is led by KSU and funded by the United States Agency for International Development (USAID). Advanced wheat lines (~1000) developed at CIMMYT-Mexico were characterized for heat tolerance at four strategic field sites in South Asia (Ladhowal, Manegaon and Pusa of India at the BISA farms), and Faisalabad of Pakistan. In addition to the above, wheat lines were also planted in six environments at Cd. Obregon (Mexico). Through rigorous line testing for various traits including yield, GS project will promote the best possible varietal options for further testing and releases by the national programs and private sectors in South Asia. The GS project developed wheat varieties will have enhanced climate-resilience, combining heat tolerance and avoidance (earliness) and maximized yield potential that may curtail heat-induced yield losses by 20 – 30 percent in these regions. The results of these trials are presented in table 5.

The best ranking genotypes indicated in table 5 at each of the 3 sites were pooled together with those out-yielding the best national checks tested for multiple years and described previously in table 3. A trial with 20 genotypes has been laid out in *Rabi* 2014-15 for their final evaluations at the three BISA centres.

Table 4. Regeneration capacity and mitigation potential for yield penalty of 29 wheat genotypes cut for green fodder at 50 days after emergence

Wheat Cultivars	Regenerated from culm (1)	Tillers from lower nodes bearing spikes (2)	Tillers without spike (3)	Culms with no growth after cutting (4)	Total # of plants m^{-2} (5)	Green fodder t/ha	Grain yield in control (without cut) t/ha	Grain yield after fodder cut, t/ha
3rdCSISA-HT-EM-10215	58	92	25	17	192	5.61	4.64	5.47
3rdCSISA-HT-EM-10212	61	77	20	3	161	7.05	5.43	5.41
3rdCSISA-HT-EM-10225	51	140	16	6	213	4.71	4.68	5.31
31ESWYT-125	156	17	7	4	184	5.31	3.44	5.26
3rdCSISA-HT-EM-10211	64	103	18	16	201	5.90	4.31	5.21
GW 366	39	177	7	60	283	7.86	6.08	5.00
3rdCSISA-HT-EM-10229	59	121	27	5	212	5.20	4.58	4.86
31ESWYT-123	130	50	15	5	200	4.05	5.61	4.76
32ESWYT-115	139	40	4	5	188	7.50	5.01	4.71
3rdCSISA-HT-EM-10205	117	82	20	5	224	3.97	6.16	4.68
HD 2967	120	79	28	7	234	3.82	5.81	4.58
31ESWYT-142	147	69	30	7	253	6.55	3.71	4.50
31ESWYT-107	98	65	22	1	185	3.90	4.88	4.49
6EBWYT-513	85	84	30	9	208	5.63	5.79	4.46
CSW 16	83	185	32	37	337	4.55	5.61	4.44
JW 3288	70	108	9	12	199	3.67	4.71	4.29
3rdCSISA-HT-EM-10204	31	138	15	58	242	5.56	5.70	4.26
6EBWYT 519	13	61	7	5	86	2.68	4.98	4.24
31ESWYT-148	91	51	31	9	182	6.46	4.89	4.19
CSW 18	42	73	15	4	134	3.15	4.90	3.97
32ESWYT-117	121	36	30	7	194	5.75	4.04	3.92
31ESWYT-141	151	22	4	9	186	7.86	3.86	3.86
31ESWYT-145	113	43	17	16	189	7.88	5.47	3.82
6EBWYT-518	99	62	7	25	193	5.58	6.06	3.57
3rdCSISA-HT-EM-10220	95	160	28	36	319	4.05	4.56	3.47
6EBWYT 530	40	89	10	4	143	2.83	3.14	3.41
32ESWYT-141	82	47	5	0	134	6.95	5.54	3.39
3rdCSISA-HT-EM-10226	51	116	23	17	207	3.68	4.12	3.23
31ESWYT 137	98	74	15	4	191	4.46	4.76	2.61

Table 5. Climate resilient high yielding promising wheat genotypes for South Asia

Entry	GID	Cross name	Best for location
1006	6464471	KACHU/BECARD//WBLL1*2/BRAMBLING	Jabalpur
1009	6681676	QUAIU #1/SUP152	Jabalpur
1038	6681793	ND643/2*WBLL1/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	Jabalpur
9050	6690805	MON/IMU//ALD/PVN/3/BORL95/4/OASIS/2*BORL95/5/KA/NAC//TRCH	Jabalpur
3027	6569056	DANPHE #1*2/CHYAK	Ludhiana
7022	6682781	MUTUS*2//TAM200/TURACO	Ludhiana
7024	6684125	MUTUS*2/HARIL #1	Ludhiana
9029	6690438	TC870344/GUI//TEMPORALERA M 87/AGR/3/2*WBLL1/4/NAVJ07	Ludhiana
4021	6680812	WHEAR/VIVITSI//WHEAR/3/BECARD	Pusa
7032	6682839	SUP152*2/TINKIO #1	Pusa
7035	6682847	SUP152//ND643/2*WBLL1/3/ND643/2*WBLL1	Pusa
9005	6691293	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/MUU	Pusa
1019	6681737	KACHU//KIRITATI/2*TRCH	All sites
1016	6568075	KACHU//KIRITATI/2*TRCH	All sites
1024	6683456	KACHU/CHONTE	All sites
1036	6683522	MUTUS//ND643/2*WBLL1	All sites
2032	6568341	CHEWINK #1/MUTUS	All sites

4.7 Maize varietal development from land races from the tribal belt of Madhya Pradesh

In 2012, one group of ARS scientists from IARI, New Delhi collected 824 lines from the Central Plateau region inhabited by tribal people in the state of Madhya Pradesh. The next group of 3 ARS Interns posted at BISA farm Manegaon, Jabalpur, developed passport data and handed over the same along with one set of genotypes to JNKVV, and

Long (23 cm, 340 g) cylindrical on stay green

Rare Maize germplasm developed from land races (20, 22 & 24 rows & long cob) deposited one set with the National Gene Bank in the National Bureau of Plant Genetic Resources (NBPGR). The high yielding, early, disease resistant genotypes tolerant to temporary water logging situations and responsive to fertiliser nutrients were selected for further studies. The waterlogging and high yielding groups (total 29 vigorous lines) grown separately during 3 cycles were further sib-mated in winter 2014. A total of best **172 cobs** were selected from the two blocks. A set of **50 cobs** (high row numbers 18, 20, 22, 24 and 26) long, and with high cob weight were selected. Equal seed from each cob was pooled together as donor, and the rest of the seed was planted on the side ridge to facilitate equal opportunities for sib-mating. In another block, the seed from 122 cobs was pooled together and seeded on the ridges. Best cobs have been re-planted in the winter cycle 2014-15.

Grains (100) from the best 50 cobs (long, cylindrical, and yellow grain cobs having high row numbers (18, 20, 22 and 24) were also handed over to IARI, New Delhi and deposited with the National Gene Bank in NBPGR, New Delhi for their future uses.

4.8 Rapid-cycle genomic selection for heat stress tolerance in maize

BISA, **Ladowal** is identified as one of the suitable phenotyping sites for heat stress (Fig. 17), with excellent discriminative ability among heat tolerant and susceptible genotypes. Phenotyping trials for genome-wide association studies (GWAS) and genomic selection (GS) under heat tolerant maize for Asia (HTMA) project were conducted during spring seasons of 2013 and 2014.

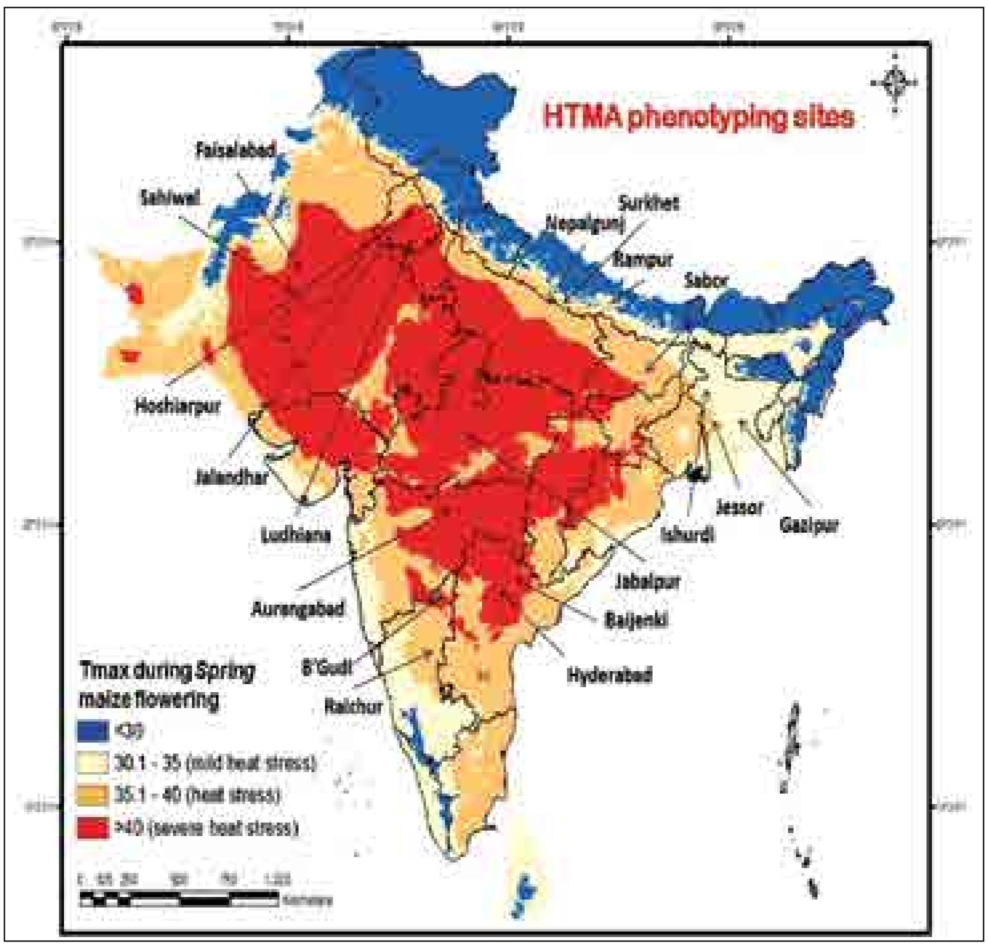


Fig. 17a. *Heat stress phenotyping sites in South Asia*

Fig. 17b. *Heat susceptible (left) and tolerant (right) hybrids at BISA, Ludhiana*

Salient findings from the phenotyping trials are as follows:

(i) **Genome-wide association studies (GWAS)**: An association mapping panel of 535 maize inbred lines was constituted involving lines with diverse genetic background, including lines from CIMMYT-Africa (106 lines) and CIMMYT-Asia (343 lines), Maize and Millet Research Institute, Sahiwal, Pakistan (52 lines); Purdue University USA (24 lines) and Kaveri Seeds (10 lines). The panel was genotyped using genotyping-by-sequencing platform, test-crossed with two CIMMYT tester, CML-286 (HG-A) and CML-451 (HG-B), and phenotyped across locations in South Asia (Fig. 17a). Findings of GWAS are as follows:

- Across-site data analysis of phenotyping showed significant genotypic variability in the panel for heat stress tolerance
- **Three** genomic regions identified for heat tolerance in tropical maize were located on **chromosomes 1, 3 and 5**. These regions can lead to yield gains ranging from 0.22 to 0.98 t/ha under heat stress.
- KASP assays are being designed for these three regions for further use in validation as well as marker-assisted selection in candidate segregating populations.

(ii) **Rapid-cycle genomic selection (RC-GS):** Two multi-parent synthetic (MPS) populations were constituted, one each in HG-A and B, involving Asia-adapted most elite lines (8-10). Approximately 500 $F_{2:3}$ progenies were derived from both the populations, test crossed and phenotyped under optimal temperature and heat stress across locations in South Asia, including BISA, Ladhowal. Salient findings are as follows:

- Top 5% $F_{2:3}$ lines, selected based on their across-location test-cross performance under optimal temperature and heat stress, are being inter-mated for developing C1
- $F_{2:3}$ families were genotyped using low density polymorphic markers (~350) within each of the multi-parent synthetic population. Marker effects are being calculated based on the phenotypes of test-crosses of the MPS families for establishing genomic estimated breeding value (GEBVs) for further use in developing advance cycles, i.e., C_2, C_3, etc.

(iii) **Identification of Asia-adapted heat tolerant hybrids:** 276 experimental hybrids were developed using existing elite heat tolerant lines in CIMMYT-Asia, and evaluated across temperature regimes in multi-location trials in

South Asia. **Top five heat tolerant hybrids** with high-stable performance were identified (Fig. 18) for large-scale testing during spring 2015, followed by scale-out by alliance partners, including seed companies.

4.9 Seed production on the BISA farms

In view of the availability of surplus land from the research experiments/trials, quality seed production of popular varieties was undertaken at all the three

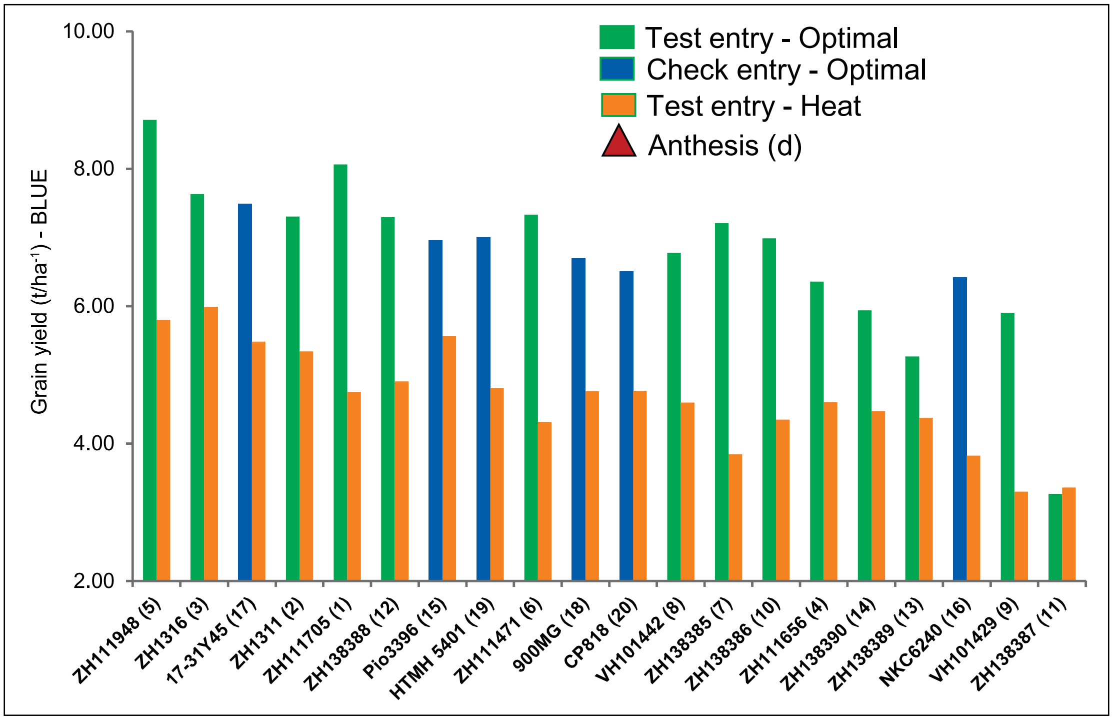


Fig. 18. Performance of CIMMYT hybrids in relation to commercial checks under heat stress

Table 6. Crop Production (tons) Statistics on the three BISA farms (*Rabi* 2013 and *Kharif* 2014)

Crops	Season	Ludhiana	Jabalpur	Pusa
Mustard	*Rabi* 2013-14	32 G	128 G	22 G
Wheat	*Rabi* 2013-14	5187 CS + 680 G	711 BS + 2786 TL + 1116 G = 4613	1060 FS + 43 TL + 272 G
Mung	*Kharif* 2014	0		13 TL
Maize	*Kharif* 2014	1050 G	649 G	649 G
Paddy	*Kharif* 2014	360 G	839 TL	
Basmati -1509/1121	*Kharif* 2014	765 G	1542 TL	
Soybean	*Kharif* 2014	33 G	-	44 FS + 10 G
Sesbania	*Kharif* 2014		4.92 TL	
Pigeonpea	*Kharif* 2014		49 G	30 G
Rice	*Kharif* 2014		2415 TL + 524 G	100 FS + 60 TL + 140 G
Gram	*Rabi* 2014		22 G	
Sorghum	*Kharif* 2014		17 G	
Grand Total		**5187 (CS) + 2920 (G) = 8107**	**711 (BS) + 7587 (TL) + 2505 (G) = 10803**	**1204 (FS) + 116 (TL) + 1123 (G) = 2443**

BS = Breeder seed, FS = Foundation seed; CS = Certified seed; TL = Truthfully labelled
G = Grains, mixture and undersize

BISA farms. Since BISA does not have varieties of its own, the Directorate of Wheat Research, Karnal was approached to allot seed of varieties that are in great demand as the concerned institutions/ universities were unable to meet the requirement of quality seeds.

The major part of the produce was returned to the institutions located in the concerned States. The leftover seed was given to the interested farmers as truthfully labelled seed (TL seed). The Centre-wise details of seed production are collated in table 6.

The different categories of high quality seed produced on the BISA research farms have the potential of replacing seed in nearly 1 million hectares in the wheat growing belt of India. Assuming a 20% yield advantage through seed replacement (5q/ha) owing to quality seeds of improved varieties, the total additional production of wheat is estimated to be around half a million ton annually.

4.10 Change Detection on the BISA farm, Manegaon

MP State Seed Corporation handed over the seed farms located in Manegaon and Lakhanwada villages to the Borlaug Institute for South Asia in November, 2011. It was not possible for us to plant winter season crops on the farms due to short time as well as due to difficulties in accessing the different parcels of the farms due to gullies formed over time and large dykes around fields. The state of the soils very poor (deep cracking soils) and irrigation water provisions inadequate for growing crops on the whole of the farms. Farm soils were heavily eroded by high intensity rains received on the farm (annually ~ 1500 mm). Many small and large gullies had formed. It was virtually impossible to move farm machinery in the fine textured black soils during the monsoon season due to poor network of farm-roads. Several dozens of large and small gullies were stone-walled to stop further soil erosion. It is a common knowledge that condition of the black soils change dramatically very quickly from wide and deep cracking soils when dry to muddy soils during monsoon rains. It is not always easy to plant crops during rainy season. The challenge for the tropical farmers is to "close the rainy season window" with crops to cover soils with residues for maintaining aggregate stability, conserve soil moisture, promote plant/root growth, sequester carbon etc.. Reducing acreages of fallow lands during *Kharif* season has been a major challenge of the black soils commonly found in the Central Plateau Region of India.

The FCCs for *Rabi* 2010 (February 2010 and Feb 2014) were studied for the change in vegetation index (mainly crops and crop conditions) using the NDVI image of Remote Sensing Data. NDVI is a crop growth indicator- higher the intensity of red colour, higher is crop cover and better is the crop condition. On the basis of remote sensing data it will be quite safe to drive few preliminary conclusions as under:

The Remotely sensed NDVI image clearly bring out that compared with 2010, there is an increase in NDVI in 2014 in different parcels of the BISA farms in Lakhanwada and Manegaon. As evidenced by increased red colour intensity of the pixels, soils on the BISA Farms responded very positively to adoption of conservation agriculture management practices in short time. Also the soil and water conservation measures adopted on the BISA farms significantly increased the acreages under the BISA Tank in North an also improved the vegetation index on the farm. It is also worth mentioning here that the NDVI on the farmers' fields also improved significantly in the village clusters of Tilgama, Sunderpur Dudi Pipariya and Sonepur. Higher NDVI observed in the these village clusters suggest that the improved resource conserving technologies pursued on the BISA farm have permeated and are also being followed by the nearby farmers.

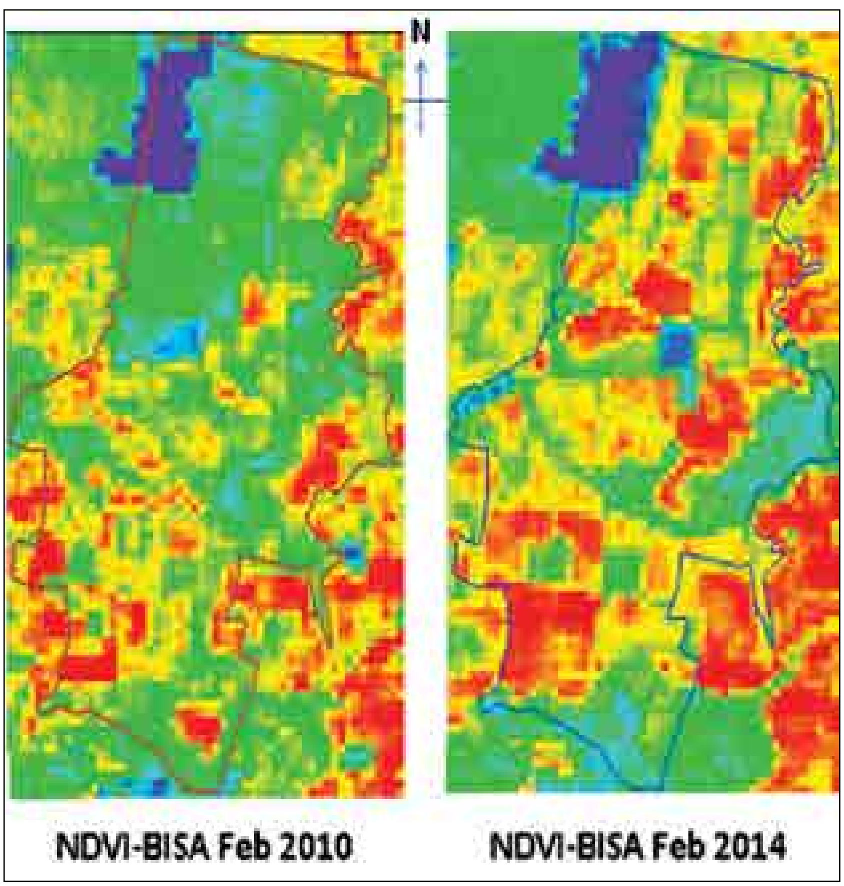


Fig. *Detecting developmental changes on BISA Farm between 2010 and 2014.*

5. Capacity Building and Partnerships

BISA Ladhowal, Ludhiana

- One Ph.D. student from the Department of Farm Machinery & Power Engineering, PAU is working on "Design and development of tractor operated seeder for wheat as relay crop in cotton".
- One Ph.D. student from the Department of Soils, PAU is working on "Enhancing yield and N- use efficiency in maize-wheat system under conservation agriculture".
- One Ph.D. student from the Department of Agronomy, HAU, Hisar is working on "Sustainable intensification of cotton-wheat cropping system through conservation agriculture based management practices".
- One M.Sc. student from the Department of Agronomy, PAU worked on "Productivity of maize (*Zea mays* L.) planted on permanent beds as influenced by crop residues and irrigation methods".

BISA Manegaon, Jabalpur

- Six ARS interns (ICAR-IARI scientists) from diverse disciplines such as Plant Pathology, Entomology, Genetics and Plant Breeding, and Agronomy, contributed to the research at BISA farms.
- A 4-week training was organised for four B. Tech interns, JNKVV Engineering College, Jabalpur.
- Three farm fests were organised in each *Rabi* season (2011-2014) wherein more than 3000 farmers participated to look at conservation agriculture management practices.
- Additional more than four thousand farmers from different parts of Madhya Pradesh visited the BISA farms under the Chief Minister's Farmers' *Tirath Yojana*, Govt. of Madhya Pradesh.

BISA Pusa, Samastipur

- One Ph.D. student of Soil Science from IARI, New Delhi is working on "Dynamics of soil organic carbon and nitrogen under conservation agriculture".
- One Ph.D. student of Soil Science from IARI, New Delhi is working on "Clay-humus stability in soils under conservation agriculture".
- One Ph.D. student of Soil Science from RAU, Pusa is working on " Effect of conservation agriculture on soil properties of a Calciorthent under rice-wheat system".
- One Ph.D. student of Plant Biotechnology from TERI, New Delhi is working on "Evaluation of micro RIL & Jupetaco (NIL population) for spot blotch".
- One Ph.D. student of Plant Breeding and Genetics from BHU, Varanasi is working on "Mapping for spot blotch resistance gene in wheat".

6. Development Works at the BISA Research Centres

A. Support received from the Government of Punjab

- A 220 KVA Electricity Grid & Substation costing Rs. 70 crores is being commissioned.
- 11-km road connectivity of BISA to PAU and NH-1 has been constructed by the State at a cost of Rs. 9 crores. A 2-km road inside BISA farm has also been constructed by the State.
- The Government has provided Rs. 1.40 crore for underground conveyance pipe, filtration units and flood point automation laboratory.

Self-Supported Developments at BISA ladhowal

- Internet Lease Line (2 Mbps), and 125 KVA Genset installed.
- Automatic weather station Davis Pro installed.
- Chain link fence was completed in the front & village side and a gate installed at the main entry. Three security check posts were constructed. Work of chain-link fencing on river side also initiated.
- 600 fruit plants, 700 avenue plants and 1500 poplar were planted.

B. Support received from the Government of Madhya Pradesh

- **A direct approach road to BISA bypassing Sonepur village :** A 500 m new approach road from Pariyat Canal embankment to BISA farm has been completed. This new road enters BISA farm directly and eliminates the need to pass through the Sonepur village. This road will help us to reach the farm in rainy season, when there is flood in Pariyat River and the cause way is under water. The Government has constructed this murram road under the rural employment scheme at a cost of about Rs. 13 lakh.
- **Piparia –Sonepur Road Connection :** Survey work for the construction of an approach road (Approx 3.5 Km. long) from the Kundam-Amarkantak Highway at Piparia has commenced after court procedures have been completed. The MP government had earlier sanctioned the funds for construction of this BISA- Piparia Road, and the work will start very soon.
- **Housing from the Ordinance Factory Khamaria (OFK) :** The OFK has allotted four residential quarters for the BISA staff in the residential complex of the Indian Army, at nominal rent. These flats are being renovated for housing the BISA staff. We expect that another set of 4 flats will be handed over to serve as guest -house and residence of senior staff. The JNKVV has also allotted one house to BISA in its Adhartal Teacher Colony, Jabalpur.
- **Post Box in Khamaria Post office :** Post and Telegraph Office, Jabalpur has allowed us to open a Post Box with postal address: **BISA, PO Box No. 1, Khamaria Post Office, Jabalpur - 482005.**
- **11/33 KVA Electric Power sub station :** The Government of MP has released Rs. 1,07,71,565/- for the establishment of a 33 KV substation in BISA farm. This amount is in addition to Rs. 9.9 million previously sanctioned for this purpose and utilized for laying a 2 km electric line.
- **Free mining permission for *murram* for BISA farm roads :** The MP Government has permitted BISA for *murram* mining for the construction and repair of 24 km long farm roads without any levies.
- **Tax Exemptions/Refund :** The State Government has issued an exemption order for the refund of VAT/Sale tax on all BISA purchases.
- **Petrol and Diesel Pump :** The Indian Oil Corporation has agreed to set up a petrol and diesel pump for exclusive fuel use in BISA operations. All approvals from the local bodies and explosive departments have been accorded and the work is to begin very soon.

- **M.P. State Seed Certification :** Agency has registered BISA-Jabalpur for seed production It will enable farmers to get high quality seed at subsidised rates.
- **BISA Farm Fencing :** The Collector, Jabalpur has issued orders for the completion of BISA fencing to the Rural Engineering and Development Department. Surveys have been completed; estimates for the fencing proposal and technical and administrative sanctions from the concerned authorities have been given. The work will be initiated soon.
- **Fibre Optic Cable for broad band connectivity :** The BSNL has laid out an underground fiber optic cable up to the BISA main gate to facilitate broad band connectivity for BISA operations. The MP Government has met all the costs for this facility.

Self-Supported works, BISA Manegaon

- Three tin sheds have been constructed.
- One Portacabin office to seat 10 staff has been commissioned.
- One resting shed cum shelter for the farm produce (30 × 115 feet) has been commissioned.
- Established a Davis Pro Vintage Auto-weather Station.
- Two new Holland tractors (70 and 55 HP, 4 × 4 W) procured.

C. Support received from the Government of Bihar

- The Government of Bihar has already widened the 11 km stretch approach road to BISA from Tajpur to Pusa.
- The Government of Bihar is being sensitized for supporting BISA on the following counts: Internet, Power Station and the shifting of overhead high tension electric cables outside the farm.

Self-Supported BISA facilities developed at Pusa, Bihar

- Established a Davis ProVintage Auto-weather Station.
- Chain link fencing of the BISA Research Centre.
- Genset (20 KVA) emergency power back-up commissioned.
- IARI Research Station has provided two Type-IV houses for BISA scientists at a nominal rent.

7. Technical Publications and other Literature

A. Research papers

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Devkota, K.P., Manschadi, A.M., Lamers, J.P.A., Humphreys, E., Devkota, M., Egamberdiev, O., Gupta, Raj, Sayre, K.D. and Vlek, P.L.G. 2013. Growth and yield of rice (*Oryza sativa* L.) under resource conservation technologies in the irrigated drylands of Central Asia*. Field Crops Research*, 149: 115-126.

Devkota, M., Martius, C., Lamers, J.P.A., Sayre, K.D., Devkota, K.P., Gupta, Raj, Egamberdiev, O. and Vlek, P.L.G. 2013. Combining permanent beds and residue retention with nitrogen fertilization improves crop yields and water productivity in irrigated arid lands under cotton, wheat and maize. *Field Crops Research*, 149: 105-114.

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Jat, M.L., Kumar, D., Majumdar, K., Kumar, A., Shahi, V., Satyanarayana, T., Pampolino, M., Gupta, N., Singh, V., Dwivedi, B.S., Singh, V.K., Singh, V., Kamboj, B.R., Sidhu, H.S. and Johnston, A. 2012. Crop response and economics of phosphorus fertilizer application in rice, wheat and maize in the Indo-Gangetic Plains. *Indian Journal of Fertilizers*, 8: 62-72.

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Jat, R.K., Sapkota, Tek, Singh, Ravi. G., Jat, M.L., Kumar, M. and Gupta, Raj 2014. Seven years of conservation agriculture in a rice-wheat rotation of eastern Gangetic Plains of South Asia: Yield trends and economic profitability. *Field Crops Research*, 164: 199-210.

Majumdar, K., Kumar, A., Shahi, V., Satyanarayana, T., Jat, M.L., Kumar, D., Pampolino, M., Gupta, N., Singh, V., Dwivedi, B.S., Meena, M.C., Singh, V.K., Kamboj, B.R., Sidhu, H.S. and Johnston, A. 2012. Economics of potassium fertiliser application in rice, wheat and maize grown in the Indo-Gangetic Plains. *Indian Journal of Fertilizers*, 8: 44-53.

Satyanarayana, T., Majumdar, K., Shahi, V., Kumar, A., Pampolino, M., Jat, M.L., Singh, V.K., Gupta, N., Singh, V., Dwivedi, B.S., Kumar, D., Malik, R.K., Singh, V., Sidhu, H.S. and Johnston, A. 2012. Economics of nitrogen fertilizer application in rice, wheat and maize grown in the Indo-Gangetic Plains. *Indian Journal of Fertilizers*, 8: 62-71.

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B. Technical presentations in conference/ seminars

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Sidhu, H.S. 2013. "What we can learn from South-Asia – CA Machinery Experience". Presentation in Project Launch & Planning Meet on "Farm Mechanization & Conservation Agriculture for Sustainable Intensification (FACASI)", March 25-30, 2013 at Arusha Tanzania.

Sidhu H.S., Jat, M.L., Singh, Parvinder and Singh, Yadvinder. 2014. "Designing & developing precision water and nitrogen management options for conservation agriculture based rice-wheat system", a paper in 4th International Rice Congress, under a special workshop on "New Paradigms of Growing Rice to Address Emerging Shortages of Water and Labour", on October 30, 2014, Bangkok International Trade and Exhibition Centre, Bangkok.

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C. Popular literature and brochures

Borlaug Institute for South Asia: An overview. *http://bisa.org*.

Borlaug Institute for South Asia : An International Agricultural Research Institute for Maize and Wheat in South Asia. *http://bisa.org*.

The 50 Pact Conference: International Conference on Renewing Borlaug's Promise. New Delhi. 16-17 August, 2013. *http://bisa.org*.

Borlaug Institute for South Asia: CIMMYT is uniquely positioned to tackle the challenges in India. *http://bisa.org*.

8. Staff

1. Internationally Recruited Staff (IRS)

(A) IRS on BISA contract

- H.S. Gupta, Ph.D., Director General
- Vibha Dhawan, Ph.D., Deputy Director
- Uttam Kumar, Ph.D., Assoc. Scientist, Wheat Improvement (Ladhowal)

(B) IRS currently on CIMMYT contract

- Raj Kumar Jat, Ph.D., Post-Doctoral Fellow, (Cropping System) (Pusa, Bihar)
- H.S. Sidhu, Ph.D., Senior Research Engineer (Ladhowal)

2. Nationally Recruited Staff (NRS)

(A) NRS on BISA contract

- S. Talekar, Ph.D., Seed Certification officer (Jabalpur)
- Nikhil Kumar, Ph.D., Research Associate (Jabalpur)
- Yogesh Kumar, Research Assistant (Jabalpur)
- Pankaj Singh, Farm Manager (Ladhowal)
- Avdesh Kumar, Research Assistant (Ladhowal)
- Manish Kumar, Research Assistant (Pusa)
- Anu Raswant, Executive Secretary (Delhi)
- Suman Gupta, Accounts Officer (Delhi)

(B) NRS currently on CIMMYT contract

- Ashok Kumar, Farm Assistant (Ladhowal)
- Varinder Kumar, Farm Technician (Ladhowal)
- Rachna Pahwa, Junior Finance and Administration Assistant (Ladhowal)
- Pradeep Jangra, Assistant Agricultural Engineer (Jabalpur)
- Pushpender Dwivedi, Farm Mechanic (Jabalpur)
- Harinder Kumar Rai, Field Assistant (Jabalpur)
- Bhajan Lal Sharma, Field Assistant (Jabalpur)
- Vineet Kumar Chaubey, Field Assistant (Jabalpur)
- Shankar Sanyal, Junior Finance and Administration Assistant (Jabalpur)
- Santosh Kumar, Junior Finance and Administration Assistant (Pusa)
- Mubarrak Ali, Driver (Pusa)

(C) Consultants with BISA

- Raj Gupta, Ph.D., Team Leader, BISA Research Station Developments (Delhi)
- Saradindu Choudhary, Ph.D., Plant Breeder (Pusa)
- Kuldeep Shukla, Local Liaison officer (Jabalpur)

3. CIMMYT Staff collaborating with BISA

- Etienne Duveiller, Ph.D., Director, South Asia
- M.L. Jat, Ph.D., Cropping System Agronomist
- P.H. Zaidi, Ph.D., Maize Physiologist
- Tek Sapkota, Ph.D., Agronomist (Climate Change)
- Parvinder Ramana, Agronomist
- Sudha Nair, Ph.D., Molecular Geneticist
- K. Kartik, Ph.D., Maize Breeder
- M.T. Vinayan, Ph.D., Maize Breeder

The Borlaug Institute for South Asia (BISA) is a non-profit international research institute dedicated to improving food, nutrition and livelihood security as well as environmental rehabilitation in South Asia, which is home to more than 300 million undernourished people. BISA is a collaborative effort involving the International Maize and Wheat Improvement Center (CIMMYT), the Indian Council of Agricultural Research (ICAR) and the Government of India. BISA harnesses the latest agricultural technologies to improve farm productivity and sustainably meet the demands of the future. Established on October 5, 2011 with R&D stations in the districts of Ludhiana (Punjab), Jabalpur (Madhya Pradesh) and Samastipur (Bihar), BISA is an institute built on the legacy of Dr. Norman E. Borlaug, the father of the Green Revolution, the winner of Nobel Peace Prize (1970) and the recipient of the Government of India's *Padma Vibhushan* (2006). BISA is committed to the people of South Asia, particularly the farmers, and is focused on catalysing a second Green Revolution. H.S. Gupta, Director General is the Chief Executive Authority of BISA.

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