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on
Conservation Agriculture

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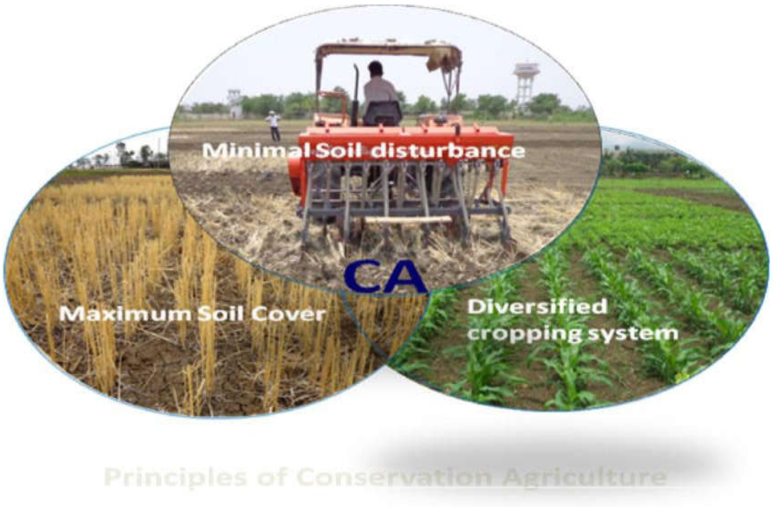

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1. Background

Agriculture is the most important sector in India; accounting for 17-18 per cent of the country's GDP and employs more than 60 per cent of the labour force. Food grain production of the country has reached a record 284.83 million tonnes during 2017-18, under favourable weather conditions those prevailed throughout the year. The mission of increasing food grain production, though somehow realized at present, but under risk due to climatic aberrations and reduced availability of land, water, nutrients along with poor and continuous degradation of the resources to cope up with the demands of increasing population. Although the country had attained self sufficiency in food grain production through intensification of agriculture with high yielding varieties and fertilizer application during the green revolution, productivity is still low and is stagnating. Conservation agriculture permits management of soils for sustainable agricultural production without excessively disturbing the soils, while protecting it from the processes of soil degradation like erosion, compaction, aggregate breakdown, loss of organic matter, leaching of nutrients, and processes that are accentuating by anthropogenic interactions in the presence of extremes of weather and management practices. The organic materials conserved through this practice are decomposed slowly, and much of it is incorporated into the surface layer, thus reduces the liberation rate of carbon into the atmosphere. In the total balance, carbon is sequestered in the soil, and turns the soil into a net sink of carbon. This could have profound consequences in our fight to reduce green house gas emissions into the atmosphere from agricultural operations and thereby help to forestall the calamitous impacts of global warming.

Conservation agricultural systems are gaining increased attention worldwide as a way to reduce the water footprint of crops by improving soil water infiltration, increasing soil water retention and reducing runoff and contamination of surface and ground water. South American countries (e.g. Brazil, Argentina, Colombia etc) practicing conservation agriculture reported to have a remarkable positive effects on water footprints of crops.

1.1 Conservation Agriculture – Indian Scenario

Unlike, in the rest of the world, CA technologies in India are spreading mostly in the irrigated areas of the Indo-Gangetic plains where rice-wheat cropping system dominates. CA systems have not been extensively tried or promoted in other major agro-ecoregions like rainfed semi-arid tropics, the arid regions and the mountain agro-ecosystems.

In India, efforts to adopt and promote resource conservation technologies have been underway for more than a decade, but it is only in the past 6-8 years that technologies are finding acceptance by the farmers particularly in the Indo-Gangetic irrigated plains under the aegis of the Rice-Wheat Consortium. Concerns about stagnating productivity, increasing production costs, declining resource quality, declining water tables and increasing environmental problems are the major factors forcing to look for alternative technologies, particularly in the northwest regions of India encompassing Punjab, Haryana and western Uttar Pradesh (UP). In the eastern region covering eastern UP, Bihar and West Bengal, developing and promoting strategies to overcome constraints to continued low cropping system productivity have been the chief concerns. The primary focus of developing and promoting CA practices in India has been the development and adoption of zero tillage cum fertilizer drill for sowing wheat crop in the rice–wheat system. Other interventions being tested and promoted in the Indo-Gangetic plains include raised-bed planting, laser-aided land-levelling, residue management alternatives, and alternatives to rice–wheat cropping system in relation to CA technologies. The area planted with wheat adopting zero-tillage drill has been rapidly increasing in the last few years. It is estimated that over the past few years, adoption of zero-tillage has expanded to cover about 2 m ha. The rapid adoption and spread of zero tillage is attributed to benefits resulting from reduction in cost of production, reduced incidence of weeds in long-run and therefore savings on account of herbicide costs, savings in water and nutrients and environmental benefits. Adopting CA systems further offers opportunities for achieving greater crop diversification. Direct seeded rice has been evaluated as an alternative to transplanted rice in view of increasing water and labour crisis and the adverse effect of green house gas emissions like methane and nitrous oxide. The work on system rice intensification in rice based production systems is also being worked out for saving water, chemical fertilizers and plant protection chemicals, and reducing green house gas emissions and also improving soil health. Information on efficient alternatives to rice-wheat cropping system, FIRB system, BBF and BBSF systems, laser-aided land-levelling, residue friendly happy and turbo seeding is available. Apart from improved soil health, up to 3 fold increase in productivity through diversification and 20% reduction in cost of production through tillage management have been achieved.

In contrast to the homogenous growing environment of the IGP, the production systems in semi-arid and arid regions are quite heterogeneous in terms of land and water management and cropping systems. These include the core rainfed areas which cover up to 60-70% of the net sown area and the remaining irrigated production systems. The rainfed cropping systems are mostly single cropped in the Alfisols while in Vertisols, a second crop is generally taken on the residual moisture. In *rabi* black soils, farmers keep lands fallow during *kharif* and grow *rabi* crop on conserved moisture. Sealing, crusting, sub-surface hard pans and cracking are the key constraints which cause high erosion and impede infiltration of rainfall. The choice and type of tillage largely depend on the soil type and rainfall. Leaving crop residue on the surface in CA is a major concern in these rainfed areas due to its competing uses as fodder, leaving very little or no residues available for surface application. Agroforestry and alley cropping systems are other options for CA practices. This indicates that the concept of CA has to be adopted in a broader perspective in the arid and semi-arid areas. Experience at IISS showed that reduced tillage in soybean-wheat system is a suitable option for growing soybean and wheat crops in Vertisols with saving of energy and labour. This also improves soil organic carbon, physical and biological properties.

Due to less biomass production and competing uses of crop residues, the scope of using crop residues for conservation agriculture is limited in dryland ecosystems. The Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, has shown that in dryland ecosystems, it is possible to raise a second crop with residual soil moisture by covering the soil with crop residues. In a network project on tillage conducted since 1999 at various centers of the All India Coordinated Research Project for Dryland Agriculture, it was found that rainfall and soil type had a strong influence on the performance of reduced tillage. In arid regions (<500 mm rainfall), low tillage was found on par with conventional tillage and weed problem was controllable in arid Inceptisols and Aridisols. In semi arid (500-1000 mm) region, conventional tillage was superior. However, low tillage + interculture were superior in semi-arid Vertisols and low tillage + herbicide was superior in Aridisols. In sub-humid (>1000 mm) regions, weed problem was severe due to rainfall and thus, there is a possibility of reducing the weed population by using herbicide in reduced tillage condition.

1.2 Challenges in adoption of Conservation Agriculture:

The CA system constitutes a major departure from the past ways of doing things. This implies that the whole range of agricultural practices, including handling crop residues, sowing and harvesting, water and nutrient management, disease and pest control, etc. need to be evolved and evaluated. The key challenges relate to the development, standardization and adoption of farm machinery for seeding amidst of crop residues with minimum soil disturbance; developing crop harvesting and management systems with residues maintained on soil surface; and developing and continuously improving site specific crop, soil and pest management strategies that will optimize the benefits of the new systems.

Residue burning: Residue burning is a quick, labour-saving practice to remove residue that is viewed as a nuisance by farmers. Burning residues facilitates seeding, reduces crop disease infestation and improves weed control. Residue burning, however, causes considerable loss of organic C, N and other nutrients by volatilization, which may affect soil microorganisms detrimentally. However, residue burning has several adverse environmental and ecological impacts. The burning of dead plant material adds a considerable amount of CO_2 and particulate matter to the atmosphere and can reduce the return of much needed C and other nutrients to the soil. The lack of a soil surface cover may also increase the loss of soil minerals via runoff. Crop residues returned to the soil maintain OM levels, and crop residues also provide substrates for soil microorganisms. In comparison to burning, residue retention increases soil carbon and nitrogen stocks, provides organic matter necessary for soil macro-aggregate formation and fosters cellulose–decomposing fungi and thereby carbon cycling.

Lack of appropriate machinery: Permanent crop cover with recycling of crop residues is a prerequisite and an integral part of conservation agriculture. However, sowing of a crop in the presence of residues of preceding crop is a problem. But new variants of zero-till seed-cum-fertilizer drill/planters such as Happy Seeder, Turbo Seeder and Rotary-disc drill have been developed for direct drilling of seeds even in the presence of surface residues (loose and anchored up to 10 t ha^{-1}). These machines are found to be very useful for managing crop residues for conserving moisture and nutrients as well as controlling weeds. In addition to moderating soil temperature, these machines are also adopted in the Indo-Gangetic plains under the rice-wheat system. There is an increasing awareness and concern for affordable and energy efficient equipment and technology for cost-effective production of crops. This more emphasis is on increased yield, reduced cost of cultivation, and efficient utilization of input resources to raise farm income. Agricultural Machinery or tools, which support conservation agriculture generally refer to the cultivation systems with minimum or zero tillage and *in-situ* management of crop residues. Different designs of direct drilling machines *viz.,* zero till drill, no till plant drill, strip till drill, roto till drill and rotary slit no till drill have been developed with controlled traffic measures for energy efficient and cost-effective seeding of crops without tillage.

Package of equipment and technology for residue-incorporation and bed planters have been developed for higher productivity with reduced irrigation water requirements. Recent development and performance of agricultural machinery have concentrated both on biological and mechanical parameters. Selection of most appropriate equipment for a specific situation is essential for maintaining soil physical environment. Besides the chosen equipment should be fuel efficient. Tractor operated/self propelled machinery/technologies used in conservation agriculture (CA) have the potential to meet the challenges encountered in CA under field conditions. Zero tillage farming on 1.2 million ha Indo-Gangetic plains reportedly saved 360 million m^3 water. It also reduces the number of operating hours of the pumps, thus reducing CO_2 emission and consumption of electrical energy.

Weed Management: Weed control is the other main bottleneck, especially in the rice-wheat system. Excessive use of chemical herbicides may not be a desirable option for a healthy environment. Continuous and high intensity rainfall during the rainy season also creates a problem in effective weed management through herbicides. Thus, increased use of herbicides is pre-requisite for adopting conservation agriculture. Countries that use relatively higher amounts of herbicides are already facing such problems of pollution and environmental hazards. Nutrient management may become complex because of higher residue levels in surface layers and reduced options for application of nutrients, particularly through manure. Application of fertilizers, especially N entirely as basal dose at the time of seeding may result in a loss in its efficiency and environmental pollution. Sometimes, increased application of specific nutrients may be necessary and specialized equipments are required for proper fertilizer placement, which contributes to higher costs.

Difficulty in input use: There are difficulties in sowing and application of fertilizer, water and pesticides under residue retained conditions. The conservation agriculture with higher levels of crop residuesusually requires more attention on the timing and placement of nutrients, and application of pesticides and irrigations.

Farmers' perception: *L*imiting factor in adoption of residue incorporation systems in conservation agriculture by farmers include additional management skills, apprehension of lower crop yields and/or economic returns, negative attitudes or perceptions, and institutional constraints. In addition, farmers have strong preferences for clean and good looking tilled fields vis-à-vis untilled shabby looking fields.

1.3 Technological Gaps

In India, efforts to adopt and promote CA practices are in increasing demand among stakeholders in intensively copped areas as in IGP. There is also limited use in other parts of India due to inappropriate knowledge about CA technologies. Concerns about stagnating productivity, increasing production costs, declining resource quality, depleting water tables and increasing environmental problems are the major factors to look for alternative technologies for improving production potential in diverse agro-ecological regions of the country. The Northern and Eastern IGP, black soil belts of central plateau, Odisha-upland systems, Coastal high rainfall regions and rainfed regions are the areas where there is a potential to improve crop productivity through CA technologies. In IGP, some of the CA components have gone to field implementation whereas in other parts of India efforts are made to popularize such technologies. Developing location specific CA practices in these regions are urgently required.

1.4 Mission

Mainstreaming conservation agriculture for sustainable use and management of natural resources to improve productivity and ensuring food security.

1.5 Objectives

- Develop and validate location specific CA technologies for sustainable intensification of cropping systems across agro-ecologies.

- Quantify impact of CA on soil health, input use efficiency, carbon sequestration and greenhouse gas emissions.

- Adapt and mainstream available best bet location specific CA practices for enhanced productivity and profitability in rainfed and irrigated eco-systems.

1.6 Thrust areas of Research

- Developing low cost, energy efficient and environment friendly CA technologies for major cropping systems both under rainfed and irrigated conditions.

- Validation and up-scaling location specific CA packages in farmers' participatory mode involving all stakeholders.

- Assessing the impact of CA practices on soil health, carbon sequestration, soil microbial biodiversity, resource use efficiency and mitigation of climate change.

1.7 Approach

1) Adaptive (Action) Research for CA Knowledge dissemination: To organize on-station and on-farm adaptive trials on CA and front line demonstrations in irrigated and rainfed cropping systems.

2)Basic & Strategic Research: To carry out research to evolve CA technologies (including suitable machinery) and its impact on soil health, input use efficiencies and GHG emissions both for irrigated and rainfed cropping systems.

3)Capacity Building and Knowledge Management: Capacity building of scientists/trainers/extension staff/students/farmers for effective dissemination of CA programme.

2. Research Highlights of Irrigated and RainfedEco-systems (2017–18)

2.1 Irrigated and Rainfed Eco-systems

Research highlights on the effect of conservation agriculture on crop productivity under rainfed region and irrigated ecosystem have been presented under this section. Various ICAR-institutes namely, IISS, Bhopal, CRIDA, Hyderabad, IARI, New Delhi, IIFSR, Modipuram, CIAE, Bhopal, DWR, Jabalpur, NRRI, Cuttack, CSSRI,Karnal, IIWBR, Karnal, ICAR-RCER, Patna and NIASM, Baramati have conducted multi-location on-farm and on-station experiments to fulfill the following objectives and objective-wise research highlights are presented here.

➢ Develop and validate location specific CA technologies for sustainable intensification of cropping systems across agro-ecologies.

➢ Adapt and mainstream available best bet location specific CA practices for enhanced productivity and profitability in rainfed and irrigated eco-systems.

2.1.1 Develope and Validate location specific CA technologies for sustainable intensification of cropping systems across agro-ecologies.

2.1.1.1 Crop Productivity and Profitability

Conservation agriculture based direct-seeded rice-wheat system (IARI)

A conservation agriculture (CA)-based direct-seeded rice (DSR)-wheat cropping system was undertaken to replace transplanted puddled rice (TPR) - Conventional till wheat (CTW) system, which has encountered host of problems related to water, nutrients, labour, fuel/energy, weed, and GHGs emission. A triple zero till (ZT) system (Table 1; Figures 1 and 2) with three crops (rice, wheat, mungbean) residue, which involved ZT DSR with summer mungbean (SMB) residue - ZT wheat (ZTW) with rice residue (RR) – ZT summer mungbean (SMB) with wheat residue (~MBR+ZT DSR - RR+ZTW-WR+SMB) gave 13% higher wheat yield and 40% higher system productivity than TPR-CTW system, although it had 7% lower rice yield. This triple ZT system with three crops residues led to a saving of almost 60 kg N/ha in rice and wheat crops in a year. This CA-based system could be a superior alternative to rice-wheat system and an important adaptation and mitigation strategy to climate change. A brown manuring option was also tried in this CA-based system, but it invited nematode problems in course of time and became inferior in rice yield to this CA based system.

Fig. 1. DSR under triple ZT conditions (with 75% N and 100% N)

Fig. 2. (A) Wheat under ZT+Rice Residue and (B) Mungbean under ZT Flat Bed in Rice-Wheat-Mungbean System

Table 1. Rice, wheat and system productivities in rice-wheat cropping system with CA practices (2018-19) Wheat equivalent yield of mungbean grain yield (t/ha) in parentheses

Treatments	Rice productivity (t/ha)	Wheat productivity (t/ha)	System productivity (rice equ.) (t/ha)
ZT DSR – ZTW (Double ZT system)	4.70	5.26	9.46
ZT DSR+BM – ZTW	4.46	5.27	9.25
WR+ZT DSR - RR+ZTW (75%N)	4.57	5.27	9.36
WR+ZT DSR - RR+ZTW (100%N)	4.64	5.33	9.48
WR+ZTDSR+BM - RR+ZTW (75%N)	4.37	5.39	9.29
WR+ZTDSR+BM - RR+ZTW (100%N)	4.43	5.47	9.43
ZT DSR – ZTW – ZT SMB (Triple ZT system)	4.83	5.76	13.29 (3.21)*
MBR+ZT DSR - RR+ZTW -WR+ SMB (75%N)	5.08	5.96	13.89 (3.38)*
MBR+ZT DSR - RR+ZTW -WR+ SMB (100%N)	5.25	6.02	14.32 (3.61)*
TPR-ZTW	5.63	5.06	10.09
TPR-CTW	5.47	4.98	9.86

Conservation agriculture (CA)-based cotton-wheat, maize-wheat and pigeonpea-wheat system

The predominant rice-wheat cropping system in the Indo-Gangetic plains has encountered a host of problems. A non-rice crop, that is as remunerative as rice, is required to diversify this system. A study was carried out in three major non-rice cropping systems, *viz*., cotton-wheat, pigeonpea-wheat and maize-wheat with suitable conservation agriculture (CA) practices revealed that cotton-wheat system among these systems was superior in terms of system productivity (Table 2). All ZT permanent broad, narrow and flat beds with residue retentions were superior to conventional till practice on system productivity. Cotton-wheat system under ZT permanent broad with residue gave significantly higher system productivity than conventional till system. These two systems performed better under 75% N than 100% N and could save 67.5 kg N/ha in cotton and wheat in a year. Thus, these CA-based systems could be promising alternatives to rice-wheat system and important adaptation and mitigation strategies to climate change.

Table 2. System productivity (wheat equ.) in wheat-based cropping systems with CA practices (2018-19)

Treatments	Cotton-wheat (t/ha)	Maize-wheat (t/ha)	Pigeonpea-wheat (t/ha)
CT	10.15	9.86	7.93
ZTNB	11.48	9.84	8.28
ZTNB+R (75N)	11.84	10.11	-
ZTNB+R(100N)	12.94	10.31	8.87
ZTBB	13.14	10.98	9.47
ZTBB+R(75N)	13.81	11.28	-
ZTBB+R(100N)	14.63	11.45	9.78
ZTFB	14.14	10.80	9.17
ZTFB+R(75N)	13.01	10.76	9.25
ZTFB+R(100N)	13.77	11.12	-

Broad bed planting without residue

Broad bed planting with residue

Fig. 3. Cotton crop in the field under broad bed with and without residue

Wheat Wheat under ZT-Narrow Bed+ Maize Residue   Wheat under ZT-Broad Bed + Pigeon pea Residue under ZT in different cropping systems   Wheat under ZT-Flat Bed+ Pigeon Pea Residue
(C-W, P-W, M-W) Fig. 4. Wheat crop under different beds with and without residue

Monetization of yield increases in CA vs CT in major cropping systems

Yield of different CA-based diversified sound alternative cropping systems rice-wheat (with mungbean), cotton-wheat, pigeonpea-wheat and maize-wheat was compared with CT systems. All major cropping systems under study showed higher yield in CA over CT, with an overall 16-45% increase (Table 3). Maximum yield increase of 45.2% was observed in CA based rice-wheat-mungbean system, which led to an earning of Rs 86,210. Yield and earnings in CA based cotton-wheat system (44.1%) were comparable to it. Pigeonpea-wheat system performed third best with an overall yield of 9.78 t/ha in CA over 7.93 t/ha in CT. There was appreciable yield increase of 16.1% in maize-wheat system as well, corresponding to earnings of approximately Rs 29117. Thus, CA based interventions increase overall yield in every major cropping system and also promote higher income for farmers.

Table 3. Wheat Eq. Yield (WEY) and monetized yield increases in CA based systems

Cropping System	Equiv. Yield (ton/ha as WEY)		Yield increase (YI) (%)
	CA	CT	
Rice-wheat (with mung-bean)	14.32	9.86	45.23 (Rs 86,210)
Cotton-wheat	14.63	10.15	44.17 (Rs 74,495)
Pigeon pea -wheat	9.78	7.93	23.34 (Rs 30,207)
Maize -wheat	11.45	9.86	16.11 (Rs 29,117)

NIASM

Effect of trash, fertilizer-nitrogen and SORF techniques on growth, yield attributes and cane yield of sugarcane:

A field experiment was conducted with ratoon sugarcane to address the problem of environmental pollution due to trash burning (~10-20 t ha^{-1}) of sugarcane trash, poor sprouting of stubbles, lower nutrient-use efficiency and cane productivity in ratoon sugarcane. There were eight treatment combinations of four methods of ratoon management (root pruning: RP; off-barring: OB; stubble shaving: SS and control), two fertilizer nitrogen (fert-N) application methods (broadcast as the farmer's practice: NBC and placement with multipurpose SORF machine: NP), three methods of trash management (clean cultivation/ no-trash: NT; burnt trash: BT and spreading the trash uniformly in the field after chopping with a trash cutter: CT) and two absolute controls (un-chopped trash without fert-N (UCT+No-N) and no-trash-no fert-N (NT+No-N)). The 50 and 75 % of recommended dose of fert-N was applied as basal under broadcast and placement of fert-N treatments, respectively. A multi-purpose SORF machine has been developed and used for stubble shaving, off-barring, root pruning and placement of basal dose of fertilizers as per the treatments (Fig. 4).


Un-chopped trash


Chopped trash


Burnt trash


Clean cultivation

Band placement of fert-N (NP) | Root pruning (RP) + NP | Off-barring (OB) + NP | Stubble shaving + OB+RP+NP

Fig. 4. Application of treatments in experimental field of sugarcane ratoon.

The perusal of data reveals that surface retention of chopped trash and adoption of SORF techniques enhanced the growth and yield parameters of sugarcane significantly ($P \leq 0.05$) over conventional farmers' practices of trash burning and broadcast application of fertilizers (Fig. 5). CT+SORF treatment recorded maximum plant height at maturity which was significantly higher as compared to N un-fertilized, N broadcast and N placement treatments, respectively. Surface retention of chopped trash and following either individual or in combination of ratoon management practices *i.e.* off-barring, root pruning and band placement of fert-N improved the plant height significantly over trash burnt/removed and broadcasting of fert-N treatments by 10-26 %.

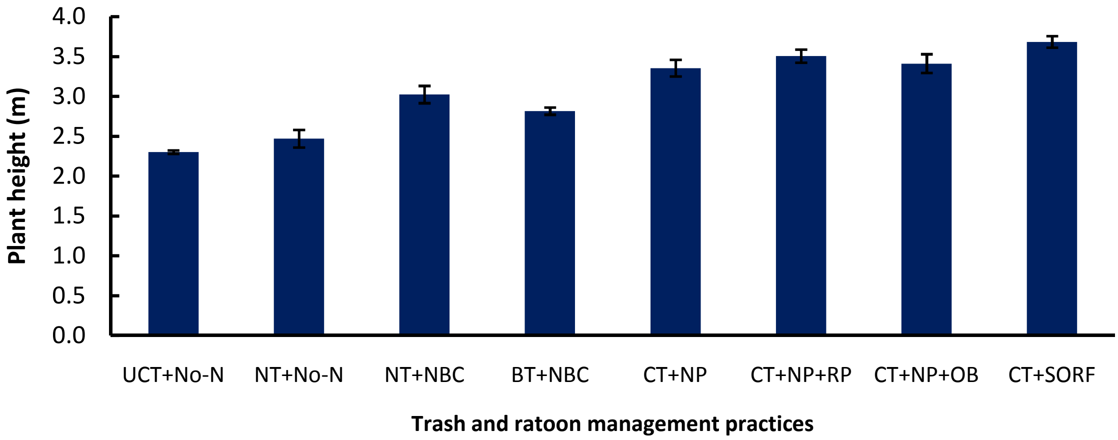


Fig. 5. Effect trash, fert.-N and SORF techniques on plant height of sugarcane.

Similarly, the maximum numbers of tillers at maturity was also recorded with CT+SORF treatment which was closely followed by CT+NP+RP treatment and both were significantly higher over the conventional trash burnt and broadcasting of fert-N and N un-fertilized treatments (Fig. 6). However, surface retention of chopped trash and band placement of fert-N alone did not improve the tillers number significantly over the conventional trash burnt and broadcasting of fert-N treatments, indicated that stubble shaving and root pruning are the important practices for sustaining higher numbers of tillers of ratoon sugarcane.

The yield attributes of sugarcane were influenced significantly due to different trash, fert.-N and ratoon management practices. The maximum values of millable cane, cane length, cane weight and juice yield were recorded with CT+SORF treatment which was significantly ($P \leq 0.05$) higher than the other treatments except in case of millable cane where it was at par with CT+NP+RP treatment (Table 4). Surface retention of chopped trash and placement of fert-N in soil (CT+NP) improved the millable cane numbers, cane length, cane weight and juice yields by 15-53, 15-37, 20-43 and 16-40 % over the conventional trash burnt and broadcasting of fert-N and N un-fertilized treatments. While pruning of older roots (CT+NP+RP) further improved these parameters over CT+NP by 6, 3, 9 and 14 %, respectively. However, these parameters did not improve significantly due to off-barring (CT+NP+OB) over the placement of fert-N (CT+NP). But, cane length, cane weight and juice yields further improved significantly due to stubble shaving (CT+SORF) by 9, 14 and 9 %, respectively over CT+NP+RP treatment, indicated the benefits of using SORF techniques together rather than their individual use.

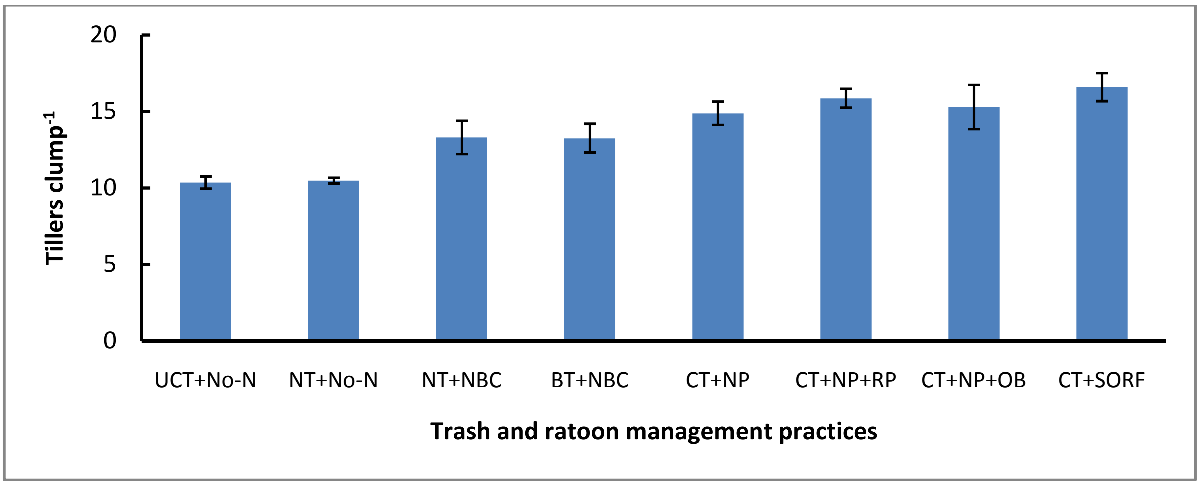


Fig. 6. Effect trash, fert.-N and SORF techniques on number of tillers of sugarcane.

Table 4. Effect of trash, fert.-N and SORF techniques on yield attributes of sugarcane.

Treatment	Millable cane (1000 ha^{-1})	Cane length (m)	Cane weight (kg)	Juice yield (ml $cane^{-1}$)
UCT+No-N	81.36	1.55	0.97	366.3
NT+No-N	86.66	1.63	0.98	384.4
NT+NBC	110.50	1.84	1.18	443.9
BT+NBC	108.02	1.84	1.16	440.2
CT+NP	124.11	2.12	1.39	511.8
CT+NP+RP	132.11	2.18	1.51	584.5
CT+NP+OB	126.20	2.17	1.46	553.0
CT+SORF	140.14	2.38	1.72	639.1
LSD ($P \leq 0.05$)	12.1	0.20	0.15	51.7

Surface retention of chopped trash and placement of fert-N in soil (CT+NP) improved the cane yield significantly by 14-21 and 60-66 % over conventional trash burnt/removed with N fertilized through broadcasting (NT/BT+NBC) and N un-fertilized with un-chopped trash (UCT+No-N) or without trash (NT+No-N) treatments, respectively. While pruning of older roots along with CT+NP (CT+NP+RP) improved the cane yield significantly by 24% over conventional trash burnt and broadcast application of fert-N. There was no significant improvement in the cane yield due to individual practices of root pruning and off-barring over the CT+NP. But, employing of stubble shaving, off-barring and root pruning practices together improved the cane yield significantly ($P \leq 0.05$) by 15, 8 and 12 % over individual practices of band placement of ferti-N, root pruning and off-barring, respectively. It indicate that shaving of stubbles, pruning of old roots of sugarcane and band placement of fert-N along with surface retention of chopped trash helps in maintaining of better plant health as reflected in the other growth and yield parameters and thus have contributed in the cane yield production. Thus, surface retention of chopped trash and adoption of SORF techniques with application of 75% recommended dose of fert-N as basal improved the cane yield by 39 % over conventional trash burnt and broadcast application of fert-N (Fig. 7).

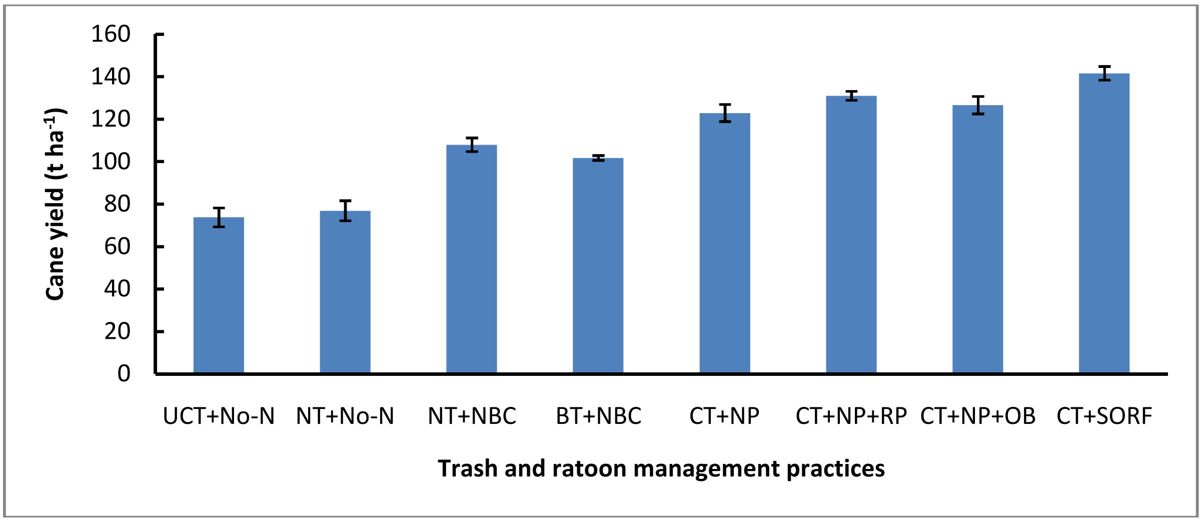


Fig. 7. Effect trash, fert.-N and SORF techniques on cane yield of sugarcane.

2.1.1.2 Tillage and Residue management

(A) Strategies to enhance crop residue retention under Rainfed Agriculture (CRIDA)

The crop residues in rainfed regions were very low due to poor crop yields, single cropping season in rainfed regions besides this the crop residues has competing use. Hence experiments were initiated in different cropping systems to enhance the crop residues to the soil.

1. Pigeonpea-Castor system

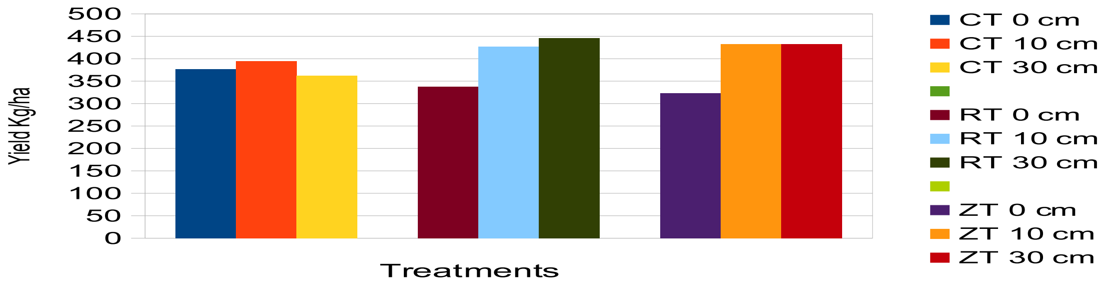
An experiment was initiated in 2009 in pigeon pea castor cropping system to study the strategies to enhance residues. The test crop in 2018 was castor. The experiment was laid out in split plot design with tillage practices as main plots and anchored residues (different harvest heights) as subplots. The different tillage practices were: conventional tillage (disc ploughing in off season, cultivator, disc harrow and sowing of crop), Reduced tillage (ploughing once with cultivator and disc harrow), Zero tillage (direct sowing in residues). The castor crop was sown in the pigeonpea residue stubbles (previous year crop) retained by harvesting the castor crop at different heights, with CRIDA precision planter. In The different residue levels besides harvesting the crop at different heights (0 cm, 10 cm and 30 cm) to increase the residue contribution to the field (Plate 1a). The daincha crop was sown in between the widely spaced castor, daincha was cut at 45 DAS and applied to the field as mulch. The additional advantage of daincha was it supplies additional dose of nitrogen and reduces weed growth (Plate 1b). This year castor was sown in first week of July. Along with castor daincha also was sown as intercrop. The germination of daincha was good in all the treatments. The crop experienced one dry spells during the vegetative phase.

Weed growth

No weed growth with Daincha Intercrop

b. Growing of green manure crop in between widely spaced Castor

Plate 1: Strategies for enhancing residue retention in Rainfed region



The rainfall ceased by the end of September. Hence the castor yields were very low in third picking. The yields of reduced tillage (RT) were higher as compared to conventional tillage (CT) and Zero tillage (ZT). This year ZT and CT were on par with each other. The crop yield increased with increase in residues in all the tillage treatments. (Fig 1).

Fig. 1 Influence of different tillage and residue levels on castor yield

a Manipulation of harvesting height

2. Sorghum-Black gram system

A long-term experiment was initiated during 2013 with sorghum and black gram as test crops in yearly rotation at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad. The experiment was laid out in a strip plot design with two tillage's: conventional (CT) and minimum (MT) (treatments effective from 1998) and three residue retention treatments (started w.e.f 2013) viz; No residue application (S1), harvesting at 35 cm height (1/3 rd height) (S2), harvesting at 60 cm height (S3) in case of sorghum. For black gram, the residue retention treatments were as follows: No residue (S0), 50% of the residue retention (S1) (Clearing of residue from alternate rows), 100% retention (S2). During the current year, blackgram (T-9) was the test crop grown in sorghum residues in rotation. It was observed that blackgram yield varied from 212 to 412 kg ha^{-1} across the treatments (Table 1). Minimum tillage recorded (341.53 kg ha^{-1}) significantly higher yield (25.09%) compared to conventional tillage (273.02 kg ha^{-1}). Blackgram yield significantly varied with residue retention treatments of previous crop. Among the residue retention treatments, harvesting sorghum at 60 cm height (S2) recorded significantly higher blackgram yield of 379.28 kg ha^{-1} followed by cutting at 35 cm height (1/3 rd height) (S1) (302.61 kg ha^{-1}) compared to control (no residue) (239.92 kg ha^{-1}). The respective increase in yield with S2 and S1 treatments was 58.08 and 26.13 % over control (Table 1)

Table 1: Effect of tillage and residue retention of previous crop (Sorghum) on blackgram grain yield (kg ha^{-1})

Tillage	**Residue**	**Blackgram grain yield (kg ha^{-1})**
Minimum tillage	S0: No residue application	267.00
	S1: Cutting at 35 cm height (1/3 rd height)	344.73
	S2: Cutting at 60 cm height	412.86
Conventional tillage	S0: No residue application	212.84
	S1: Cutting at 35 cm height (1/3 rd height)	260.50

	S2: Cutting at 60 cm height	345.71
CD (0.05)		
Tillage		25.05
Residues*		17.28
T X R		NS

*** p=0.05**

3. Finger millet + Pigeonpea

Studies were initiated in fingermillet+pigeonpea (8:2) in rainfed ecosystem at Bangalore. Horsegram and field bean were tested as cover crops to utilize the off season rainfall and increase the residues. The performance of both the cover crops was good as the rainfall in May was good and above normal (Table 2).

Table 2: Biomass yield of field bean and horse gram

Treatment	Field bean (t/ha)	Horse gram (t/ha)
M_1C_2	12.60	10.46
M_2C_2	12.44	10.32
M_3C_2	11.11	9.00

Among different tillage practices, reduced tillage registered higher finger millet grain equivalent yield (1956 kg ha^{-1}) compared to conventional tillage (1652 kg ha^{-1}) and zero tillage (1307 kg ha^{-1}). But the fingermillet equivalent yields were on par with each other in all the tillage treatments (Table 3).

Both the cover crops horsegram and fingermillet increased the fingermiller equivalent yield. Among the cover crops horsegram as cover crop increased the finger millet grain equivalent yield (1963 kg ha^{-1}) as compared to field bean (1566 kg ha^{-1}) and control (1387kg ha^{-1}). The interaction between the tillage treatments and residues were non significant.

Table 3: Yield influenced by conservation agriculture practices in finger millet+ pigeonpea intercropping (8:2)

Treatment	Yield (kg ha^{-1})							
	2018				Pooled (2 years)			
	Grain	Straw	Pigeonpea	FME	Grain	Straw	Pigeonpea	FME
M_1: Conventional tillage	1367	1730	171	1652	1853	2872	120	2058
M_2: Reduced tillage	1520	1845	262	1956	1816	2668	178	2118
M_3:Zero tillage	1036	1390	163	1307	1340	1885	117	1538
S. Em. ±	215.28	488.97	58.92	259.63	117.03	314.69	19.85	140.56
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
C_1: Control	1132	1411	153	1387	1454	2119	120	1658
C_2: Field bean	1280	1719	172	1566	1595	2425	140	1832
C_3: Horsegram	1510	1835	271	1963	1960	2882	155	2223
S. Em. ±	95.22	95.74	40.43	114.90	54.21	118.65	10.92	60.44
CD (p=0.05)	293.40	295.01	NS	354.04	167.02	365.5	NS	186.24
M_1C_1	1167	1509	123	1371	1630	2491	113	1822
M_1C_2	1423	1719	129	1638	1750	2807	122	1957
M_1C_3	1512	1963	261	1947	2178	3319	126	2394
M_2C_1	1181	1656	203	1519	1576	2202	160	1846
M2C_2	1524	1776	246	1934	1663	2516	181	1969
M_2C_3	1855	2103	336	2416	2210	3287	194	2538
M_3C_1	1050	1068	132	1270	1157	1664	88	1306

M_3C_2	894	1663	139	1126	1372	1953	116	1570
M_3C_3	1164	1440	217	1525	1491	2038	146	1738
S. Em. ±	164.92	165.83	70.02	199.01	93.89	205.50	18.91	104.69
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

FME- Finger millet Equivalent

(B) Integration of in-situ moisture conservation with CA principles

In general,in rainfed regions, the gap in the crop yields between conservation agriculture and conventional tillage is higher under low rainfall years whereas, this yield gap is narrow in good rainfall years. The low yields in zero tillage in low rainfall years might be due to poor residue yields which results in low soil moisture retention hence, integration of in-situ soil moisture conservation along with three principles of CA is essential to increase the soil moisture content and thereby improve the crop yields in CA systems. Hence, experiments were initiated in maize-horsegram/pigeonpea and maize–pigeonpea in Alfisols at Hyderabad and one experiment at Akola in soybean-chickpea system in vertisol to explore the possibility of including insitu moisture conservation as fourth principle in CA systems.

1. Maize- Pigeonpea system

An experiment was initiated with the integration of insitu moisture conservation with CA practice in maize-pigeonpea system in 2014. This year, the maize, test crop was laid out in RBD with different treatments (Conventional planting without residues, conventional tillage formation of raised bed every year, conventional planting with conservation furrow, CA flat sowing, permanent raised bed reshaping every year with residues, CA+ conservation furrows reshaped every year. The bed and furrows and conservation furrow were reshaped at the time of sowing in zero tillage (Plate 2), whereas in conventional method, furrows and beds were prepared every year before sowing with the implements. Integration of insitu moisture conservation practices either through conservation furrow or bed and furrow method in both CA and Conventional tillage has recorded higher yield as compared to no moisture conservation treatments. Among the conservation treatments permanent conservation furrow recorded higher yields (Fig 2). The higher yields in moisture conservation treatments was due to higher retention of soil moisture as compared to no moisture conservation

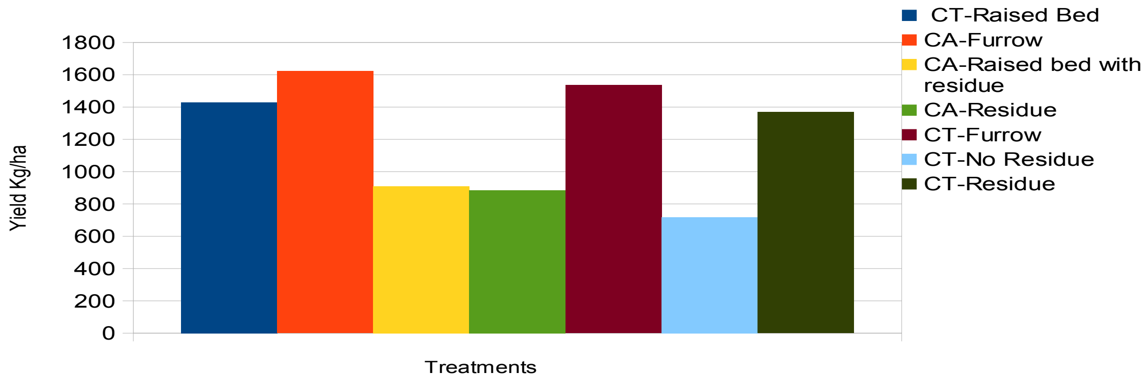


Fig 2: Influence of different Moisture conservation treatments on Maize yield in Maize-pigeonpea cropping system

Plate 2: Reshaping of a) Bed and furrow in Zero tillage b) Conservation furrow

2. Soybean-Chickpea

Experiments were initiated in 2016 in soybean-chickpea system in black soils at Akola. With the following treatments in soybean in Kharif Conventional tillage (CT) - Ploughing once in 3 years + 2 pre-sowing harrowings + One hand weeding + Opening of furrow with hoe in each row at 30-35 DAS + Crop residue mulch ($T_{1)}$, Conventional tillage (CT) - Ploughing once in 3 years + 2 pre-sowing harrowings + One hand weeding + Opening of furrow with hoe in each row at 30-35 DAS without crop residue mulch (T_2), Reduced tillage (RT) – Broad bed and furrow every year + Pre and post emergence herbicide application + crop residue (T_3), Zero tillage + crop residue (T_4), Permanent BBF furrow after every 4 rows + crop residue mulch (T_5). In Rabi Conventional tillage (CT)- Pre sowing harrowing + One hoeing + One hand weeding + Crop residue mulch (T_1), Conventional tillage (CT) - Pre sowing harrowing + One hoeing + One hand weeding + No crop residue mulch (T_2), Reduced tillage (RT) – Pre sowing harrowing + Broad bed and furrow every year + Pre-emergence herbicide application + Crop residue mulch (T_3), Zero tillage + crop residue (T_4), Permanent Broad bed and furrow + Pre-emergence herbicide application + crop residue mulch (T_5)

It was observed that the growth and yield attributes of soybean and chickpea were influenced by tillage treatments significantly (Table 4). In soybean both seed and straw yield were higher in T_3 and was significantly superior over other treatments but was on par with T_1. In Soybean-Chickpea cropping system the soil moisture at 0-15 and 15-30cm depth, recorded at different crop growth stages (Table 5) the soil moisture status observed was good during vegetative and flowering stage and very less during maturity stage of crop growth. It was better in all treatment combinations during flowering stage of crop growth at 0-15 and 15-30cm depth. The soybean crop was under mild moisture stress initially at pod formation/ seed initiation due to dry spell of 23 days but later on it recovered (Plate 3).

Table 4: Growth, yield attributes and productivity of soybean as influenced by different treatment combinations

Treatments	Plant height (cm)	Number of pods/plant	Grain weight (g plant^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	30.20	29.2	7.81	1982	2457
T_2	28.35	28.1	7.69	1900	2302
T_3	29.88	30.6	8.07	2140	2673
T_4	27.60	26.6	7.51	1879	2229
T_5	27.05	26.3	7.12	1806	2141
S. E. (m)	0.299	0.377	0.169	63.10	70.67
C.D. at 5%	0.931	1.17	0.527	196	220

Table 5. Soil moisture content at different crop growth stages recorded at 0-15 and 15-30cm depth

Treatments	Depth (cm)	Soil Moisture Content (%)		
		Vegetative stage (30/07/18)	Flowering stage (28/08/18)	Maturity stage (29/09/18)
T_1	0-15	30.45	30.80	25.42
	15-30	32.30	32.70	26.26
T_2	0-15	30.40	30.55	25.14
	15-30	31.23	32.05	25.94
T_3	0-15	32.15	33.12	27.10
	15-30	33.30	34.06	28.54
T_4	0-15	31.80	32.00	26.05
	15-30	32.70	33.75	27.15
T_5	0-15	31.85	32.11	26.12
	15-30	33.10	33.86	27.20

In chickpea the grain yields were significantly influenced by the treatments whereas the straw yield was not influenced by the tillage treatments. In chickpea T_2 recorded significantly superior yields over T_4 and T_5 and was on par with T1 and T_3 (Table 6).

Table 6. Yield of chickpea as influenced by different treatment combinations

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	1008	1620
T_2	1080	1696
T_3	992	1600
T_4	812	1280
T_5	884	1400
S. E. (m)	30.54	101.66
C.D. at 5%	95.14	NS

T_1

T_2

T_3

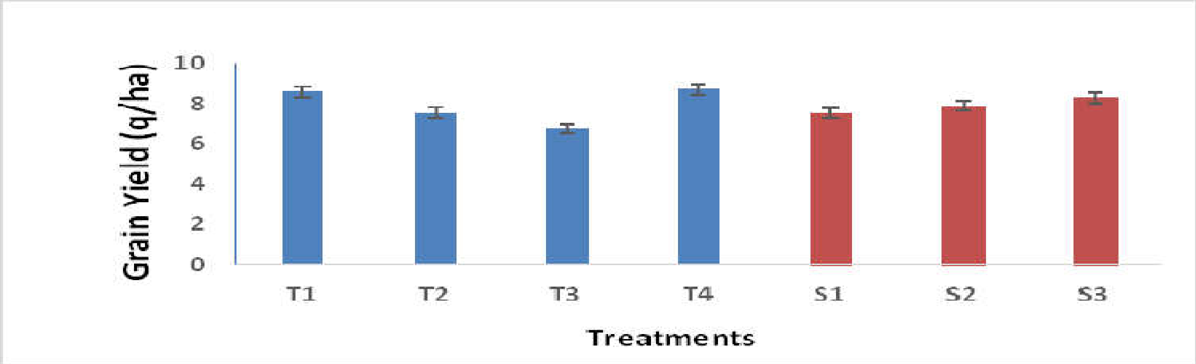
T_4

T_5

Plate 3: Performance of Soybean in different treatments

3. Maize – Horsegram/ Pigeonpea

An experiment was initiated with four tillage treatments in maize – horsegram/ pigeonpea system as main plots viz., conventional (T1) (CT) minimum tillage (T_2) (MT), zero tillage (T3) (ZT) and zero tillage with soil and moisture conservation practices (T_4) and three residue retention treatments, viz., farmers' practice of harvesting close to the ground without any retention of residues, harvesting maize at a height of 30 cm and retaining them, harvesting only cobs and retaining the entire stubbles as such in sub plots (Plate 4). Among the tillage practices, T_4 recorded higher grain yield which was on par with T_1 treatment and significantly superior over rest of the treatments. Among the residue retention levels, S3 recorded significantly higher yield over S_2 and S_1 (Fig 3). Significantly lower yield was observed in S_1. The interaction effects of tillage and residue levels were found to be significant. Maximum yield was obtained in T_4S_3 which was on par with T_4S_2, T_1S_1 and T_1S_2 and significantly superior over other treatment combinations.



. Fig 3: Effect of different tillage practices and residue retention levels on grain yield

Plate 4: Crop growth in various treatments during the Kharif 2018

IIWBR

Long term effect of tillage, residue and nutrient management in maize-wheat-green gram system

At ICAR-IIWBR(29°42'22"N; 85°40'13"E), a long term experiment was initiated during Kharif 2015, to evaluate the "Long term **effect of tillage, residue and nutrient management in maize-wheat-green gram system**" in a systems' perspective. The experiment was conducted in split plot design with three replications. The main plot consisted of four treatments involving the combination of tillage and residue management {ZT (Zero tillage); ZT with residue retention (CA); CT (Conventional tillage) and CT + residue incorporation} and sub plots were having the four nutrient management options (Control; Recommended N alone; Recommended NPK; and Rec. NPK + FYM 10 t/ha). Wheat cultivar HD 2967 was sown on 30th Oct 2018 at row to row spacing of 20.0 cm using a seed rate of 125 kg/ha considering the 1000 grain weight as 38 g. The sowing was done using Turbo Happy Seeder. The full residue load of maize (170 q/ha) after removing the cobs was either removed, or retained or incorporated. The incorporation was done using rotary tiller. The irrigations were given as per the recommended practices. For control of weeds clodinafop 60 g/ha fbmetsulfuron 4 g/ha were applied at 35 DAS. The recommended dose of N:P:K consisted of 150:60:40 kg/ha. Full P and K were applied as basal before pre seeding irrigation. Whereas N was applied in two equal splits (half dose each just before first and second irrigation).

The perusal of data in Table-7 revealed that the effect of nutrient management was significant, whereas the effect of tillage and residue management and their interactions were non-significant. The plant height was minimum in absolute unfertilized control treatment. Among four nutrient management options minimum yield was recorded in unfertilized controlplots having a mean yield of 15.42 q/ha. The poor yield in this treatment was due to lesser yield attributes mainly the effective tillers. The wheat grain yield was maximum (73.50 q/ha) when FYM @ 10t/ha was applied along with Rec. NPK. However, statistically this treatment was at par with Rec. N alone and Rec. NPK application.

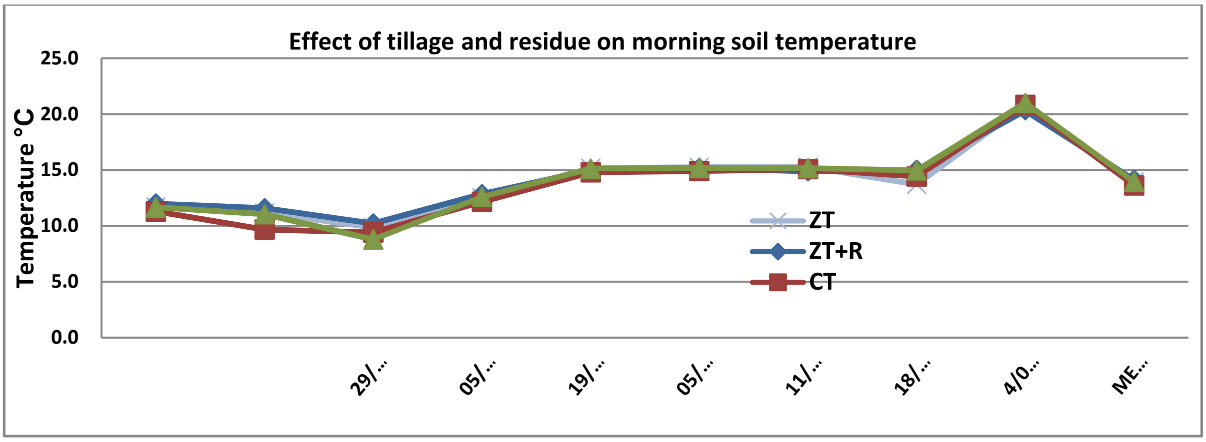
Table 7. Effect of tillage, residue and nutrient management in wheat under Maize-wheat system during 2018-19

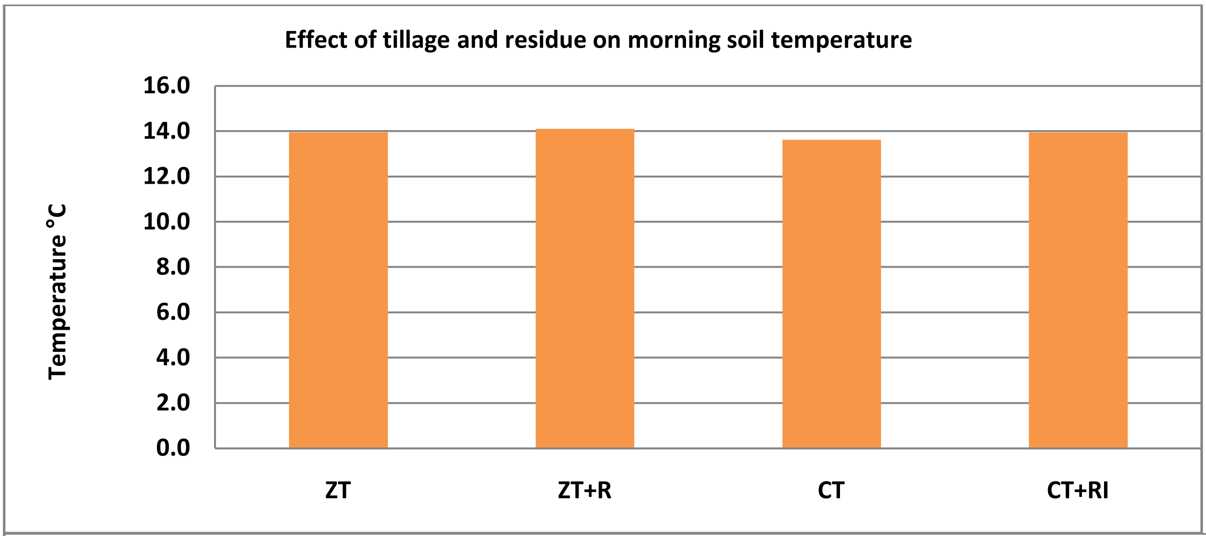
Tillage and residue management	Tillers/m^2	Yield q/ha	1000 grain weight, g
ZT	383.5	58.25	43.51
ZT+R*	398.5	57.50	44.00
CT	385.4	57.75	43.67
CT+RI*	382.1	56.54	43.26
CD at 5%	NS	NS	NS
Nutrient management			
Control	310.4	15.42	41.04
N Alone	406.7	68.56	43.91
Rec. NPK	416.0	72.55	44.52
Rec. NPK+ FYM 10t/ha	416.5	73.50	44.97
CD at 5%	16.75	1.36	0.77

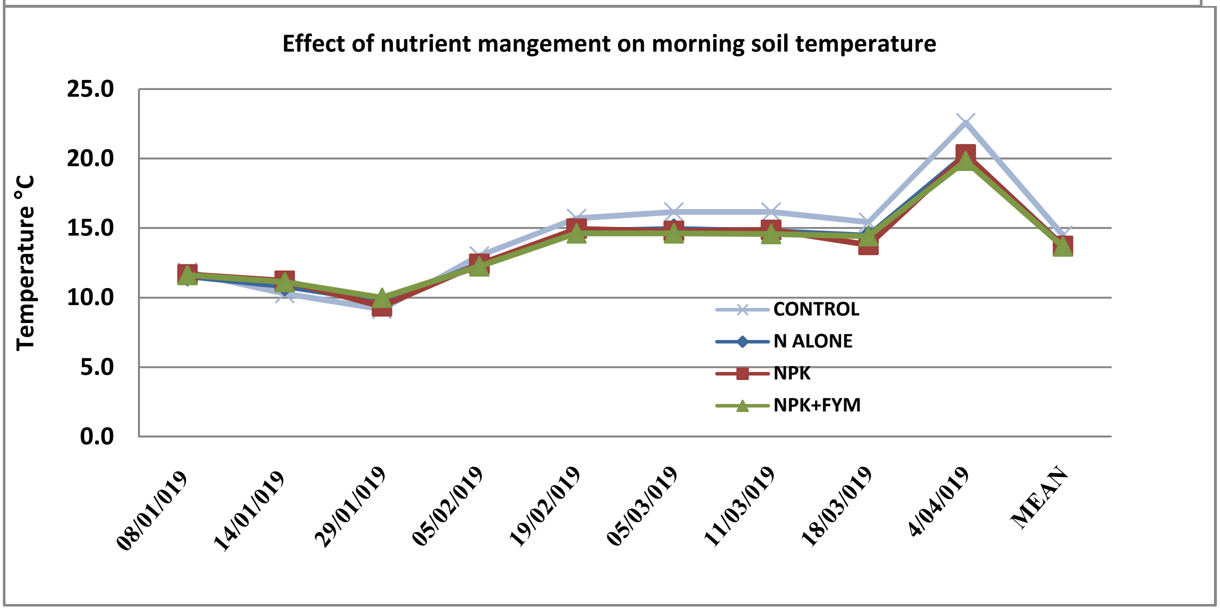
*R=Residue Retention and RI= Residue incorporation

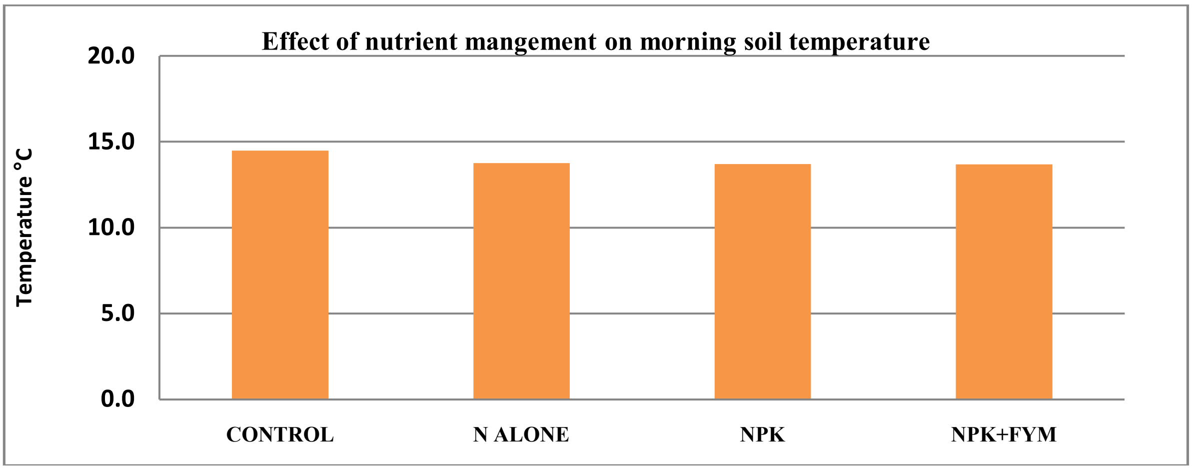
Observations were also taken on soil temperature in the morning and noon on different dates. The morning temperatures were on slightly higher in CA system where as reverse in the noon, where the temperatures were on lower side. The noon temperatures in the control plots were higher than different nutrient management treatments.

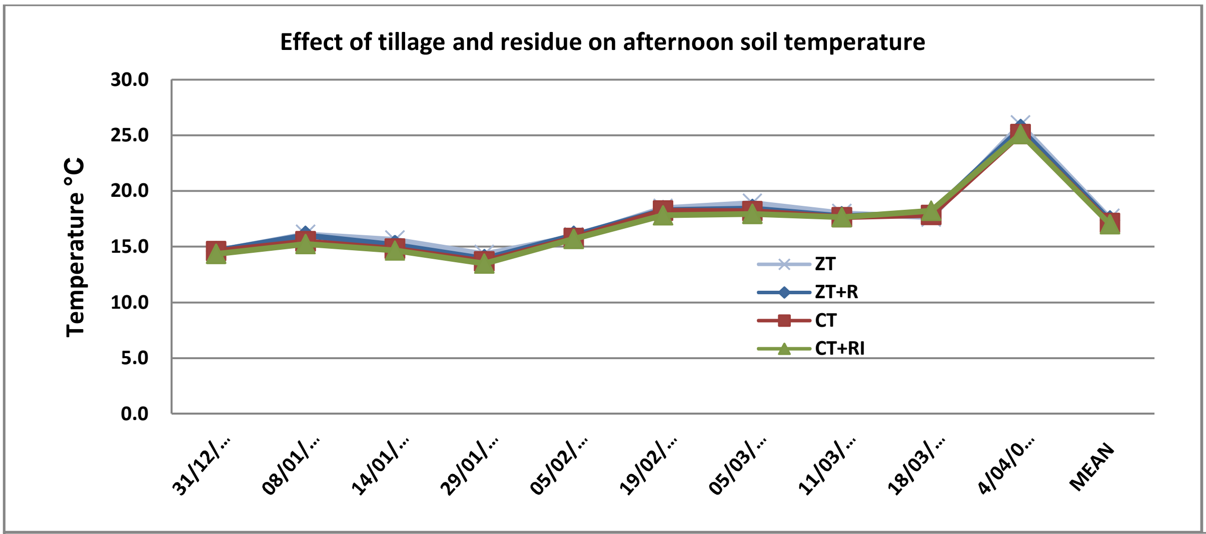
Canopy temperature as measured by LT300 Infrared Thermometer was higher in unfertilized control plots. Whereas the Normalized Difference Vegetation Index (NDVI) values recorded using hand held green seeker, a direct indicator of the crop growth was drastically less in unfertilized control plots, which was reflected in lower crop yields.

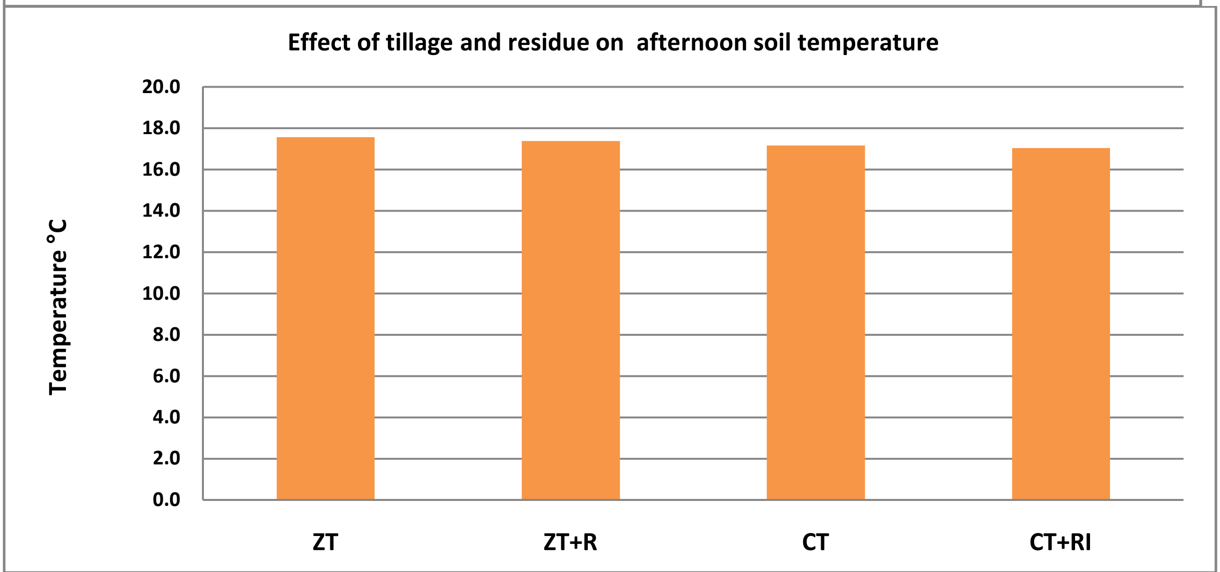


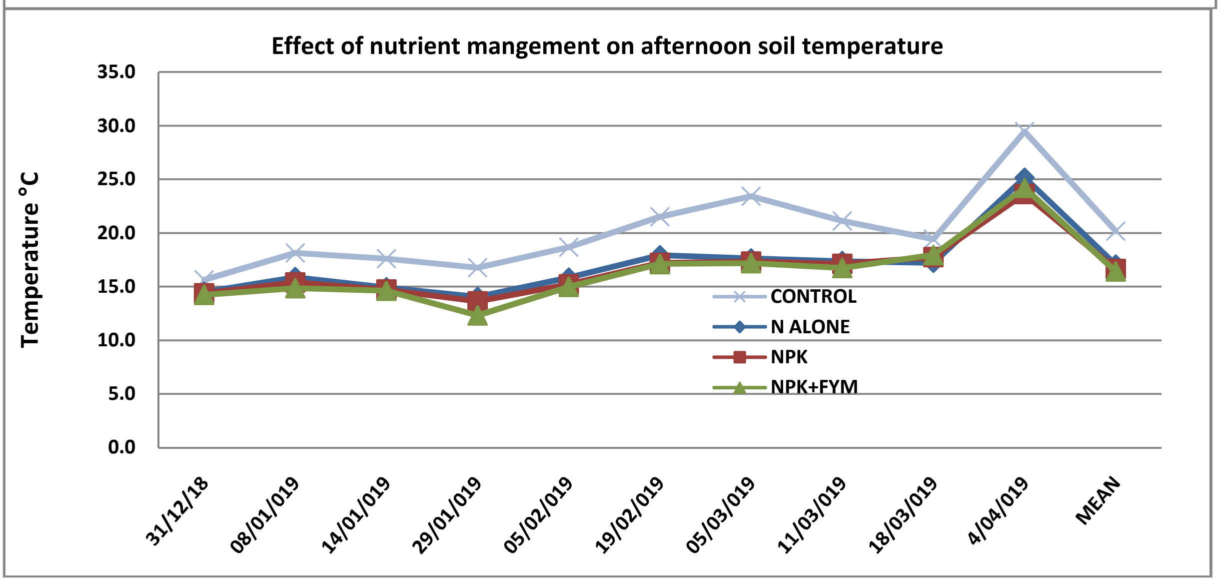

Effect of tillage and residue on morning soil temperature
Temperature °C
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
ZT
ZT+R
CT
CT+RI

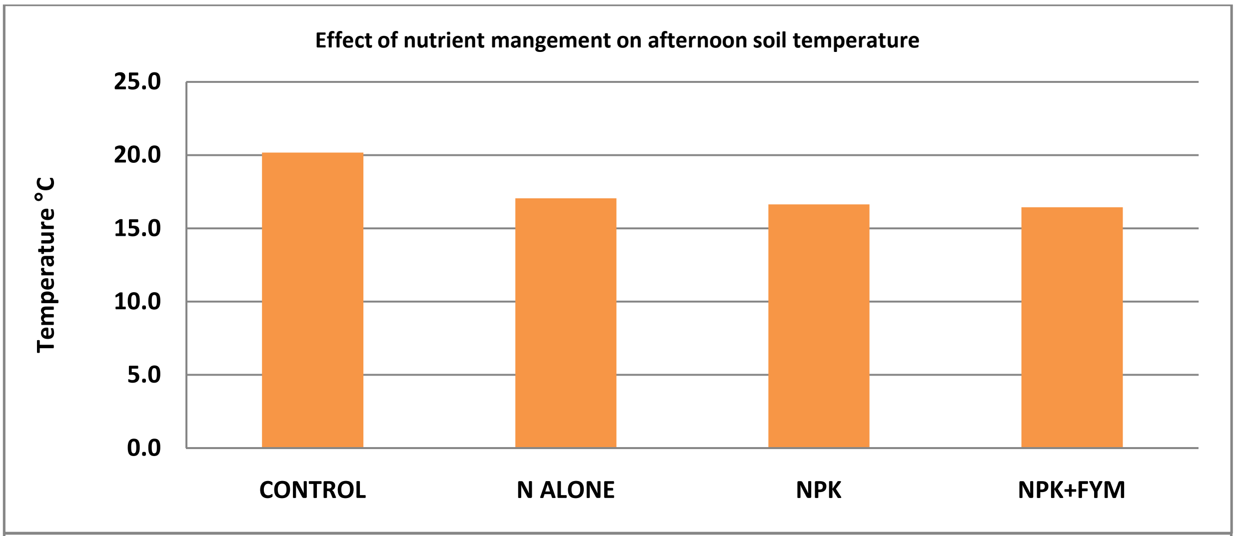

Effect of nutrient mangement on morning soil temperature
Temperature °C
25.0
20.0
15.0
10.0
5.0
0.0
CONTROL
N ALONE
NPK
NPK+FYM
08/01/2019
14/01/2019
29/01/2019
05/02/2019
19/02/2019
05/03/2019
11/03/2019
18/03/2019
4/04/2019
MEAN

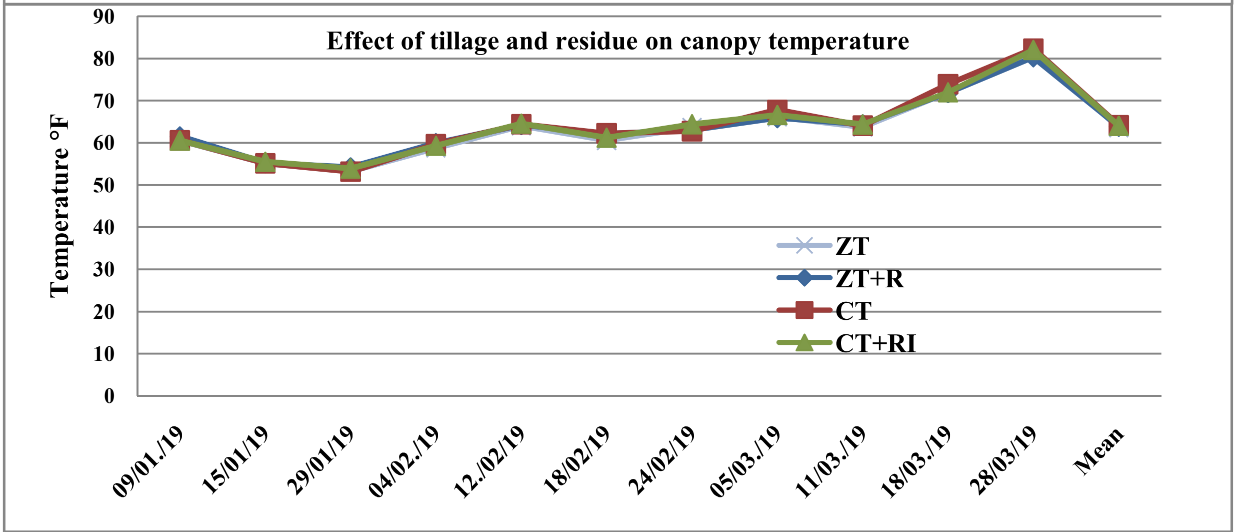

Effect of nutrient mangement on morning soil temperature
Temperature °C
20.0
15.0
10.0
5.0
0.0
CONTROL
N ALONE
NPK
NPK+FYM

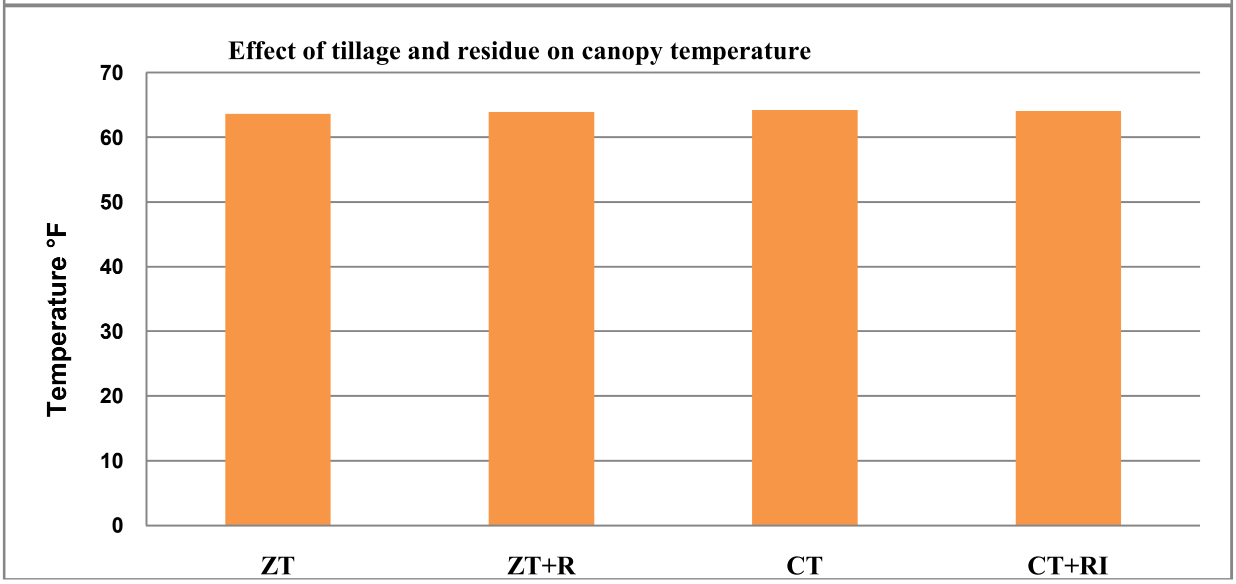

Effect of tillage and residue on afternoon soil temperature
Temperature °C
30.0
25.0
20.0
15.0
10.0
5.0
0.0
ZT
ZT+R
CT
CT+RI
31/12/...
08/01/...
14/01/...
29/01/...
05/02/...
19/02/...
05/03/...
11/03/...
18/03/...
4/04/0...
MEAN

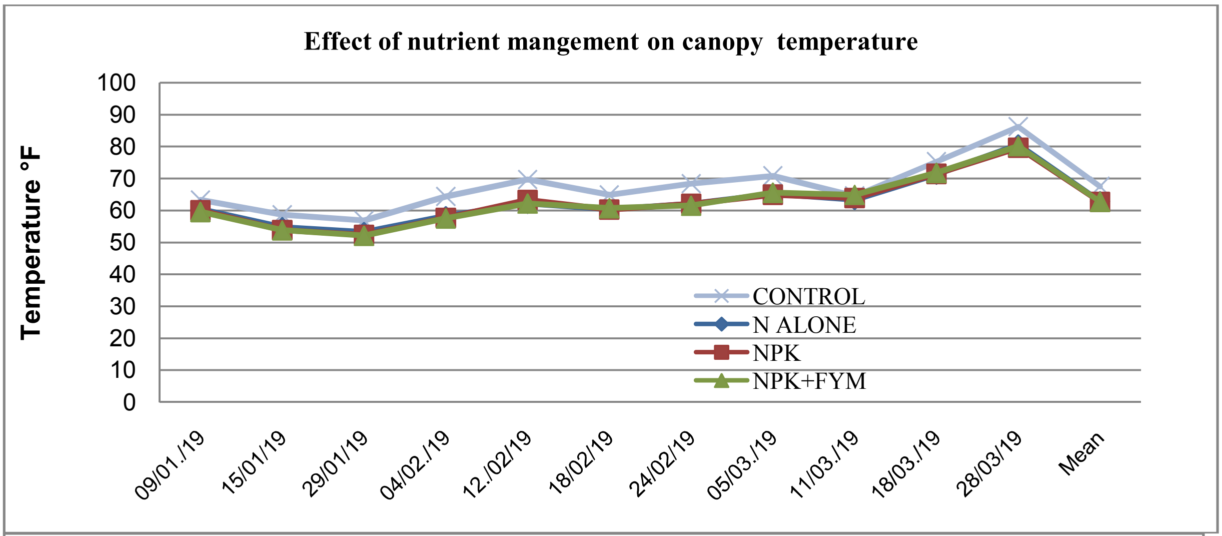

Effect of tillage and residue on afternoon soil temperature
Temperature °C
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
ZT
ZT+R
CT
CT+RI


Effect of nutrient mangement on afternoon soil temperature
Temperature °C
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
CONTROL
N ALONE
NPK
NPK+FYM
31/12/18
08/01/019
14/01/019
29/01/019
05/02/019
19/02/019
05/03/019
11/03/019
18/03/019
4/04/019
MEAN


Effect of nutrient mangement on afternoon soil temperature
Temperature °C
25.0
20.0
15.0
10.0
5.0
0.0
CONTROL
N ALONE
NPK
NPK+FYM


Effect of tillage and residue on canopy temperature
Temperature °F
90
80
70
60
50
40
30
20
10
0
ZT
ZT+R
CT
CT+RI
09/01./19
15/01/19
29/01/19
04/02./19
12./02/19
18/02/19
24/02/19
05/03./19
11/03./19
18/03./19
28/03/19
Mean


Effect of tillage and residue on canopy temperature
Temperature °F
70
60
50
40
30
20
10
0
ZT
ZT+R
CT
CT+RI


Effect of nutrient mangement on canopy temperature
Temperature °F
100
90
80
70
60
50
40
30
20
10
0
CONTROL
N ALONE
NPK
NPK+FYM
09/01./19
15/01/19
29/01/19
04/02./19
12./02/19
18/02/19
24/02/19
05/03./19
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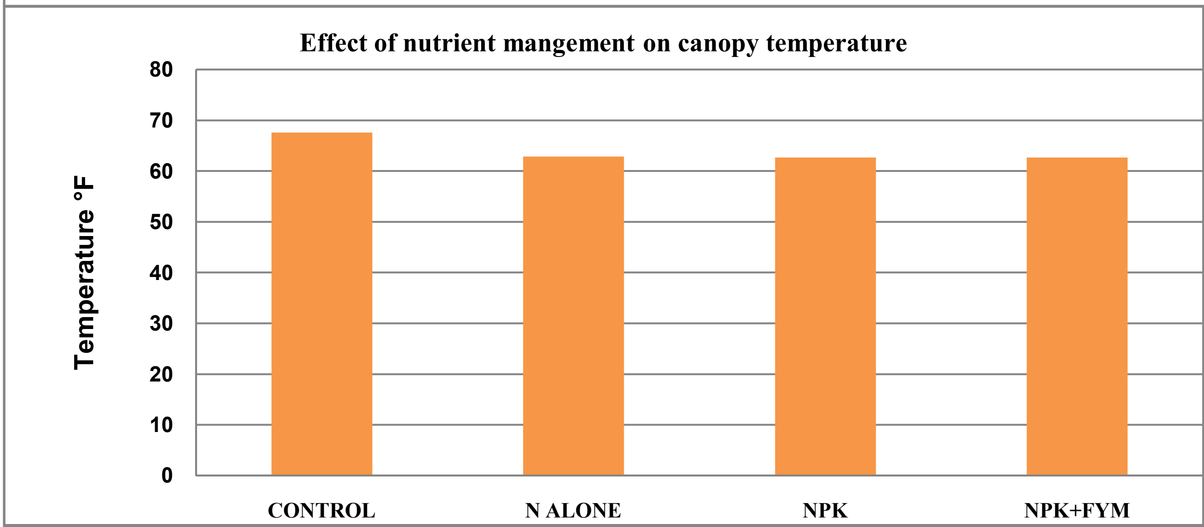
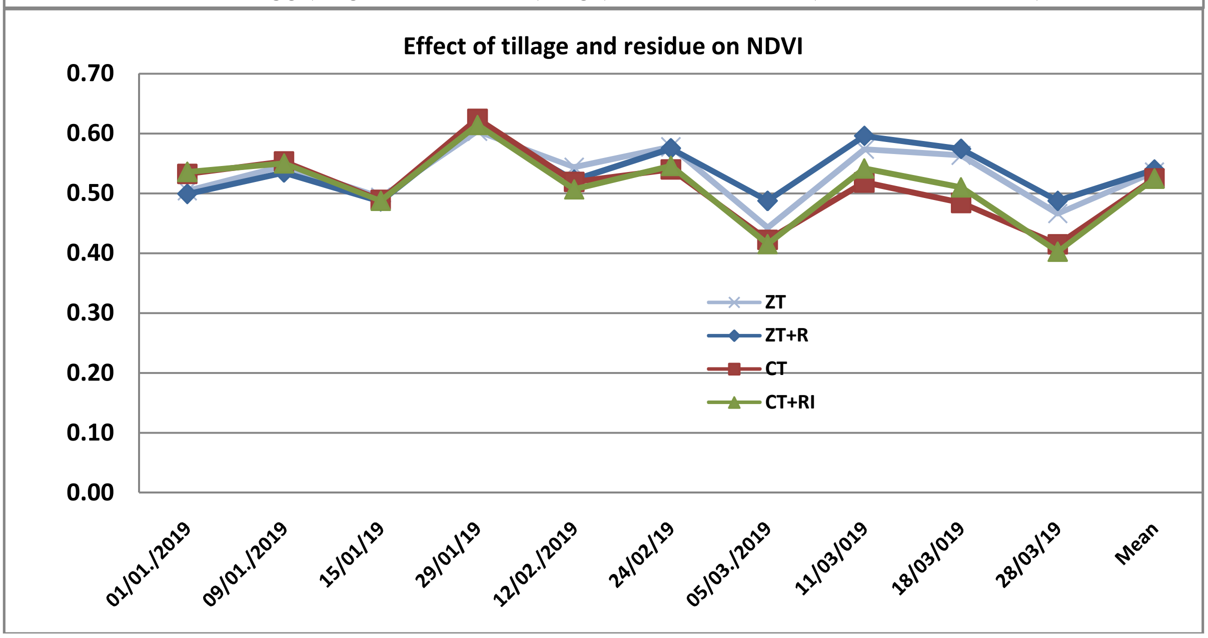
18/03./19
28/03/19
Mean


Effect of nutrient mangement on canopy temperature
Temperature °F
80
70
60
50
40
30
20
10
0
CONTROL
N ALONE
NPK
NPK+FYM


Effect of tillage and residue on NDVI
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
ZT
ZT+R
CT
CT+RI
01/01./2019
09/01./2019
15/01/19
29/01/19
12/02./2019
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05/03./2019
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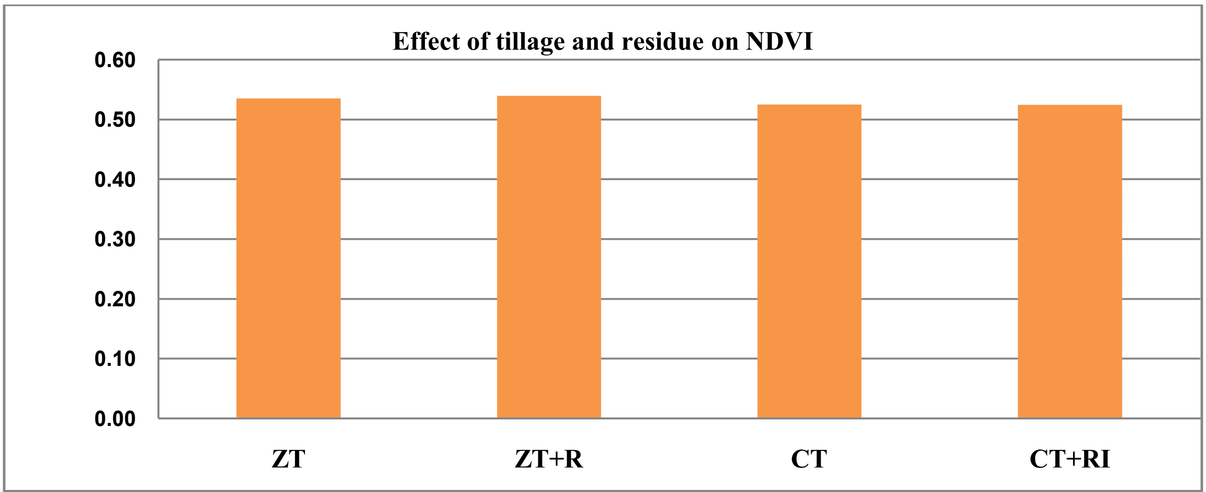
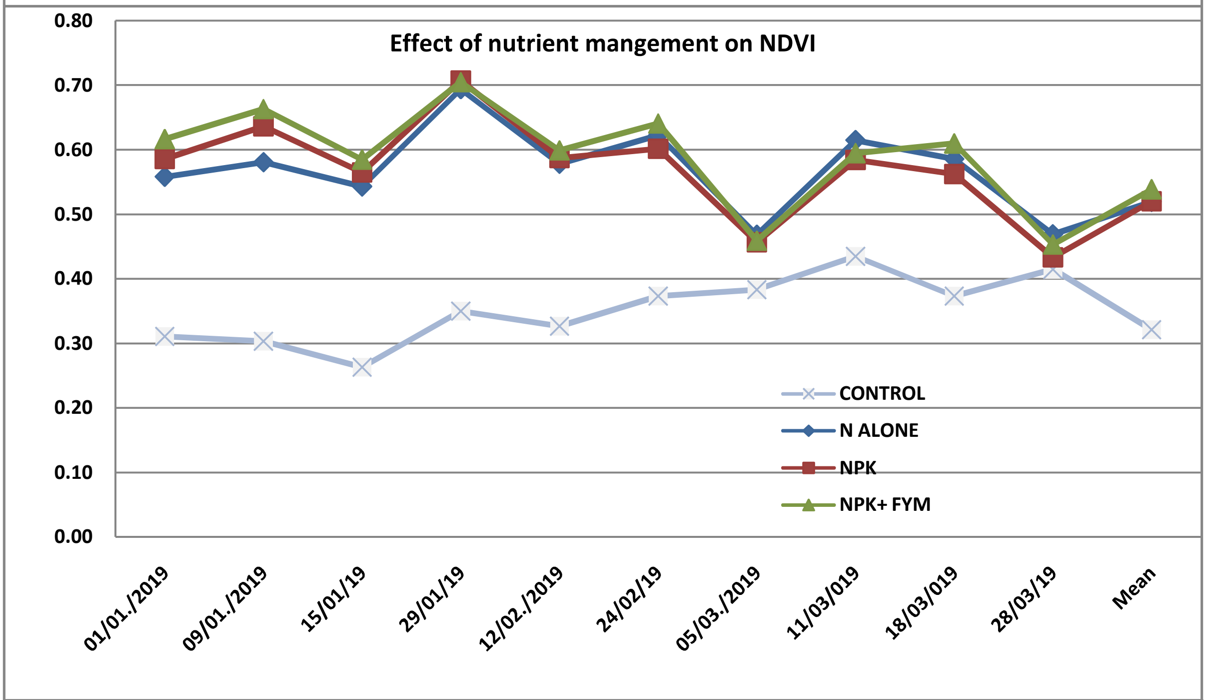
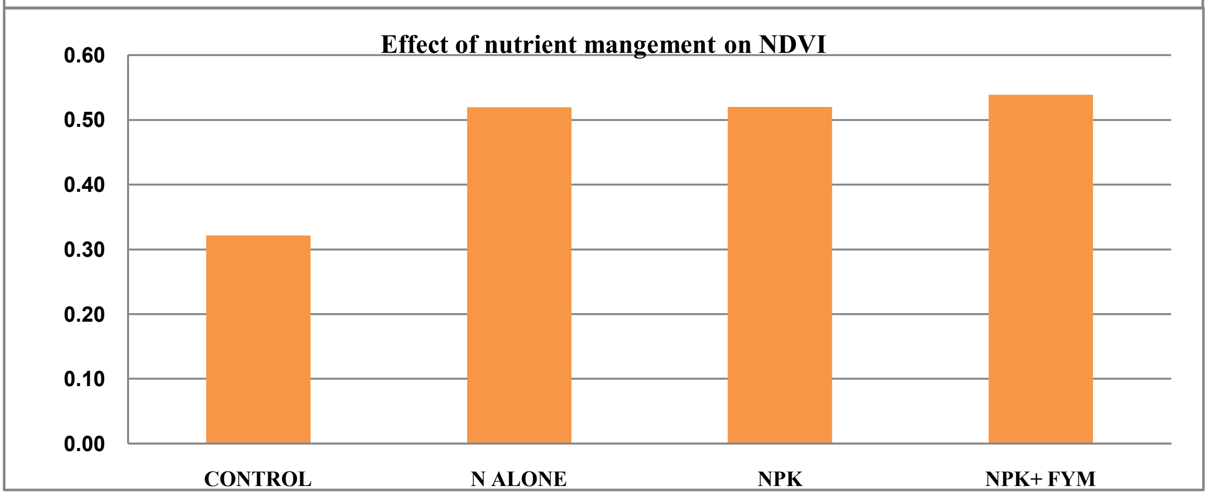
18/03/019
28/03/19
Mean



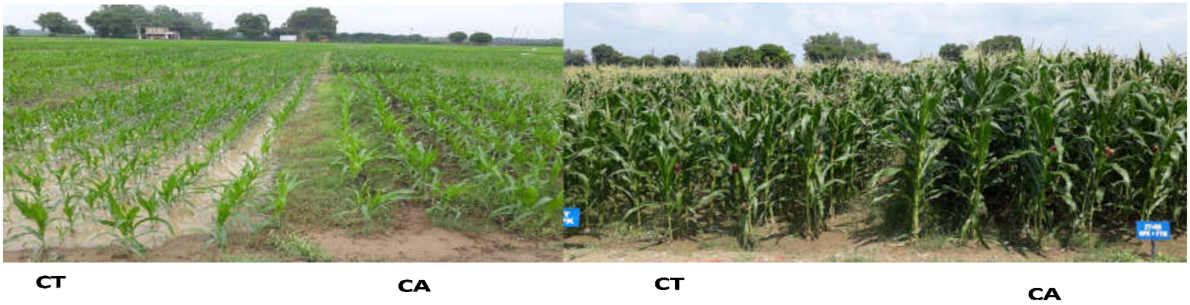


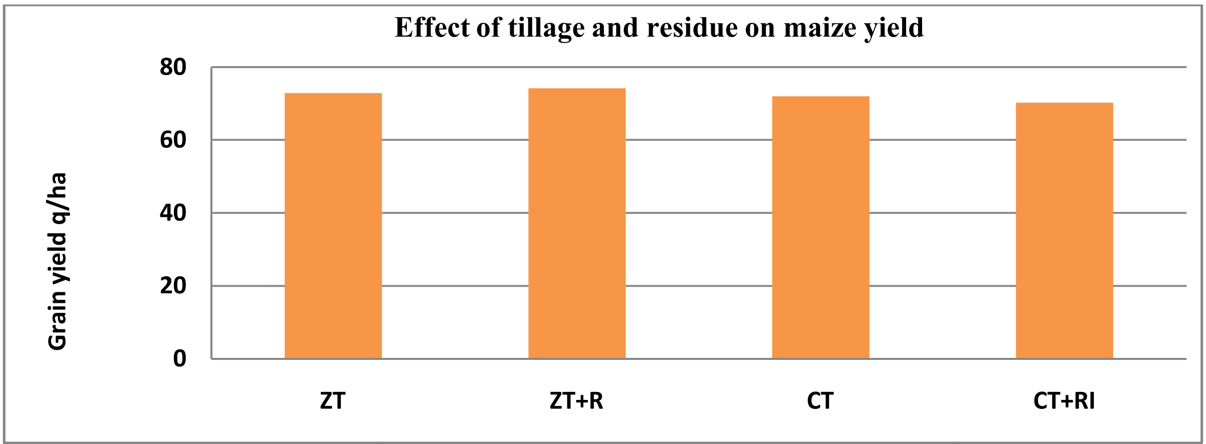


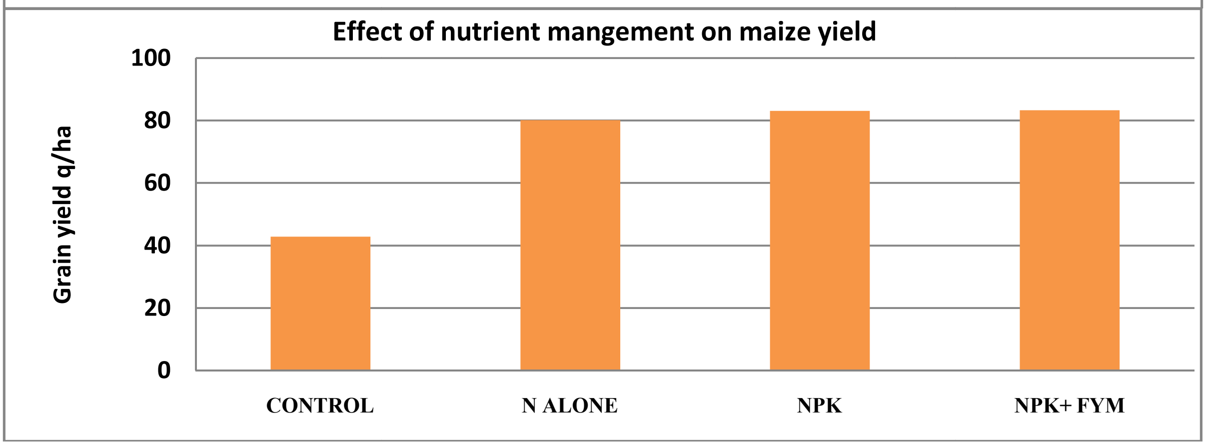
Performance of maize in long term experiment in Maize-wheat-greengram system:

With the same set of treatments as in wheat, here the full residue of wheat crop was either incorporated or retained on the surface before greengram sowing. After picking of pods, greengram was also either removed, retained or incorporated as per treatment. n ZT and CA preplanting glyphosate was also applied at 1.2% spray solution. Maize hybrid DKC 9164 was sown using a seed rate of 25 kg/ha at a row spacing of 60 cm. For weed control tembotrione at 110 g a.i./ha + atrazine 1000 g/ha were applied at 20 DAS. Among tillage and residue management options, maximum yield was obtained in CA treatment (74.16 q/ha). The main reason for the response in CA was better infiltration and less adverse effect of water logging due to heavy rain as observed in CT system (Photo below). Unfertilized plots recorded significantly lowest yield (42.92 q/ha).

Comparative performance of maize under CA and CT system







IIFSR

Residue retention in CA & CP practices: On an average 8.63 t/ha residue was left on the soil surface under CA practices where as it was to the tune of 3.06 t/ha under CP practices (table 08). Higher amount of residue left in the soil helps in building of organic carbon content and reducing bulk density of soil.

Table 08: Residue retention in CA& CP practices

Tillage	CS1	CS2	CS3	CS4

CA	7.2	11.5	14.5	1.34
CP	1.4	6.4	3.9	1.52

CS1- Rice- wheat- green gram
CS2-Rice- wheat- sesbania
CS3-Maize (cob)- pea (veg)-wheat-cowpea
CS4-Sugarcane-ratoon- wheat

NIASM

Effect of micro irrigation, planting techniques and residue management practices on sugarcane productivity:

Sugarcane water requirement is very high (~ 3000 mm) and due to changing climatic scenario inadequate supply of water will result in great yield penalty. Subsurface drip irrigation (SSDI) technique offers many advantages over surface drip irrigation (SDI) such as; reduced evaporation, efficient water use, greater water uniformity and thus reduces the water requirement of the crop. However in case of sugarcane, SSDI is taken up in very less area and mostly advocated with paired row planting technique. Though, paired row planting technique saves the irrigation water and also number of drip laterals and their installation costs but also often have resulted lower cane yield production due to inter-row competition between the paired rows. Thus, standardization of planting geometry of paired rows and spacing of drip laterals for SDI and SSDI under paired row planting systems is needed. In addition to this, surface retention of crop residues in conjunction with micro irrigation techniques would be helpful in improving hydro-thermal regimes and soil health further. Keeping these things in mind, a field experiment was conducted with six main plot treatments viz., M1: parallel planting of each plant in single rows spaced at 150 cm with surface drip irrigation (PSR-150 cm + SDI); M2: parallel planting of each plant of paired rows by maintaining spacing of 90 cm between the rows and 210 cm between the pairs with SDI (PPR-90-210 cm + SDI); M3: zigzag planting of each plant of paired rows by maintaining spacing of 75 cm between the rows and 225 cm between the pairs with SDI (ZPR-75-225 cm + SDI); M4: ZPR-60-240 cm + SDI; M5: ZPR-75-225 cm + SSDI; M6: ZPR-60-240 cm + SSDI. Two treatment of soil surface cover management practices *viz.,* T1: Residue; covering of soil surface with a live mulch of mungbean followed by retention of mungbean residue and trash as mulch and T2: without residue were accommodated in sub-plots. An absolute control surface irrigation management practices was also maintain the compare of treatment effects.

The amount of applied irrigation water was equal to 100 and 80 % of the crop evapotranspiration (ETC) under surface and subsurface irrigation methods. The crop was irrigated at 2 days intervals under SDI and SSDI and at 80 mm CPE under surface irrigation method.

The maximum cane yield (141.7 t ha^{-1}) was recorded under the M5 (ZPR-75-225 cm + SSDI) treatment which was significantly higher by 5-14 % as compared to remaining planting and micro irrigation techniques, except M1 (PSR-150 cm + SDI) and M3 (ZPR-75-225 cm + SDI) treatments (Fig. 4). While covering of soil surface with live mulch of mungbean followed by retention of mungbean residue and trash in the field improved the cane yield on an average by 11 % as compared to without residue retained treatment. This indicated that yield of paired row planted sugarcane could be improved significantly with adoption of zigzag planting, micro irrigation techniques and retaining the crop residues on soil surface.

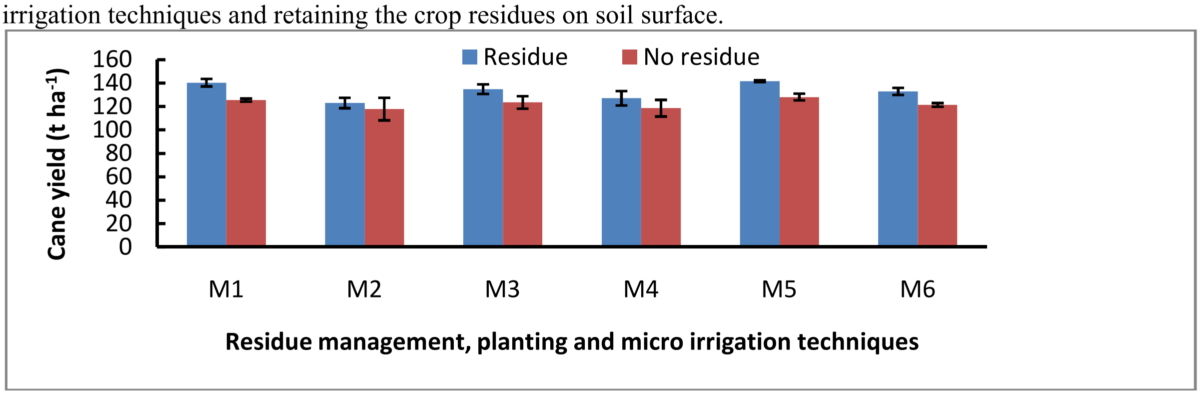


Fig.4 Effect of crop residue, micro irrigation and planting techniques on cane yield of Sugarcane

Seed yield of mungbean (3.8-7.9 q ha^{-1}) could also be obtained while growing of mungbean as intercrop with sugarcane for live mulch and recyclable residue (Fig 5). The mungbean seed yield of was recorded maximum with M1 (PSR-150 cm + SDI) which was 39-84 % higher than rest of the treatments

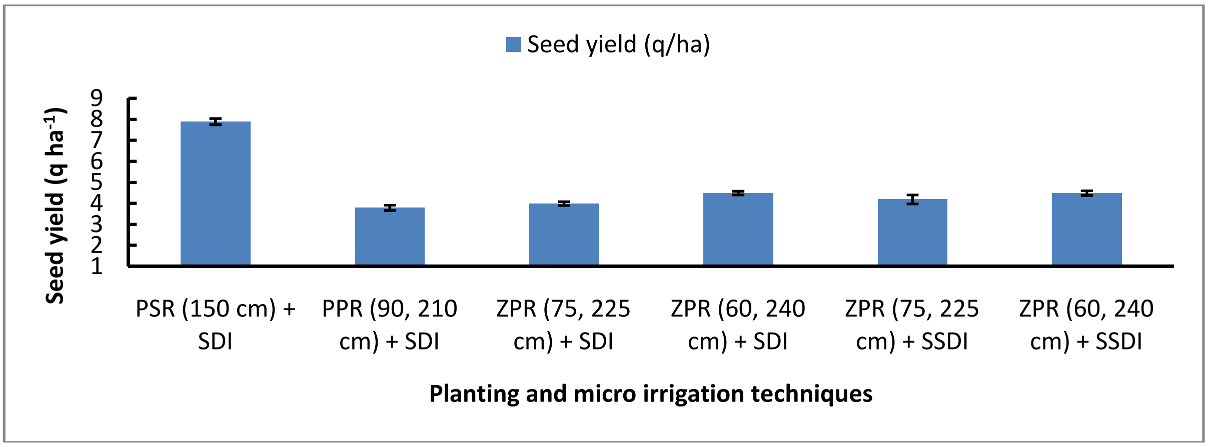


Fig. 5. Effect of planting and micro irrigation techniques on seed yield of mungbean

Effect of tillage, crop residue and nutrient management practices on sugarcane productivity:

A field experiment was conducted with three main plot treatment combination of tillage and nutrient scheduling and application methods *viz.,* M1: laser land levelling (LLL) + conventional tillage (CT) + 10 % of recommended dose of fertilizers (RDF; 250:120:120; N:P:K; kg ha^{-1}) applied as basal and remaining 90 % doses of fertilizers applied through fertigation, M2: LLL + reduced tillage (RT) by excluding deep tillage + 10 % of RDF as basal and 90 % through fertigation and M3: LLL + RT + 10 % of RDF as basal, 40 % through band placement and remaining 50 % through fertigation. In M3 treatment, 40 % of RDF was band placed with SORF machine rather than broadcasting in standing crop at 60 days after planting of sugarcane. The fertigation was done at 15 days interval started at 15 days after planting as per the treatments. Two treatment of soil surface cover management practices *viz.,* T1: Residue; covering of soil surface with a live mulch of mungbean followed by retention of mungbean residue and trash as mulch and T2: without residue were accommodated in sub-plots. An absolute control with CT without LLL, recommended nutrient and surface irrigation management practices was also maintained to compare the treatment effects.

The results revealed that there was no significant difference in cane yields (var. MS 10001) under conventional tillage (M1) and reduced tillage practices (M2) practices. It indicated that reduced tillage could be adopted without compromising with the cane yield. Furthermore, application of 40 % of RDF through band placement and 50 % of RDF through fertigation (M3) improved the cane yield significantly over the application 90 % of RDF through fertigation (Fig. 6 & 7). The yield improvement with M3 over M1, M2 and conventional sugarcane management practices (M4) treatments was 11, 8 and 28 %, respectively. This might be due to that band placement of 40 % of RDF provided the initial boost to the crop growth and remaining 50 % applied through drip fertigation helped in sustaining the crop growth during the grand growth stage through synchronized supply of nutrients.

M1: CT + RDF (90% fertigation) **M2:** RT + RDF (90% fertigation) **M3:** RT + RDF (40% SORF + 50% fertigation)

Fig. 6. Effect of tillage and nutrient management practices on performance of sugarcane.

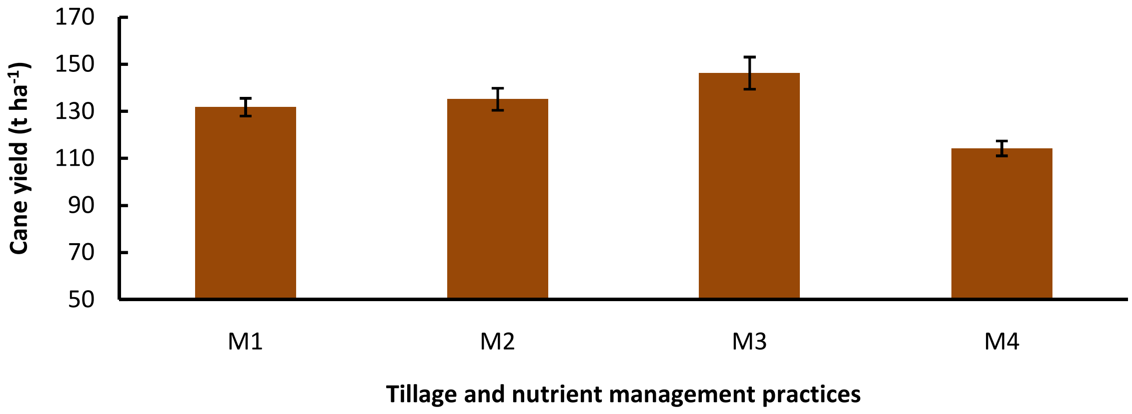


Fig. 7. Effect of tillage, residue and nutrient management practices on cane yield of sugarcane.

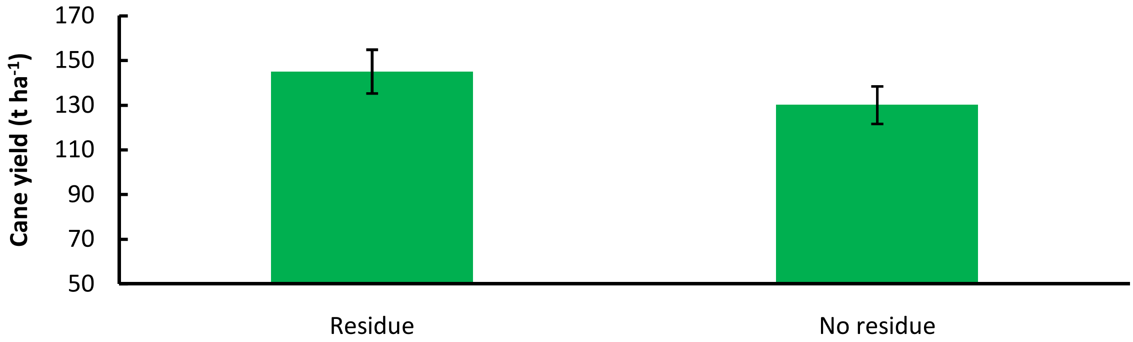
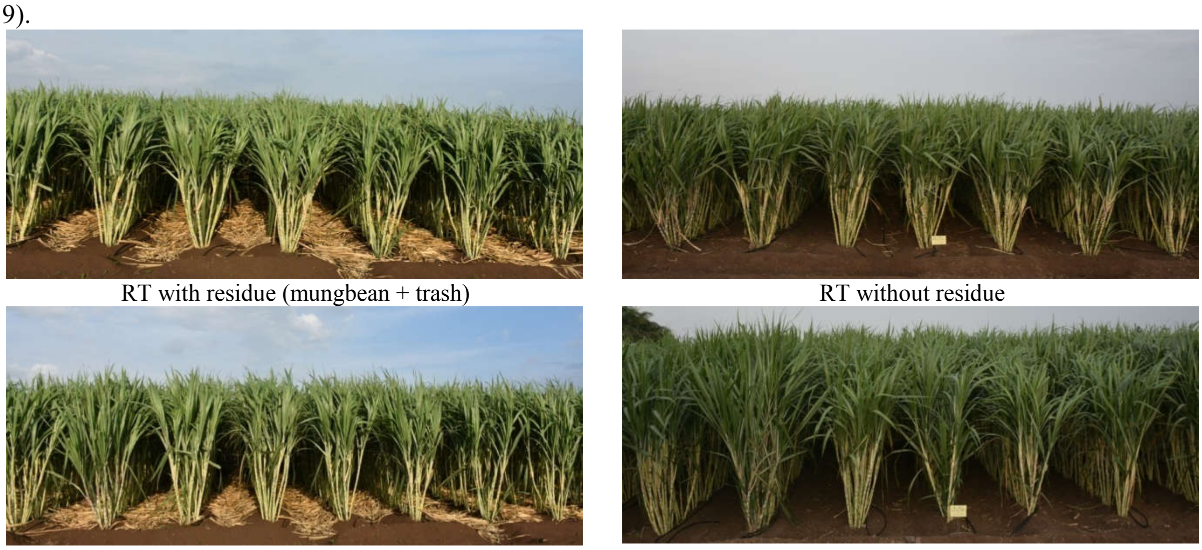


Fig. 8. Effect of crop residues (mungbean + trash) on cane yield of sugarcane.

Furthermore, covering of soil surface with live mulch of mungbean followed by retention of mungbean residue and trash in the field improved the cane yield on an average by 10 % as compared to without residue (Fig. 8 & 9).



RT with residue (mungbean + trash) | RT without residue

CT with residue (mungbean + trash) | CT without residue

Fig. 9 Effect of crop residues (mungbean + trash) on performance of sugarcane.

Moreover, growing of mungbean with sugarcane as live mulch not only served the purpose of soil surface cover but also provided the economic seed yield and crop residues. The maximum seed yield of mungbean was recorded under M3 treatment (RT+RDF applied with SORF (40%) & fertigation (50%)) which was 4 and 8 % higher than M1 and M2 treatments, respectively (Fig. 10). However, stover yield did not influence much due to different tillage and nutrient management practices.

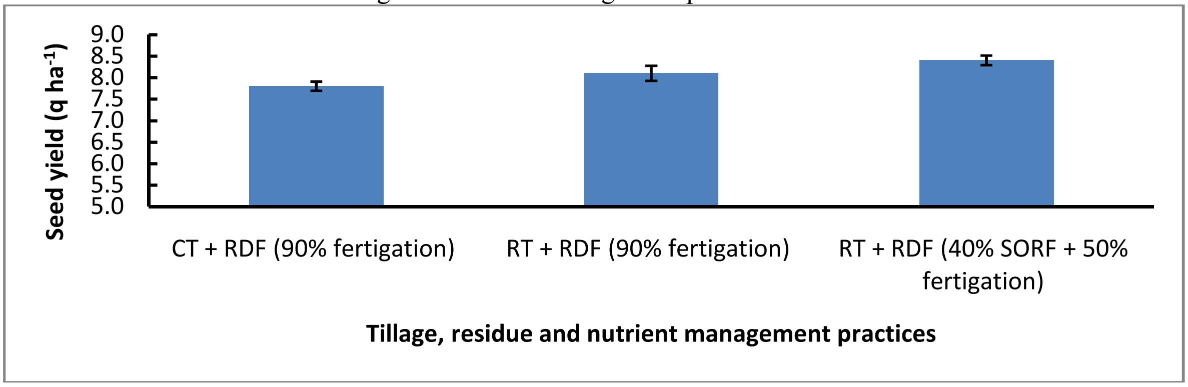


Fig. 10. Effect of tillage, residue and nutrient management practices on seed yield of mungbean.

Carbon source utilization pattern of M2T2N2, M2T1N2, M1T2N3, M2T1N2, M1T2N2, M2T1N3, M2T1N1, M3T1N1; while another group being M2T2N1, M1T1N3, M3T1N2, M3T2N3, M1T2N1, M3T2N2, M1T1N1, M3T2N1, M2T2N3, and M3T2N3.

Therefore, LLL+RT+10% RDF as basal and 90% through fertigation (M2), followed by LLL+CT+10% RDF as basal and 90% through fertigation (M1) dominated in first group, indicating significance of nitrogen supplement in instalments through fertigation (fig 15). On the other hand, LLL+RT+10% RDF as basal, 40% band placement 50% fertigation (M3) alone comprised 50% abundance within the second group, indicating influence of advanced placement of nitrogen on microbial community development.

No mulching treatment dominated in second group with a couple of exceptions; while reverse was noted in the first group where the alterations in carbon source utilization could be attributed to the trash mulching.

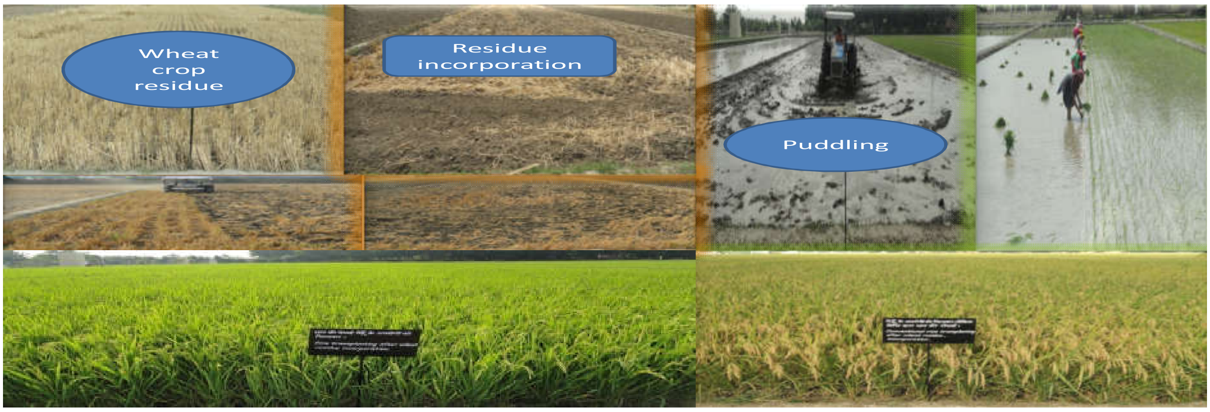
Among nitrogen treatments, 50% nitrogen placement with SORF (N2) dominated in first group; while the same was replaced in second group together by 25, and 75% N placement with SORF.

CSSRI

1) Tillage and Residue management

a) TPR

Higher grain yield (6.85 tha^{-1}) was recorded under conventional puddle transplanted rice with wheat residue incorporation (PTR+R) than without residue incorporation (6.66 tha^{-1}). So, residue incorporation in conventional puddle transplanted rice increased the grain yield by 2.9%. The grain yield in puddle transplanted rice with residue incorporation was lower than DSR under reduced tillage with drip irrigation (7.17 tha^{-1}) and DSR under reduced tillage with residue incorporation (7.01 tha^{-1}). The lower grain yield under conventional puddle rice was due to false smut at grain filling stage. The severity of false smut was higher in transplanted rice than direct seeded rice. High humidity due to frequent rainfall coupled with high temperature increased its severity. This resulted in chalkiness of grains with reduced test weight and ultimately lower grain yield.



Experimental view of transplanted rice with wheat residue incorporation

Experimental view of DSR in reduced tillage (residue incorporation, sowing and germination) and DSR in zero tillage with wheat residue, germination in anchored residue and rice performance)

b) DSR-RT with wheat residue

DSR under reduced tillage with crop residue produced grain yield of 7.01 tha^{-1}, which was 5.26 and 5.60% higher in comparison to TPR (6.66 tha^{-1}) and DSR-RT without crop residue (6.64 tha^{-1}), respectively (Fig 11). Residue incorporation in DSR-RT gave higher grain yield along with saving of 34.17% irrigation water, 37.94% energy and more than 34.15% electricity compared to TPR. DSR under RT was free from false smut which leads to its higher grain yield than TPR.

c) DSR-ZT with anchored wheat residue

Grain yield under zero tilled DSR with anchored wheat residue was 5.74 tha^{-1} which was 5.7% higher than without anchored residue treatment (5.43 tha^{-1}). Higher grain yield in DSR-ZT with anchored residue was due to better weed management practice and higher plant population.

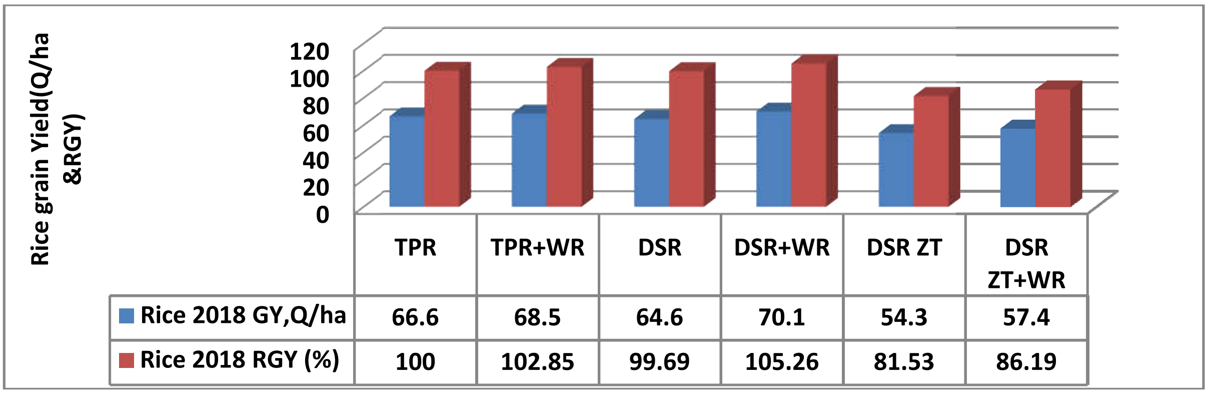


Figure 11: Effects of different tillage and residue management on rice grain yield and relative grain yield during *kharif* 2018

(**Note**: TPR= Transplanted rice; WRI= wheat residue incorporation; DSR= direct seeded rice; ZT= zero tillage; WR= Wheat residue retention/anchored; GY=Grain yield)

2) Economic feasibility of rice crop during *kharif* 2018 under tillage and crop residue management

The economic analysis of rice crop during *kharif* 2018 (Table 9) which clearly shows that B:C in TPR and DSR crop establishment techniques with or without residue incorporation varied from 1.65 to 2.30. It was maximum (2.30) in DSR under reduced tillage with residue incorporation with grain yield of 7.01 tha^{-1}. Minimum B:C ratio was recorded in puddle transplanted rice without residue incorporation with grain yield of 6.66 tha^{-1}. Cost of cultivation was lower in DSR (₹36646 ha^{-1}) compared to TPR (₹44,560 ha^{-1}).

I[st] option: Higher net income (₹86,431 and 79,882 ha^{-1}) were observed in DSR under reduced tillage with and without residue incorporation, respectively, with 2.30, 2.12 B:C and 1.56, 1.48 kg/m^3 grain water productivity (Table 9). This option (DSR-RT with residue incorporation) of rice–wheat cultivation takes care of water saving, crop residue incorporation and saved 50% tillage operations.

However, 2[nd] option was puddle transplanted rice with wheat residue incorporation (T_2) which produced rice grain yield 6.85 tha^{-1} with net income of ₹76,685 ha^{-1} and B:C of 1.72 (Table 9). This option (PTR with residue incorporation) is also associated with the use of crop residue for increasing crop productivity as well as improving soil health.

Table 9: Economic analysis of rice under different tillage and residue management practices at CSSRI, Karnal on station trial during *kharif* 2018

Economic analysis of rice 2018							
TPR and DSR crop establishment techniques							
RCTs	Grain yield, (tha^{-1})	B-1 Cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	B:C	Net income differences and % net income over CV	
TPR	6.66	44,560	1,17,882	73,322	1.65	-	-
TPR+WR	6.85	44,560	1,21,245	76,685	1.72	3363	4.59
DSR-RT	6.64	37,646	1,17,528	79,882	2.12	6560	8.95
DSR-RT+R	7.01	37,646	1,24,077	86,431	2.30	13109	17.88
DSR-ZT	5.43	35,646	96,111	60,465	1.70	-12857	-17.53
DSR-ZT+R	5.74	35,646	1,01,598	65,952	1.85	-7370	-10.05
SE(m)±	0.12	-	-	-	-	-	-
CD (0.05)	0.32	-	-	-	-	-	-
MSP of Rice 2018: Rs.1770 per quintal. Cost of cultivation includes only operational cost (B-1)							

Two options of rice cultivation in specified situation might be promising for increasing rice productivity in sustainable manner. Overall, DSR under reduced tillage with residue incorporation performed better than rest of the treatments. Among transplanted rice technologies, PTR with wheat residue incorporation, found productive where irrigation water is not a constraint. Similarly, it was observed that wheat sowing under zero tillage is relatively better option for increasing its productivity under changing environmental scenario. It is clear from results and discussion that residue management option is economic and feasible with small labour work in TPR as well as DSR.

12.1.2 Details of wheat crop during *rabi* 2018-19

The experimental results have been divided into two aspects and discussed below in clarity to know the real residual effects of technologies on succeeding crop, the results presented in graphs with support of data as:

1) Tillage and residue management in wheat crop

a) Effects of tillage on grain yield of wheat

The experiment of wheat under basic research trial is continuing and data presented in Table 10 and Fig. 12 shows that wheat under 50% reduced tillage with rice residue incorporation produced highest grain yield of 6.44 tha^{-1} compared to 5.52 tha^{-1} under conventional practice during 2018-19, respectively and this was 16.67% higher than conventional wheat sowing.

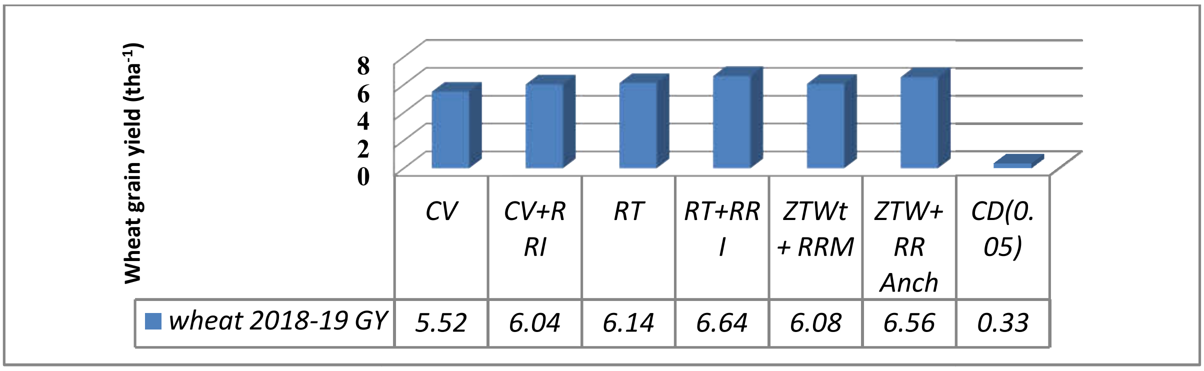


Fig. 12: Effects of different resource conservation techniques on wheat grain yield during the period of 2018-19. (CV= conventional tillage; RRI= rice residue incorporation; RT= reduced tillage; ZT= zero tillage; RRM=rice residue mulch and SPL= sprinkler irrigation)

Among the different tillage treatments, 50% reduced tillage grain yield of wheat increased by 11.23% over the conventional wheat sowing method. It is clear from the results that reduced tillage plays an important role in increasing wheat grain yield. Minimum soil disturbance helps to protect soil organic carbon and saved from deformation of soil physical properties.

In zero tilled wheat, grain yield increased significantly during 2018-19 (Table 10). Zero tilled wheat without rice crop residue increased grain yield by 10.14% (Table 10). Minimum soil disturbance under this practice helped in protecting soil organic carbon and saved from deformation of soil physical properties.

Results indicate that wheat grain yield increased under both tillage treatments, i.e. 50% reduced tillage and zero tillage. Grain yield obtained under zero tillage and reduced tillage without residue was statistically similar to each other.

b) Residual effects of crop residue management on wheat crop yield

Long term residual effects of crop residue management in residue incorporation /anchored/mulched all influenced wheat productivity. The data given in Table 3 & 4 and Fig. 2 shows that grain yield under conventional tillage with rice residue (1/3 part) was ~13.04% higher than conventional wheat sowing method without rice residue treatment. However, wheat grain yield under 50% reduced tillage with rice residue incorporation treatment was 16.67 % higher in comparison to conventional wheat sowing method.

Table 10: Effects of tillage and residue management on wheat grain yield during 2018-19 in rice-wheat cropping system.

RCTs	Tillage Management	
	Without crop residue	% Grain yield increased over conventional tillage
Crop/year	Wheat 2018-19	Wheat 2018-19
CV-tillage –T_1	5.52	-
50% Reduced tillage T_3	6.14	11.23

Zero tillage-T_5	6.08	10.14
CD (0.05)	0.31	-

In zero tillage with anchored rice residue treatment grain yield was 14.86% higher than 0.that of conventional wheat sowing method (Table 11) after 12 years of experimentation. Higher yield of wheat during 2018-19 crop seasons was recorded due to favorable weather condition at the time of grain filling stage and maturity. Not observed terminal heat at all and wheat crop harvested in April month after 10-4-2019.

Table 11: Effect of tillage with residue on wheat grain yield during 2018-19 in rice- wheat cropping system

RCTs	Tillage management with crop residue	
	With crop residue	% Grain yield increased over conventional tillage
Crops	Wheat-2018-19	Wheat-2018-19
CV-R T_1	5.52	-
CV+R T_2	6.24	13.04
RT T_4	6.44	16.67
ZT T_6	6.34	14.86
CD (0.05)	0.31	-
CV-R=conventional wheat without rice residue		

c) Economic of wheat crop during r*abi wheat crop-2018-19* under different tillage and crop residue management

The economic analysis of wheat crop during 2018-19 presented in Table 12 shows that B:C ratio of wheat crop under different establishment techniques, varied from 2.32 to 4.34. B:C ratio was maximum under zero tilled wheat in anchored rice residue.

Net income under zero tilled wheat was 34.58 % higher than conventional wheat sowing method. The net income in wheat under conventional tillage with rice residue reduced tillage with and without residue were 11.26 and 28.66 % and 17.84 % higher than conventional tillage without residue.

Table 12: Economic analysis of wheat crop during 2018-19

RCTs	Wheat 2018-19 (HD2967)						
	Operation Cost (B1-cost)	Grain yields, t/ha	Gross Income with straw (Rs./ha)	Net Income (Rs./ha)	B:C	Differences & % Net income over CV	
CV wheat-T1	36578	5.52	121568	84990	2.32	-	-
CV+RR-T2	36578	6.04	131136	94558	2.59	9568	11.26
RT wheat-T3	32828	6.14	132976	100148	3.05	15158	17.84
RT+RR-T4	32828	6.64	142176	109348	3.33	24358	28.66
ZT wheat-T5	26328	6.08	131872	105544	4.01	20554	24.18
ZT+RR - anchors-T6	26328	6.56	140704	114376	4.34	29386	34.58
Whereas, MSP @1840/q in 2018-2019 and straw @ Rs.20,000.0/ha; CV=conventional wheat sowing; RR= rice residue; RT= reduced tillage; ZT=zero tillage; B:C=Net income/Cost							

Data shows that wheat under different treatments i.e., conventional tillage with residue incorporation, reduced tillage or zero tillage, observed feasible economically and sustainable. The possible reason is that organic matter was added to the soil through rice residue or root system improved soil physical, chemical and biological condition resulted into better crop productivity. Among the tillage system, Zero tillage wheat sowing was found more profitable as compared to CV and RT tillage practices.

Cost of cultivation was lower under zero tillage as compared to CV and RT tillage practices. Zero tillage wheat sowing will improve soil heath, checks air pollution and improves crop productivity.

The result shows that grain yield of wheat increased under all tillage options with *in-situ* management of rice residue. Among all three tillage practices, zero tillage with anchored rice residue was relatively better compared to other practices. It may be due to optimum soil moisture and favorable temperature regulation under residue management to facilitate better seed germination and crop growth as compared to no-residue practice.

2) Economic analysis of Rice –wheat cropping system

The economic analysis of cropping system under different tillage and residue management is given in Table 13 It shows that production cost of rice crop was 35.89% - 43.79% higher than wheat crop. Higher production cost was observed in conventional and reduced tillage crop establishment techniques than zero tillage cultivation of rice –wheat crops. Production cost of residue incorporated plots was higher than residue removed plots in rice crop.

Total cost of cultivation of rice-wheat system varied from Rs.61974.0 ha^{-1} in DSR/ ZT-R to Rs.81138.0 ha^{-1} in TPR+R/CVW+R treatment. Maximum net return of Rs.185599.0 ha^{-1} was calculated in DSR+R/RT+R while lowest under TPR/CVW (Rs.158312.0 ha^{-1}). However B: C ratio was highest in DSR+R/ZTW+R (2.74), followed by DSR/RT (2.68) and DSR+R/RT+R (2.63). Zero tillage wheat with rice residue anchors in rice-wheat cropping system calculated 7.24% more net income than conventional wheat sowing method. DSR in zero tillage performed poor because of excessive weed growth and lower plant population in comparison to TPR and DSR in RT.

"Wheat sowing with rice residue incorporation/anchors in reduced tillage and zero tillage wheat was found better option for sustainable, profitable and eco-friendly cropping system"

Table 13: Rice–wheat cropping system economic analysis during 2018-19

Treat.	RCTs in rice	Grain Yield, B:C ratio and Net income of system							Net income difference and % net income over CV	
		Rice grain yield (tha^{-1}) 2018	Wheat grain yield in (tha^{-1}) 2018-19	SP in terms of REY (tha^{-1})	Gross income with straw (Rs ha^{-1})	Total cost (Rs ha^{-1})	Net income (Rs ha^{-1})	B:C		
T1	TPR/CVW	6.66	5.52	12.40	239450	81138	158312	1.95	-	-
T2	TPR+R/CV+R	6.85	6.24	13.34	249561	81138	168423	2.08	10111	6.39
T3	DSR/RT	6.64	6.14	13.02	250504	70474	180030	2.55	21718	13.72
T4	DSR+R/RT+R	7.01	6.44	13.70	256073	70474	185599	2.63	27287	17.24
T5	DSR/ZT	5.43	6.08	11.75	227983	61974	1666009	2.68	7697	4.86
T6	DSR+R/ZT+R	5.74	6.34	12.33	231754	61974	169780	2.74	11468	7.24
CV (%)		5.23	5.85	5.56	-	-	-	-	-	
SE(d)		0.13	0.16	0.24	-	-	-	-	-	
CD at 5%		0.31	0.37	0.59	-	-	-	-	-	
Whereas, MSP of Rice 2018: ₹1770/q, and rice straw @ Rs.2000/acre. MSP of wheat 2018-19: ₹1840 per quintal and straw @ ₹ 20,000 ha^{-1}, included in gross income & SP=System productivity										

IISS

Fine-tuning of Conservation Agricultural Practices for Vertisols of Central

Major cropping systems followed in this zone were evaluated at ICAR-IISS, Bhopal to identify and evaluate potential cropping systems and conservation tillage practices best suited for the Vertisols of central India, to formulate suitable weed and residue management options for major cropping systems and refining and validation of component technologies of conservation agriculture. To fulfil the objectives, two field experiments on soybean-wheat and maize-chickpea cropping systems were initiated during *kharif* 2015 with five tillage treatments as the main plot and three nutrient treatments as sub-plot with three replications following split plot experimental design. However, after 2016, due to some problem in crop establishment using the existing strip till seed drill and also to evaluate the optimum load of residues for crop establishment and sustainable productivity under conservation tillage system, the main plot tillage treatments were modified and the details of the changes are given below:

Table 14. Treatment details of the field experiments for both the soybean-wheat and maize-chickpea cropping system

Treatments	Tillage System (From 2015-2016)	From 2017 onwards

T1:	No-tillage	No Tillage (NT) with 30cm height residue
T2:	RT-3 (Strip tillage - sowing with strip till- drill with residues, Hand weeding)	No Tillage (NT) with 60cm height residue;
T3:	RT-2 (Strip tillage – sowing with strip till- drill with residues, WC with herbicides),	Reduced Tillage with 30cm height residue
T4:	Reduced tillage (RT) -1 (sowing with residues + 1 duck foot, weed control (WC) with herbicides),	Reduced Tillage with 60cm height residue
T5:	Conventional tillage (No residues and manual weed control),	Conventional Tillage (CT)/Farmers practices
	Nutrient Doses	
	N1: 75% Recommended Dose of Fertilizer (RDF)	N1: 75% RDF
	N2: 100% RDF	N2: 100% RDF
	N3: STCR dose	N3: STCR dose

Experimental crops were sown using no-till seed drill/happy seeder during rainy and winter seasons by adopting standard package of practices (Fig 13). Soil profile moisture content, soil temperature and crop biometric observation were recorded periodically during crop growth period. Regardless of tillage systems, higher nitrogen application namely N100% and N application based on STCR recorded higher grain yield under soybean-wheat and maize-gram systems (Fig14).

Fig13. Sowing of crop and crop establishment in residue retained plots under conservation agriculture

Crop Yield

Crop yield recorded under different tillage system were depicted in Fig 14 and 15. Results indicated that tillage system did not have significant effect on crop yield after four crop cycles. System productivity calculated in terms of soybean grain equivalent yield (SGEY) revealed that no-tillage and reduced tillage with crop residue retention have slightly increased productivity. The SGEY varied from 3411 to 3720 kg ha^{-1} under CA practices as compared to 3493 kg ha^{-1} under conventional tillage (CT).

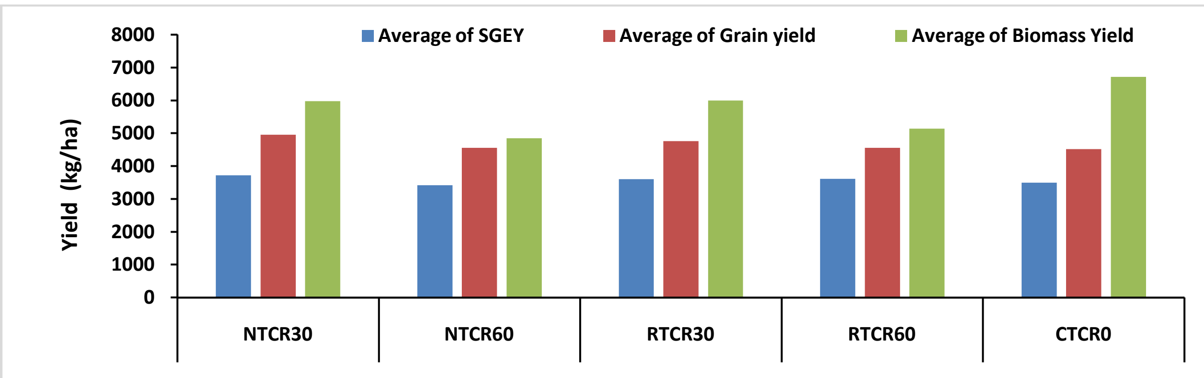


Fig14. System productivity in terms of Soybean Grain Equivalent Yield (SGEY, kg ha^{-1}) under different tillage systems

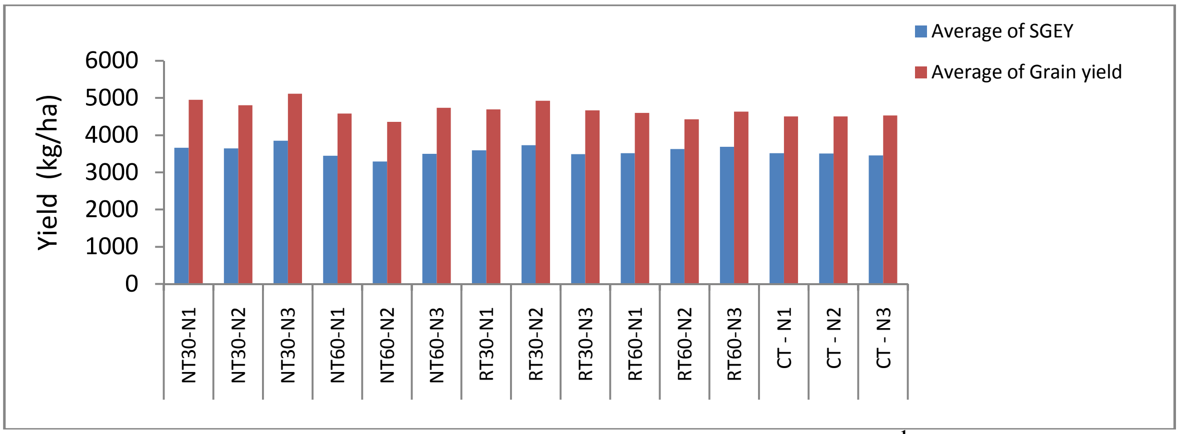


Fig 15. System productivity in terms of Soybean Grain Equivalent Yield (SGEY, kg ha^{-1}) under different nutrient doses (N1: 75% RDF; N2: 100% RDF; N3: STCR dose; RDF: Recommended Dose of Fertilizer) and tillage system

Amount of residue addition under different tillage systems

After harvest of wheat crop, residue addition was quantified under soybean-wheat system (Fig. 16). Results clearly showed that residue addition was higher under conservation agricultural practices (T1 to T4) as compared to CT (T5).

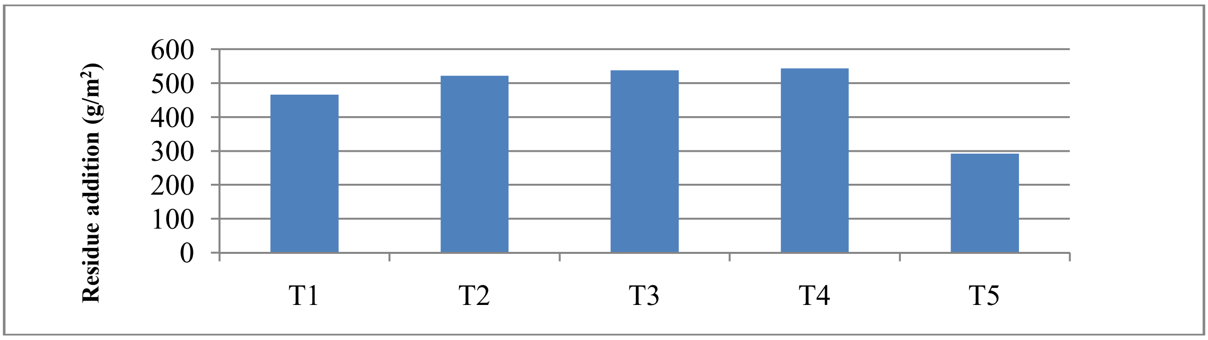
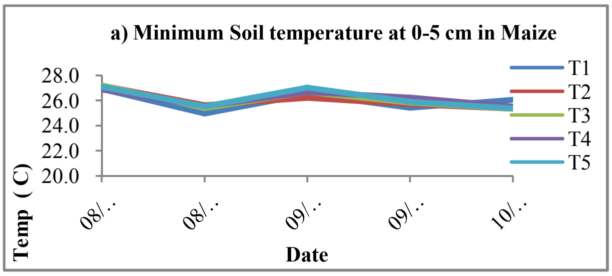


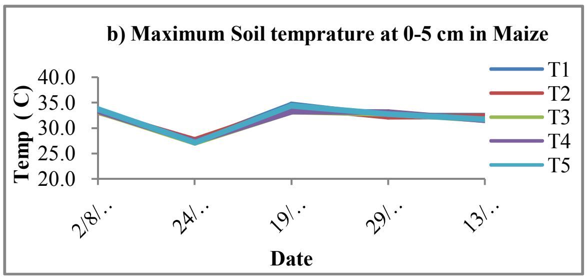
Fig 16. Residue addition under different tillage system under soybean-wheat system.

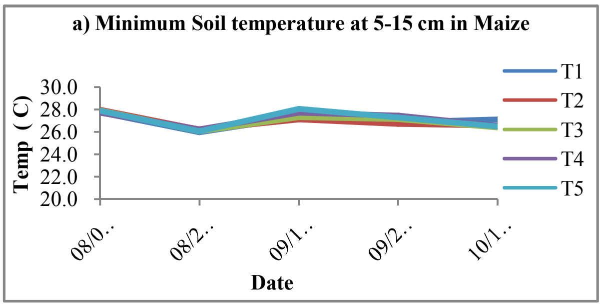
Soil temperature recorded under different tillage system

Soil temperature was measured at periodical interval during both *kharif* and *rabi* seasons under soybean, maize, wheat and gram crops. Results showed that both the no- and reduced tillage with residue retention have favourably moderated soil temperature especially during winter season as compared to conventional tillage without residue (Fig 17 to 19).

Fig 17. Temporal variation of soil temperature under maize during the *kharif* season







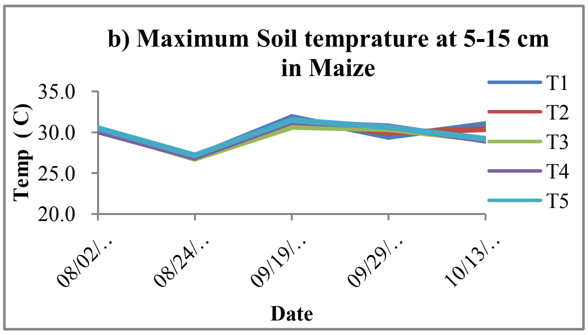
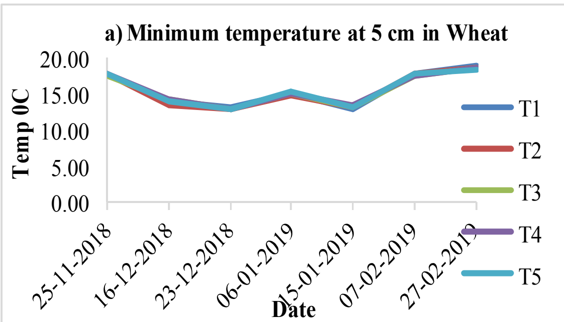
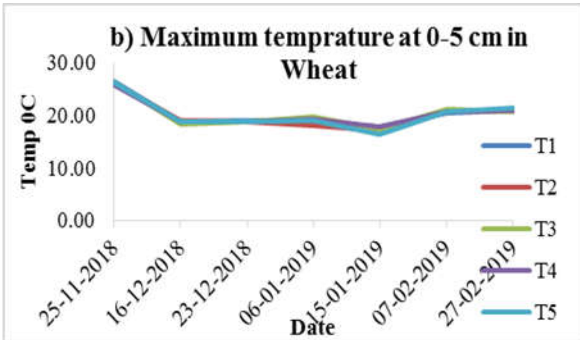
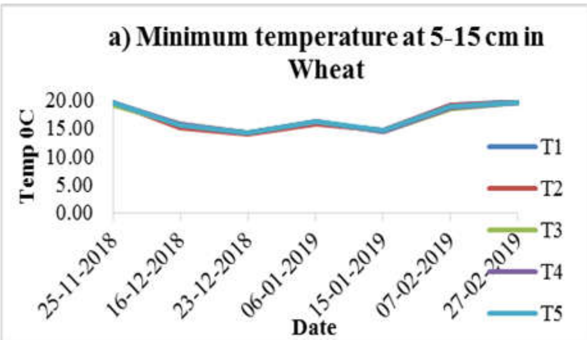
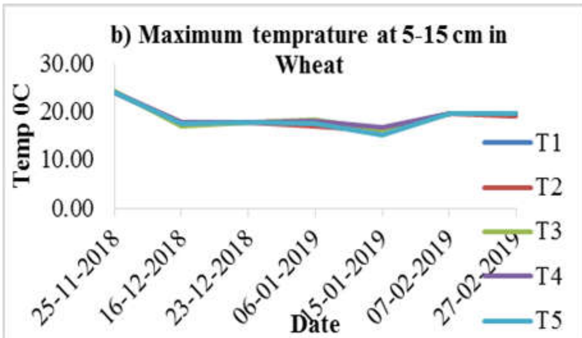


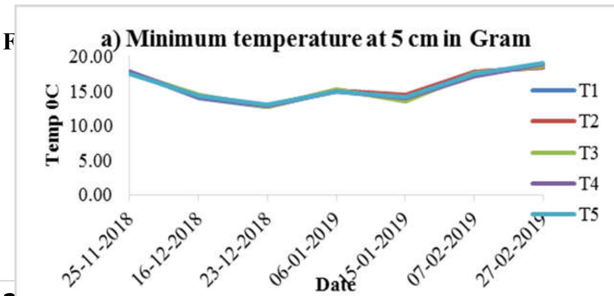
Fig 18. Soil temperature observation in wheat crop during Rabi season

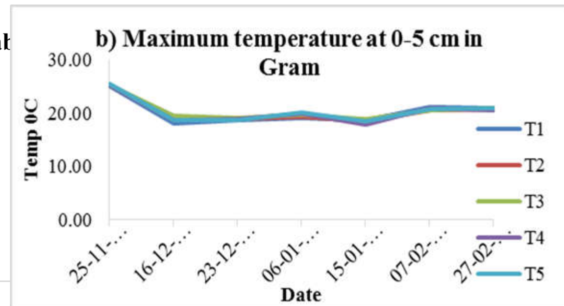


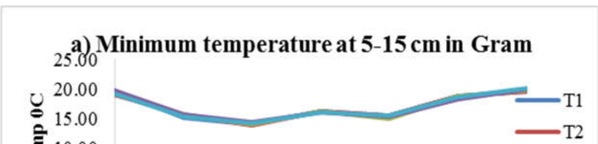


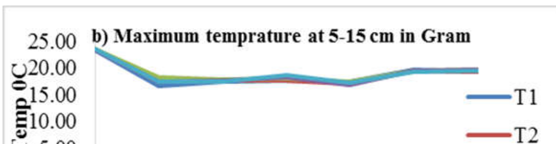












Soil aggregation as influenced by different tillage and cropping system after 9 crop cycles

Soil aggregation often provides information on structural stability and physical condition of soil. Thus, soil aggregation is important process to physically protect organic carbon (C) thereby increasing C content in soil. In general trend, mean weight diameter (MWD) decreases with increase in soil depth under different tillage and cropping system. Tillage had significant effect on soil aggregation after 9 crop cycles (Fig. 20). But cropping system effect on MWD was not significant. The surface layer recorded higher MWD compared to subsurface layer (0-5 cm) and it decreased with depth. The mean MWD of surface layer for CT and NT was 1.60 and 1.80 mm, respectively. The interaction effect of tillage x cropping system x depth was not significant. Results indicated that conservation agriculture management practices had a positive effect on soil aggregation and aggregate stability.

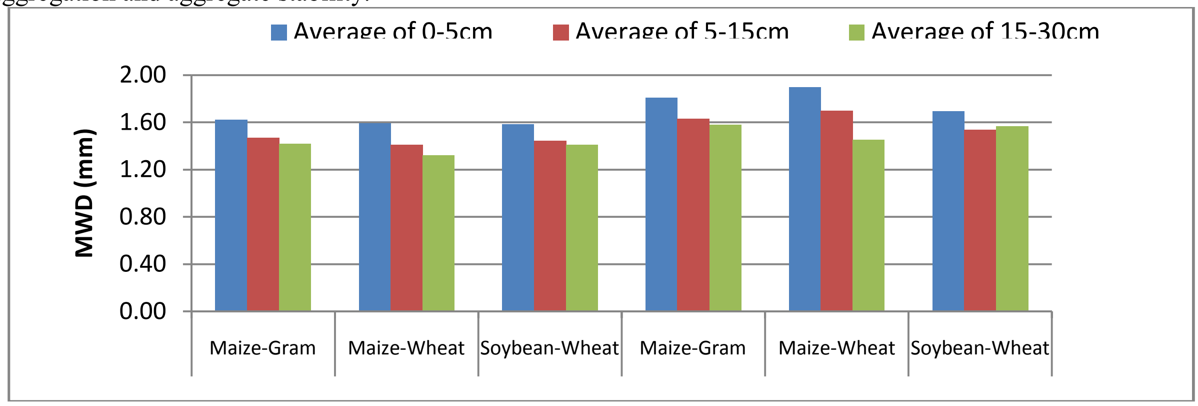


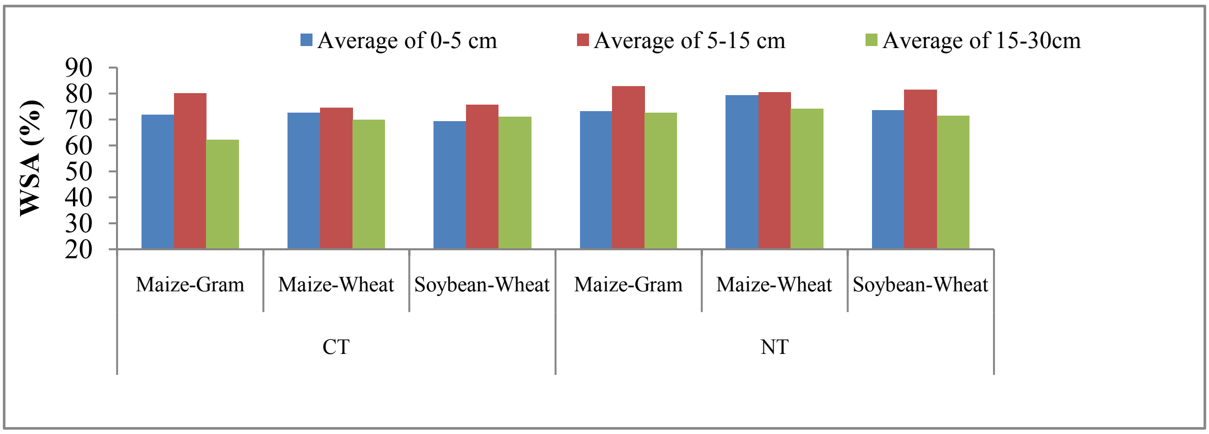
Fig. 20. Soil aggregation under different tillage and cropping system after 9 crop cycles

Water stable aggregates (WSA) under different tillage and cropping systems

Ability of aggregates to resist degradation is known as aggregate stability. Application of organic matter/crop residue into the soil improves the stability of aggregates. Changes in aggregate stability may serve as early indicators of recovery or degradation of soils. Aggregate stability is a credible indicator of organic matter content, biological activity, and nutrient cycling in soil. Generally, the particles in small aggregates (< 0.25 mm) are bound by older and more stable forms of organic matter. Microbial decomposition of fresh organic matter releases products (that are less stable) that bind small aggregates into large aggregates (> 2-5 mm). These large aggregates are more sensitive to management effects such as tillage system, cropping system and fertilizer/organic manure application.

Effect of different tillage and cropping system on water stable aggregate (WSA, %) at different soil depths were presented in Fig 20. The mean values for WSA across tillage systems showed that no-tillage with residue retention had relatively higher WSA (81.5%) than under CT (76.65) at surface layers and these values were decreased with increasing depth, irrespective of tillage and cropping system. Results indicated that tillage and cropping did not have significant effect on WSA. Higher percent of WSA was recorded at surface layer and decreased with depth (Fig 21).

Fig 21. Water stable aggregates (%) under different tillage and cropping system



Long-term Impact of CA practices on Soil Organic Carbon (SOC) after 9 crop cycles

The mean data of SOC during the 9th years of experimentation is depicted in Fig. 22. In general, concentration of SOC was significantly decreased with increasing depth. The SOC content was significantly affected by different tillage systems and cropping system. The mean data of SOC concentration for CT and NT were varied from 0.69 to 0.83 percent and 0.46 to 0.57 per cent at surface layer (0-5 cm), and subsurface layer (5-15 cm), respectively. In general, surface layer (0-5 cm) recorded higher SOC compared to lower soil depths. Irrespective of soil depths, higher SOC was recorded under NT compared CT practices. The NT recorded significantly higher SOC (0.83%) than CT (0.69%) in surface depth (0-5) cm. Similarly, in the sub-surface layer (i.e. 5-15 cm) tillage systems had a significant effect SOC. It is inferred from the data that cropping system had significant effect on SOC content. Among the cropping systems evaluated, maize-gram and maize-wheat recorded significantly higher SOC (0.84%) followed by soybean-wheat (0.81%) under NT. Whereas, under CT maize-wheat recorded minimum SOC (0.65%) at 0-5 cm depth and SOC value decreased with increasing depth. It was evident from the data that the SOC content under NT is significantly higher than CT. Results indicated that interactive effect of tillage × cropping system × soil depth was not significant for SOC. The increased SOC in the surface soil was attributed to a combination of crop residue addition and relatively less soil disturbance by tillage operations under NT.

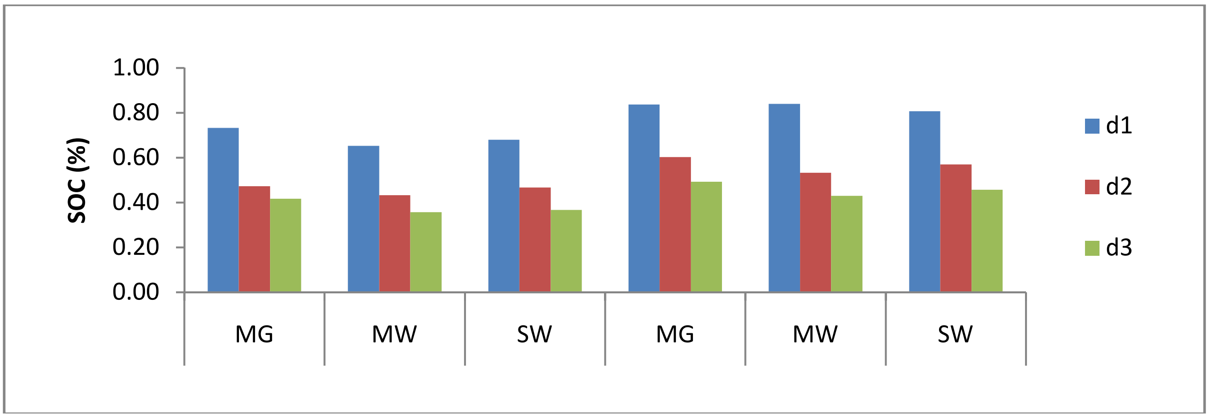


Fig 22. Effect of different tillage and cropping system on soil organic carbon (SOC) at different soil depths (MG-Maize-Gram; MW-Maize-Wheat; SW-Soybean-Wheat; d1-0-5cm, d2-5-15cm, d3-15-30cm)

Aggregate associated carbon under different tillage and cropping systems

Effect of different tillage and cropping system on aggregate associated C at different soil depths were presented in Fig 23. Perusal of data indicated that the aggregate-associated C content increased with aggregate size and it was in the following order of large macraggregate (LM) > small macroaggregate (SM) > silt+clay (S+C) > micro-aggregate (M) in the soil samples. Overall, LM had the highest aggregate C but small macro-aggregate and micro aggregate had almost on par aggregate C. However, Silt +Clay had relatively higher aggregate C, regardless of tillage the lowest aggregate associated C across different tillage and cropping system. Tillage practices and cropping systems had significant effect on large macro aggregate associated-C. Similarly, tillage had a significant effect on small macro-aggregate. In contrast, cropping system had an significant effect on micro-aggregate C and Silt+Clay aggregate C. The interaction of cropping system × depth was significant for LM-C but was not having significant effect on the other aggregate classes. There was more LM aggregate C for NT (0.93 %), and CT (0.83) at 0-5 cm depth (Table 3) and aggregate C decreased with lower depth i.e. 5-15 cm and 15-30 cm. Similar trend was observed in SM aggregate C, M aggregate C and S+C aggregate C.

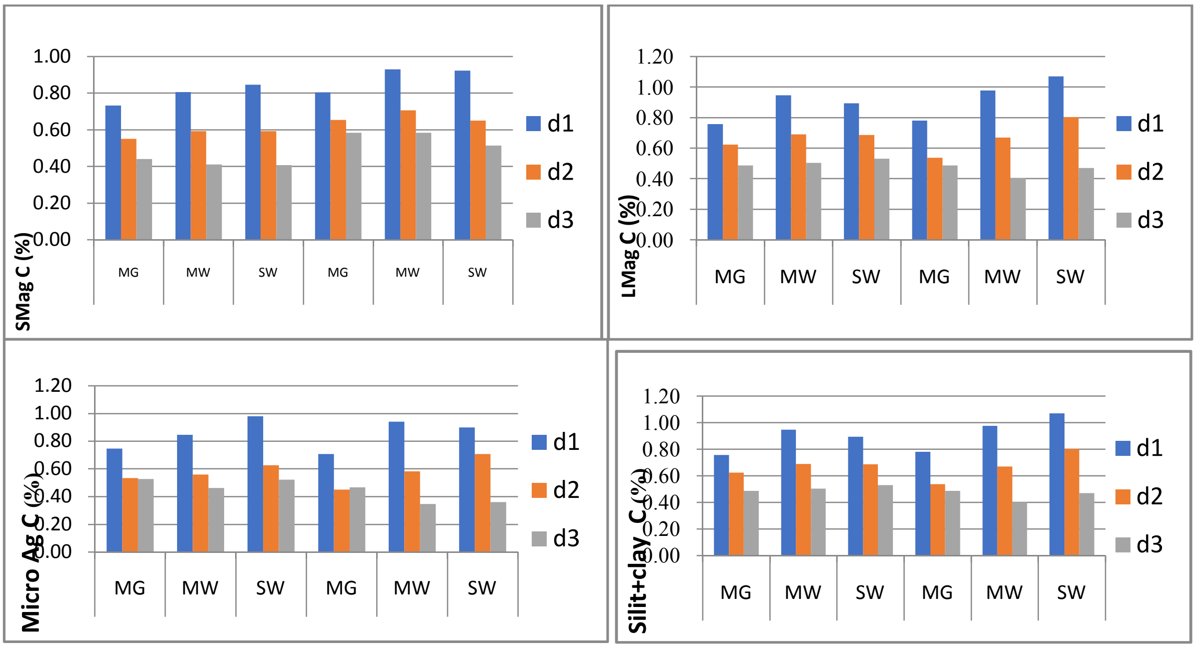
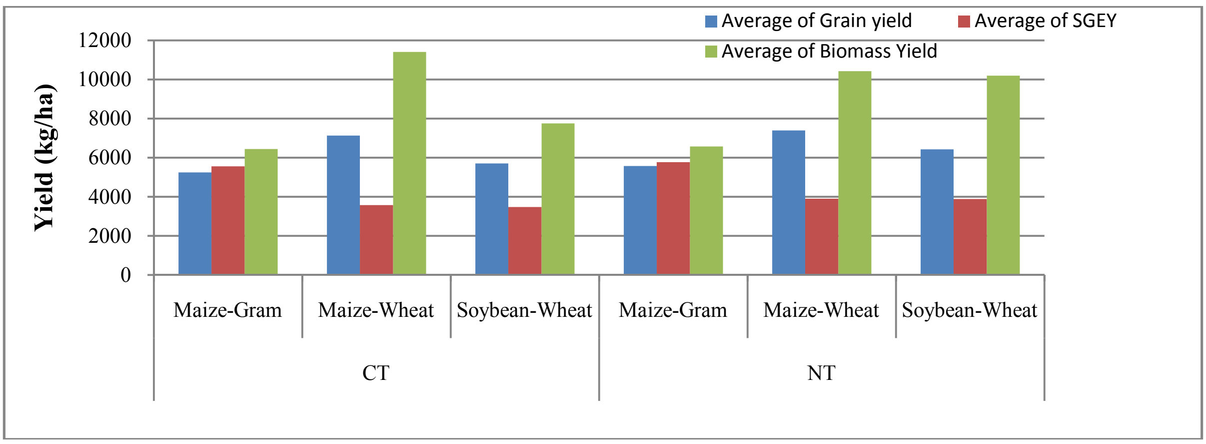


Fig 23. Effect of different tillage and cropping system on aggregate associated carbon at different soil depths A) large macro aggregate C, B) Small macro-aggregate C, C) Micro-aggregate C, D) Silt+Clay C

Impact of CA practices on Crop Yields

Grain yields of different crops were recorded and converted into soybean grain equivalent yield (SGEY) for comparing different cropping systems (Fig 24). Tillage had no significant effect on the soybean grain equivalent yield (SGEY), whereas cropping system had a greater effect on SGE yield. Among various cropping system studied, maize-wheat had significantly higher yield (7401 kg/ha) followed by soybean-wheat (6432 kg/ha) under NT. Similarly trend was observed under CT. SGEY indicated that maize-gram cropping system recorded higher average yield compared to other cropping system, regardless of tillage system.



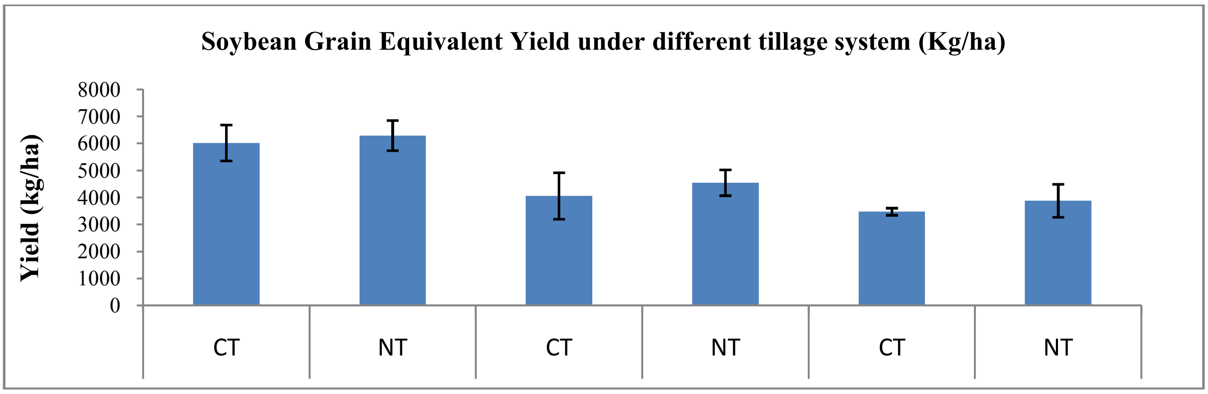


Fig. 24. Effect of different tillage and cropping system on A) Grain Yield and Biomass Yield B) soybean grain equivalent yield (kg/ha) [MSP/q in 2018-2019; soybean Rs 3399; maize Rs1700; wheat Rs 1840; gram(Rs 4620]

Effect of different residue levels on crop performance under conservation agriculture in Vertisols.

A field experiment was initiated in 2016-17 with the aim to study the impact of different residue levels on crop establishment, soil health, ease of utilizing machinery (happy seeder) under different residue levels, weed management and resource conservation in terms of water and energy saving, in soybean –wheat and maize-chickpea cropping systems. Four levels of residues viz., 0, 30, 60 and 90% under no tillage system were compared. Results showed that under no tillage system with increase in residue levels the crop performance expressed in terms of crop height at harvest, biomass yield, seed yield and other yield parameters improved for all the four crops grown during the *kharif* and *rabi* seasons.

Soybean-wheat cropping system

Wheat (C-306) was sown with Happy Seeder at a seed rate of 80 kg ha^{-1} and row to row spacing of 27.5 cm in different levels of residue retained plots. Recommended doses of nutrients NPK, @ 80 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1} through Urea, DAP and MoP respectively, was applied uniformly in all the treatments. Among different residue level treatments maximum plant height at harvest (103.2cm) was recorded in T_4 treatment (90% residue) and minimum plant height at harvest (100.4cm) was recorded in T_1 (control without residue) (Table 15). Among different residue level treatments maximum grain and straw yield (43.6 q/ha and 83.5 q/ha, respectively) was recorded under T4 (90% residue) and minimum grain and straw yield (35.3 q/ha and 79.7 q/ha, respectively) was recorded under T1 (control).

Table 15. Effect of different residue level retention under conservation agriculture on plant height, grain and straw yield of wheat.

Treatment	Plant height (cm)	Grain Yield (q/ha)	Straw yield (q/ha)
T_1 (Control)	100.4	35.3	79.7
T_2 (30% residue)	101.2	39.4	80.6
T_3 (60% residue)	102.0	41.2	82.3
T_4 (90% residue)	103.2	43.6	83.5

Fig. 25. Performance of wheat grown under different residue levels

Soybean (RVS 2001-4) was sown in the field with Happy Seeder @ 80 kg ha^{-1} at a row to row spacing of 27.5 cm in the standing residue of wheat crop in the field as per treatments. The Recommended doses of nutrients @ 30 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1} through Urea, DAP and MoP respectively, was uniformly applied in all the treatments. Among different residue level treatments maximum plant height at harvest (61.1cm) was recorded with T_4 treatment (90% residue) and minimum plant height at harvest (51.7cm) was recorded under T_1 (control without residue). Among different residue level treatments, maximum number of branches at harvest (6.33/ plant) was recorded under T4 (90% residue) and minimum no. of branches (4.44/ plant) was recorded under T1 (control). Similarly, maximum no. of seeds/pod, pods/plant, seed index, no. of seed/plant, grain yield, straw yield and harvest index; 2.67, 43.22, 10.35, 84.17, 19.7, 29.5 and 40.02 respectively were recorded with T4 (90% residue) treatment (Table 16).

Table 16. Effect of different residue level retention under conservation agriculture on growth and yield parameters of soybean at harvest

Treatment	Plant Height (cm)	Branches/ plant	Pods/ plant	No. of seed/pod
T_1 (Control)	51.7	4.44	35.44	2.56
T_2 (30% residue)	54.9	5.17	37.67	2.61
T_3 (60% residue)	58.2	5.67	40.89	2.67
T_4 (90% residue)	61.1	6.33	43.22	2.67

Table 17. Effect of different residue level retention under conservation agriculture on yield and yield parameters of soybean

Treatment	**No. of seed /plant**	**Seed index**	**Grain yield q/ha**	**Straw yield q/ha**	**HI (%)**
T_1 (Control	59.56	9.13	15.4	23.6	39.48
T_2 (30% residue)	71.56	9.57	17.5	26.6	39.61
T_3 (60% residue)	80.94	10.24	19.2	28.9	39.88
T_4 (90% residue)	84.17	10.35	19.7	29.5	40.02

Fig. 26. Soybean (RVS 2001-4) grown under different residue levels

Maize- Chickpea cropping system

Chickpea (JG-16) was sown in the field (2017-18) with Happy Seeder @ 80 kg ha^{-1} at a row to row spacing of 27.5 cm in the standing residue of maize crop in the field as per treatments. The Recommended doses of nutrients @ 30 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1} through Urea, DAP and MOP respectively, was uniformly applied in all the treatments. Among different residue level treatments maximum plant height at harvest (51.9 cm) was recorded with T_4 treatment (90% residue) and minimum plant height at harvest (46.6 cm) was recorded under T_1 (control without residue). Among different residue level treatments in Chickpea maximum grain and straw yield (20.5 q/ha and 24.25 q/ha) was recorded under T4 (90% residue) and minimum grain and straw yield (16.00 q/ha and 18.50 q/ha) was recorded under T1 (control).

Table 18. Effect of different residue level retention under conservation agriculture on plant height, grain and straw yield of chickpea.

Treatment	Plant height (cm)	Grain Yield (q/ha)	Straw yield (q/ha)
T_1 (Control)	46.6	16.00	18.50
T_2 (30% residue)	48.9	18.25	21.75
T_3 (60% residue)	50.5	19.75	23. 50
T_4 (90% residue)	51.9	20.50	24.25

Maize (variety – Nath Samrat- 1144) was sown @ 25 kg/ha with the help of Happy Seeder at a plant to plant and row to row spacing of 55 x 20 cm. The residue of chickpea crop was applied manually after threshing as per the treatments. The recommended doses of nutrients @ 120 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1} through Urea, DAP and MOP respectively, was uniformly applied in all the treatments. Among different residue level, treatments maximum yield (60.6 q/ha) was recorded under T_4 (90% residue) treatment and minimum grain yield (49.8 q/ha) was recorded under T_1 (Control).

Table 19. Effect of different residue level retention under conservation agriculture on plant height at harvest and grain yield of maize

Treatment	Plant height (cm) at harvest	Grain yield q/ha
T_1 (Control)	160.8	49.8
T_2 (30% residue)	163.5	55.0
T_3 (60% residue)	166.3	58.5
T_4 (90% residue)	166.6	60.6

Fig. 27. Maize grown at different residue levels under conservation agriculture

3. Development of Water and Nutrient Management Practices in Conservation Agriculture for Vertisols of Central India

Soybean Crop (*Kharif*, 2018

During the rainy season a field experiment on soybean crop was conducted with three tillage treatments viz. CT-Conventional tillage, RT-Reduced tillage and NT- No tillage and three fertilizer doses, viz. F1=100% recommended dose of fertilizer (RDF), F2=75% RDF, F3=STCR (soil test crop response). Soybean was sown on June 28, 2018 and harvested on October 12, 2018. Observation on growth and crop yield parameters were recorded during the crop growth period. Slightly higher grain yield was recorded under conventional tillage compared to the no tillage treatment but the treatment difference was not significant. Among the fertilizer treatments, 100% RDF recorded higher grain yield followed by STCR dose treatment and the lowest yield was recorded in 75% (Table 20 and 21).

Fig 28. Soybean crop during the vegetative stages

Fig 29. Soybean crop at maturity

Table 20. Effect of tillage management and fertilizer dose on grain and straw yield of soybean

	Soybean yield (kg ha^{-1})				Straw yield (kg ha^{-1})			
	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	1880	1778	1848	1835	2416	2358	2330	2368
RT	1796	1731	1703	1743	2251	2319	2302	2291
NT	1592	1663	1608	1621	2192	2055	2110	2119
Mean	1756	1724	1720		2286	2244	2247	
	Tillage : NS, Fertilizer Dose : NS, Tillage x Fertilizer dose : NS				Tillage : NS, Fertilizer Dose : NS, Tillage x Fertilizer dose : NS			

Table 21. Effect of tillage management and fertilizer dose on pod number and 100 seed weight of soybean

	100 seed weight (g)				No of pods/plant			
	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	97	100	95	97	57	74	66	66
RT	94	98	92	95	55	70	65	63
NT	92	95	91	93	52	54	63	56
Mean	94	98	93		55	66	65	
	Tillage : NS, Fertilizer Dose : NS, Tillage x Fertilizer dose : NS				Tillage : NS, Fertilizer Dose : NS, Tillage x Fertilizer dose : NS			

Wheat crop 2018-2019

To study the interaction effect of tillage, irrigation and nutrient management on wheat, a field experiment with three irrigation methods (Flood, Sprinkler and Drip irrigation in the main plot), three tillage treatments (CT-Conventional tillage, RT-Reduced tillage and NT- No tillage) in the sub plot and four fertilizer management treatments (100 % RDF, 75% RDF, STCR and 75% RDF with 25% LCC) in the sub-sub plot was conducted during the winter season of 2018-19. Observations on soil temperature, crop growth, yield and yield attributes were recorded. The grain yield of wheat was the highest under flood irrigation followed by sprinkler irrigation and yield was the lowest under drip irrigation but the yield differences among the irrigation methods were not significant. Yield differences among the different tillage systems and fertilizer treatments were not significant. Similar trend was also recorded in the growth, yield attributes parameter of wheat.

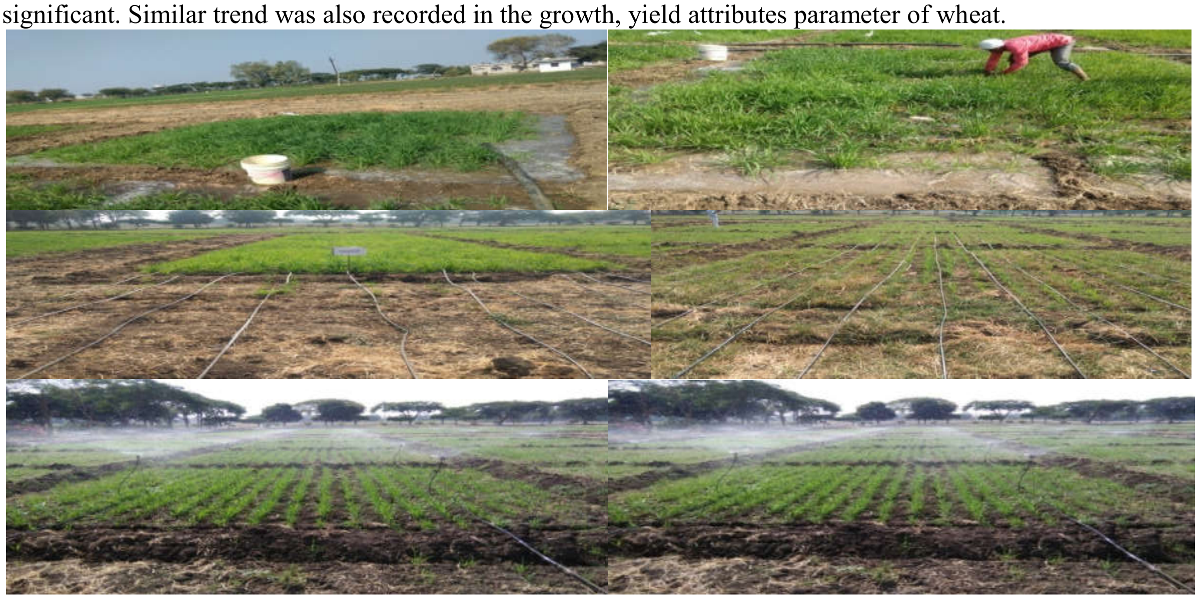
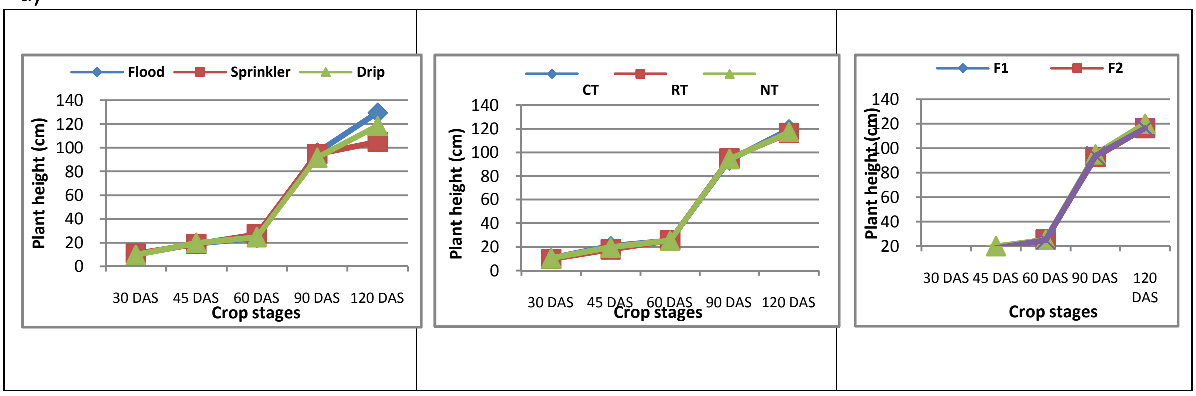


Fig. 30. Wheat crop grown under different irrigation system

a)



b)

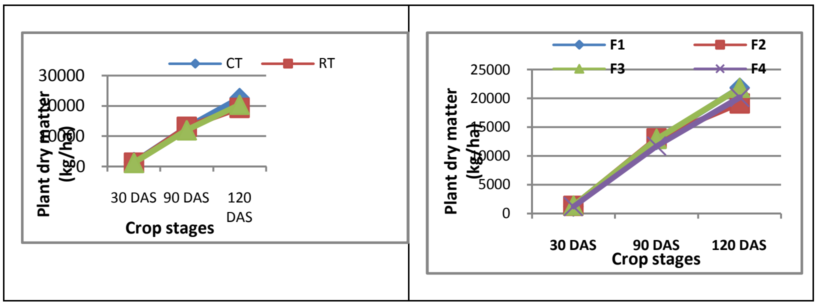


Fig 31. Effect of different irrigation system, tillage practices and fertilizer doses on temporal variation of a) plant height and b) biomass of wheat

Table 22. Effect of irrigation methods, tillage practices and fertilizer doses on yield attributes of wheat

Treatment	Length of ear head (cm)	No. of grain /Ear head	Grain weight /ear head (g)	1000 seed weight (g)
Irrigation methods				
Flood	8.17	42.4	1.89	44.3
Sprinkler	8.12	42.0	1.81	42.9
Drip	8.02	40.4	1.72	41.9
LSD (0.05)	NS	NS	NS	NS
Tillage systems				
CT	8.32	43.2	1.86	43.3
RT	8.01	41.0	1.81	42.9
NT	7.99	41.1	1.79	42.9
LSD (0.05)	NS	NS	NS	NS
Nutrient Doses				
100% RDF	8.10	42.7	1.88	43.4
75% RDF	8.16	41.8	1.82	43.0
STCR Dose	8.15	41.9	1.82	43.0
75% +25% LCC	8.01	40.7	1.76	42.8
LSD (0.05)	NS	NS	NS	NS

Table 23. Effect of irrigation methods, tillage practices and fertilizer doses on grain and straw yield and harvest index of wheat.

Treatment	Grain yield (q $ha^{-1)}$	Straw yield (q/ha^{-1})	Harvest Index (%)
Irrigation methods			
Flood	5143	7095	42
Sprinkler	4536	5739	44
Drip	4758	6624	42
LSD (0.05)	NS	NS	NS
Tillage systems			
CT	4837	6352	44
RT	4835	6403	43
NT	4765	6703	42
LSD (0.05)	NS	NS	NS
Nutrient Doses			
100% RDF	5007	6755	43
75% RDF	4753	6640	42
STCR Dose	4693	6195	44
75% +25% LCC	4796	6354	43
LSD (0.05)	NS	NS	NS

Soil temperature during the *rabi* season (2018-19)

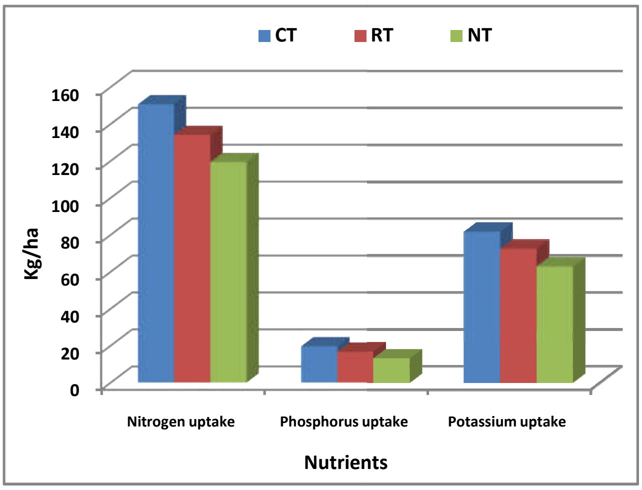
Soil temperature at 5 and 15 cm depth were measured twice during the *rabi* season under wheat crop in all the treatments. The temperature difference between the maximum and minimum values measured during the afternoon and morning hours were higher at 5 cm soil depth compared to the 15 cm soil depth in all the treatments (Table 24). The maximum and minimum temperatures on 26.11.2018 were higher than that on 18.12.2018 in both the soil depths and in all the treatments. The temperature differences among the treatments were not significant.

Table 24: Effect of irrigation methods, tillage practices and fertilizer doses on soil temperature

Treatment	Soil temperature (^{0}C) (26.11.2018)				Soil temperature (^{0}C) (18.12.2018)			
	Soil depth (cm)							
	0-5	0-5	5-15	5-15	0-5	0-5	5-15	5-15
	7 AM	2 PM	7 AM	2 PM	7 AM	2 PM	7 AM	2 PM
Irrigation methods								
Flood	17.8	25.6	20.4	23.7	12.3	19.2	14.1	18.2
Sprinkler	17.3	25.6	20.2	23.5	13.4	19.4	15.8	18.3
Drip	17.0	25.5	19.8	23.6	13.4	19.6	15.3	18.5
LSD (0.05)	NS	NS	0.325	NS	0.574	NS	NS	NS
Tillage systems								
CT	17.3	25.4	20.4	23.5	13.1	19.5	14.7	18.5
RT	17.2	25.6	19.9	23.6	13.2	19.3	15.0	18.2
NT	17.5	25.7	20.1	23.7	13.0	19.3	15.4	18.3
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient Doses								
100% RDF	17.2	25.8	20.2	23.9	13.1	19.2	14.8	18.2
75% RDF	17.3	25.7	20.0	23.6	13.2	19.5	15.9	18.4
STCR Dose	17.4	25.4	20.1	23.5	12.9	19.3	14.7	18.3
75% +25% LCC	17.5	25.5	20.2	23.4	13.1	19.5	14.8	18.5
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Uptake of NPK by soybean

Uptake of nutrients by soybean differed significantly due to tillage and nutrient management practices. The uptake of N, P and K varied from 113.15 to 157.95, 15.16 to 22.13 and 56.47 to 86.14 kg/ha, respectively among different tillage and nutrient treatments. Uptake of N, P and K by soybean grown under conventional tillage system (150.77, 19.82 and 81.75 kg/ha) were higher than that under reduced tillage (134.23, 16.8 and 72.67 kg/ha) and no tillage (119.47, 13.28 and 63.05 kg/ha) system (Fig 23). Among the different nutrient levels N, P and K uptake was higher in 100 % NPK (141.09, 18.0 and 77.12 kg/ha) followed by 75% NPK (134.71, 16.54 and 72.03 kg /ha) and STCR (128.66, 15.16 and 68.32 kg/ha) treatment. The interaction effect of tillage systems and nutrient levels was also significant. The total N, P and K uptake was the highest under conventional tillage with 100% NPK dose and it was the lowest was under no tillage with STCR dose.



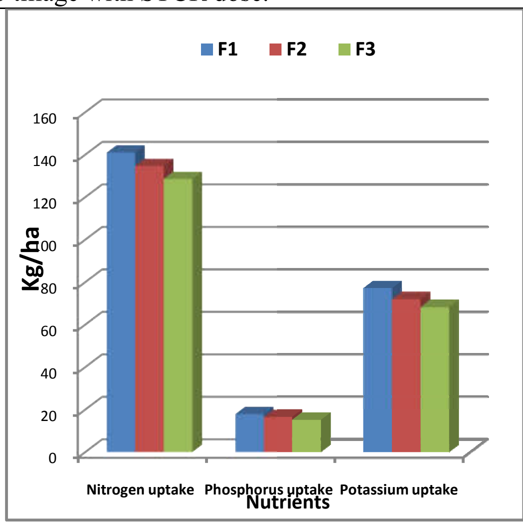


Fig 32. Effect of tillage and nutrient doses on N, P and K uptake by soybean.

2.1.1.3 Weed Management

Weed management in rice – wheat - greengram based cropping system under conservation agriculture-DWR

Study on weed management in long term rice-wheat-greengram cropping system under conservation agriculture was conducted, under the study following major findings were observed.

In wheat 2017-18,

In the study area wheat field comprised with *Medicago polymorpha, Chenopodium album, Rumex dentatus, Sonchus oleraceus, Vicia sativa, Cichorium intybus, Convolvulus arvensis* and *Lathyrus aphacea* were major broadleaved weeds, *Avena fatua, Phalaris minor, Dinebra retroflexa, Digitaria sanguinalis, Echinochloa colona* and *Paspaladium* sp. were major grassy weeds and there was no sedge present. *Medicago polymorpha, Chenopodium album* and *Avena ludoviciana* was the dominating weed species in wheat. *Physalis minima, Sonchus oleraceus. Lathyrus sativus, Phalaris minor, Rumex dentatus, Cichorium intybus, Convolvulus arvensis* were other weed flora present at 60 DAS. It was noticed that *Digitaria sanguinalis, Echinochloa colona* and *Paspaladium* sp. were late emerging weeds in wheat. ZT plots were more with *Avena*, whereas, *Phalaris* was more in CT plots. Weed densities in CT and ZT was comparable and higher than the TPR-CT. Weed density of *Medicago polymorpha* and *Chenopodium album* was higher in CT than ZT and TPR-CT whereas, *Avena ludoviciana* germination was higher in ZT compared to the CT and TPR-CT. *Convolvulus arvensis* was present only in CT plots.

Shannon diversity index in wheat was higher in TPR-CT and ZT compare to the other crop establishment methods (**Fig. 1**). However, CT has the lowest diversity due to *Medicago polymorpha* dominating in the tillage practice. Among weed management rotational use of herbicides and clodinafop+sulfosulfuron has comparable diversity but was lower than weedy check.

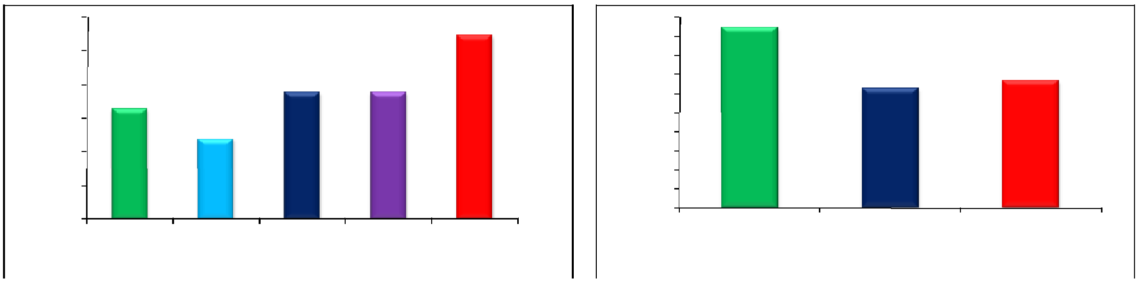


Fig. 1. Effect of weed diversity on crop establishment methods (tillage practices) (A) and weed management (B) in wheat

Seed bank study shows that, in wheat there is a decreasing trend of *Medicago polymorpha* emergence with the depth in all crop establishment method (tillage practices) (**Fig. 2**). *Avena fatua* are present mainly in upper layer of ZT and ZTR. However, C*henopodium album* are almost equally distributed in all three layers but in CTR at 0-5 cm depth very few seed germinated and similarly, in TPR-CT at 5-10 cm depth. Seeds of *Avena ludoviciana* were germinated in upper layer (0-5 cm depth) in all the tillage practices except TPR-CT, whereas, in lower layer only few seeds germinated TPR-CT (5-10) and, CT, CTR and ZTR (10-15cm depth).

Weed seed bank was measured and it was found that ZT plots had more of weeds on top 0-2 cm depth, followed by CT. Inclusion of crop residues significantly reduced the weed seed bank. At 2-5 cm depth, no specific trend was recorded. However, at 5-10 cm depth, CT plots had more seeds than ZT and it was further reduced with the plots where previous crop residues were retained. Regardless of all the depths, ZT plots had 17.2 and 41.6% lower broadleaved and grassy weed seeds, respectively over CT. Residue retention lowered 5.2% of BLW and 43.7% of grassy weeds than residue removal. The highest species diversity was recorded in ZT followed by TPR-CT, whereas, lowest species diversity was recorded in CT. Among weed management practices, tank mix of clodinafop + sulfosulfuron (60+25 g/ha) recorded lowest diversity followed by rotational use of herbicides (clodinafop + 2, 4-D 60+ 500 g/ha), whereas, the highest diversity recorded with weedy check.

It was found that weed density was lower in TPR-CT (33.4 no./m^2) and DSR ZT+R+S-ZTR-ZTR (34.3 no./m^2), whereas, dry biomass was lowest with DSR ZT+R+S-ZTR-ZTR (18.4 g/m^2) followed by TPR-CT but, both were statistically comparable (**Table 1**). Reduction in weed density under DSR ZT+R+S-ZTR-ZTR significantly achieved the higher weed control efficiency (63.7%) followed by TPR-CT (61.8%), whereas, lower weed control efficiency was recorded in DSR CT+S-CT-ZT (45.8%). The highest weed density and dry biomass was recorded with DSR CT+S-CT-ZT (44.7 no./m^2 and 27.5 g/m^2, respectively). It was estimated that weed dry biomass was 14.3% lower in ZT over CT plots, and retention of crop residue further reduced the weed dry biomass by 21.2% over without residues. Among weed management practices tank mix of clodinafop + 2, 4-D has lowest weed density and dry biomass (12.0 no./m^2 and 6.6 g/m^2, respectively) followed by clodinafop + sulfosulfuron, whereas the highest values was measured in weedy check (88.5 no./m^2 and 50.7 g/m^2, respectively). Rotational use of herbicide i.e. tank mix of clodinafop+2, 4 D was controlled the wide range of grassy and broadleaved weeds resulted highest weed control efficiency (87%) followed by clodinafop+sulfosulfuron (80.7%) over weedy check

Among the crop establishment methods, grains/spike ranged from 39.5 - 42.7/spike, which was statistically comparable. But, grain yield was significantly higher in DSR ZT+R+S-ZTR-ZTR (4.13 t/ha) followed by DSR CT+R+S-CTR-ZTR (3.87 t/ha) which were 21 and 13.4%, respectively better than TPR-CT (3.41 t/ha). Straw yield had followed the trend of grain yield and higher straw yield in DSR ZT+R+S-ZTR-ZTR (5.23 t/ha) followed by DSR CT+R+S-CTR-ZTR and lowest with TPR-CT (**Table 1**). Among the weed management practices grains/spike, grain and straw yield was significantly higher with clodinafop+sulfosulfuron (43.2, 4.94 and 6.27 t/ha respectively) which was close to clodinafop+2, 4 D (42.2, 4.63 and 5.95 t/ha, respectively). However, the lowest yield attributes and yield was recorded with weedy check (39.9, 1.46 and 1.93 t/ha, respectively).

The energy use pattern on long term impact of herbicides in wheat under different crop establishment method was studied during *Rabi,* 2017-18. The highest grain yield (5.4 t/ha) and energy output (168632.8 MJ/ha) was obtained in ZT+R along with clodinofop + sulfosulfuron (60+25 g/ha). However, the energy use efficiency (11.08) and energy productivity (0.35 kg/MJ) was highest in ZT along with clodinofop + sulfosulfuron (60+25 g/ha), whereas net energy (135949.9 MJ/ha) was highest in CT along with clodinofop + sulfosulfuron (60+25 g/ha). The least performance of the treatment was observed in CT+R along with weedy check plots (**Table 2 & Fig. 3**), in which, the net energy return was in negative (-39727.51 MJ/ha).

Table 1. Weed and yield parameters of wheat as influenced by crop establishment and weed management practices on wheat in rice-wheat-greengram cropping system under CA

Treatment	Weed density (no./m^2)	Weed dry biomass (g/m^2)	WCE (%)	Grains /spike	Grain yield (kg/ha)	Straw yield (kg/ha)
Crop establishment						
DSR CT+S-CT-ZT	6.05^{a}(44.7)	4.82^{a}(27.5)	45.8	39.5^{a}	3622.2^{c}	4662.9^{c}
DSR CT+R+S-CTR-ZTR	5.39^{bc}(35.2)	4.32^{bc}(22.3)	56.1	41.0^{a}	3866.7^{b}	4937.9^{b}
DSR ZT+S-ZT-ZT	5.96^{ab}(43.8)	4.53^{ab}(24.3)	52.2	41.0^{a}	3355.6^{d}	4358.4^{d}
DSR ZT+R+S-ZTR-ZTR	5.30^{c}(34.3)	3.93^{c}(18.4)	63.7	42.7^{a}	4133.3^{a}	5225.4^{a}
TPR-CT	5.16^{c}(33.6)	3.96^{c}(19.4)	61.8	41.2^{a}	3411.1^{d}	4408.3^{d}
LSD (p=0.05)	0.64	0.42		(ns)	184.4	236.13
Weed management						
Weedy check	9.41^{a}(88.5)	7.14^{a}(50.7)	-	37.9^{b}	1460.0^{c}	1930.7^{c}
Clodinafop+Sulfosulfuron	3.84^{b}(14.4)	3.18^{b}(9.8)	80.7	43.2^{a}	4943.3^{a}	6274.2^{a}
Clodinafop+2,4 D	3.47^{b}(12.0)	2.62^{c}(6.6)	87.0	42.2^{a}	4630.0^{b}	5950.8^{b}
LSD (p=0.05)	0.49	0.38		2.86	277.23	323.05

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; **TPRCT:** Transplanted rice followed by CT wheat; **S:** Sesbania. Weed data subjected to SQRT transformation; original values are in parentheses

Table 2. Energy consumption and energy output for wheat cultivation under different tillage and weed management practices on wheat in rice-wheat-greengram cropping system under CA

Treatments	Energy input (MJ/ha)	Yield (kg/ha)	Energy output (MJ/ha)	Net energy (MJ/ha)	Energy use efficiency	Energy productivity (kg/MJ)
CT-Wheat:W1	16147.5	1400.0	45080.0	28932.5	2.8	0.09
CT-Wheat:W2	16210.1	4800.0	152160.0	135949.9	9.4	0.30
CT-Wheat:W3	16341.6	4666.7	137116.3	120774.6	8.4	0.29
CT-Wheat+R:W1	91147.5	1600.0	51420.0	-39727.5	0.6	0.02
CT-Wheat+R:W2	91210.1	5233.3	164587.8	73377.7	1.8	0.06

CT-Wheat+R:W3	91341.6	4766.7	151282.2	59940.5	1.7	0.05
ZT-Wheat:W1	13098.7	1300.0	42022.5	28923.8	3.2	0.10
ZT-Wheat:W2	13161.3	4600.0	145820.0	132658.7	11.1	0.35
ZT-Wheat:W3	13292.8	4166.7	133645.9	120353.1	10.1	0.31
ZT-Wheat+R:W1	88447.5	1766.7	56887.2	-31560.3	0.6	0.02
ZT-Wheat+R:W2	88510.1	5383.3	168632.8	80122.7	1.9	0.06
ZT-Wheat+R:W3	88641.7	5250.0	165112.5	76470.8	1.9	0.06
CT-Wheat (TPR):W1	16147.5	1235.0	39861.9	23714.3	2.5	0.08
CT-Wheat (TPR):W2	16210.1	4700.0	148990.0	132779.9	9.2	0.29
CT-Wheat (TPR):W3	16341.6	4300.0	137116.3	120774.6	8.4	0.26

W1: Weedy check; W2: Clodinofop + sulfosulfuron (60+25 g/ha); W3: Clodinofop + 2, 4-D (60+500 g/ha)

In greengram 2018

At 45 days after sowing (DAS), the study area comprised of weeds i.e. *Echinochloa colona, Cyperus rotundus, Euphorbia geniculata, Paspalidium flavidum, Commelina communis* and *Convolvulus arvensis*. The highest weed density was recorded in DSR CT+S-CT-ZT (74.1no./m^2) followed by TPR-CT-CT (65.8 no./m ^{2}), whereas the lowest weed density was recorded with DSR ZT+R+S-ZTR-ZTR (41.0 no./m^2). The lower weed density in DSR ZT+R+S-ZTR-ZTR was mainly due to the retention of previous crop residues created an obstacle for germination and emergence of weeds, which was not present in CT and ZT without crop residues. This treatment has a lesser weed population resulted in lower weed seed rain, which further lowered the establishment of weeds. Among weed management practices, weedy check recorded the highest weed density (139.8 no./m^2), whereas the lowest weed density was recorded with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (4.3 no./m^2). Application of pendimethalin at 678 g/ha has considerably suppressed the weed density (28.8 no./m^2), yet their effect was less pertaining to pendimethalin 678 g/ha *fb* hand weeding at 30 DAS.

Among the crop establishment methods, the highest weed dry biomass was recorded with DSR CT+S-CT-ZT (47.5 g/m^2), whereas the lowest weed dry biomass was recorded in DSR ZT+R+S-ZTR-ZTR (23.6 g/m^2). Weed dry biomass in rest of the tillage treatments was fall in between these two. However, their effect was less pertinent to DSR CT+S-CT-ZT. The lower weed density in DSR ZT+R+S-ZTR-ZTR resulted to achieve 50.3% WCE over DSR CT+S-CT-ZT. The higher WCE in DSR ZT+R+S-ZTR-ZTR recorded higher seed and stover yield (1.09 and 2.34 t/ha, respectively) followed by ZTWR-ZT-ZTSR. The lowest seed and stover yield was recorded with DSR CT+S-CT-ZT (0.94 and 1.95 t/ha, respectively) (**Table 3**).

Table 3. Weed density, dry biomass, weed control efficiency, grain and straw yield as influenced by crop establishment methods and weed management practices in greengram

Treatments	Total weed density (g/m^2)	Total weed dry weight (g/m^2)	WCE (%)	Yield (kg/ha)	% increase	Straw (kg/ha)	% increase
Crop establishment methods							
DSR CT+S-CT-ZT	7.5(74.1)	6.1(47.5)		941.11		1946.76	
DSR CT+R+S-CTR-ZTR	5.7(47.3)	4.7(30.7)	0.354	1023.89	1.088	1973.47	1.014
DSR ZT+S-ZT-ZT	6.5(59.9)	5.1(35.9)	0.244	938.33	0.997	1830.61	0.940
DSR ZT+R+S-ZTR-ZTR	5.2(41.0)	4.0(23.6)	0.503	1089.44	1.158	2342.8	1.203
TPR-CT-CT	7.0(65.8)	5.4(38.9)	0.181	955	1.015	1896.63	0.974
LSD (p=0.05)	0.37	0.26		NS		299.08	
Weed management							
Weedy check	11.8(139.8)	9.2(85.0)		397.67		777.01	

Pendimethalin 678g/ha	5.4(28.8)	4.3(18.2)	0.786	1221.67	3.072	2460.82	3.167
Pendimethalin 678 g/ha *fb* HW at 30 DAS	2.0(4.3)	1.7(2.9)	0.966	1349.33	3.393	2756.33	3.547
LSD (p=0.05)	0.44	0.32		89.87		180.82	

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; **TPRCT:** Transplanted rice followed by CT in wheat; **S:** Sesbania as brown manure. Weed data subjected to SQRT transformation (x+0.5); original values are given in parentheses; **WCE**: weed control efficiency

Among weed management practices, weedy check has the highest weed dry biomass (85 g/m^2) and the lowest with pendimethalin 678 g/ha *fb* hand weeding (2.9 g/m^2). The lowest weed dry biomass with pendimethalin 678 g/ha *fb* hand weeding recorded the highest WCE (96.6%) followed by pendimethalin 678 g/ha (78.6%) over the weedy check. Lower weed parameters and better WCE helped in formation of more yield attributes (branches, pods/plant, seeds/pod) resulted the highest grain and stover yield in pendimethalin 678 g/ha *fb* hand weeding (1.35 and 2.76 t/ha, respectively) followed by pendimethalin 678 g/ha (1.22 and 2.46 t/ha, respectively), whereas the lowest yield attributes and yield was recorded with weedy check.

In Rice 2018

Rice field was severely infested with a wide range of weeds, at 60 DAS, *Cyperus iria* and *Echinochloa colona* were the major weeds, with the progress of time, the weed like *Alternanthera sessilis, Caesulia axillaris, Dinebra retroflexa* and *Ludwigia parviflora* were become dominant along with *C. iria* and *E. colona*. In DSR, *Phyllanthus urinaria, Physallis minima, Commelina benghalensis* and *Digera arvensis* were other weeds but with lower density. All the treatments except weedy check and puddle transplanted rice (TPR) were sown with 30 kg/ha of *sesbania* (S) and this was knock down by applying 2,4 D 500 g/ha at 32 DAS.

The highest weed density was recorded in CT DSR+S (63.44 no./m^2) followed by ZT DSR+S (62.89 no./m^2), whereas the lowest weed density was recorded with TPR (27.56 no./m^2). The lower weed density in TPR was mainly due to puddle field where existing weeds were incorporated and transplanting of 21 days old seedlings and also with the presence of thin water layer since the beginning, which was not present with CT and ZT with and without crop residues. Among weed management practices, weedy check recorded the highest weed density (119.07 no./m2), whereas the lowest weed density was recorded with herbicide rotation and application of cyhalofop+ pinoxsulam 135 g/ha (10.13 no./m^2). Continuous application of bispyribac sodium 25 g/ha in rice recorded weed density of 20.73 no./m^2, this was considerably lower than the weedy check but was less pertinent to cyhalofop+ pinoxsulam 135 g/ha. The higher weed density in continuous bispyribac was due to poor control of grasses and some of the broadleaved weeds.

The highest weed dry biomass was recorded with DSR ZT+S (93.5 g/m^2) followed by DSR CT+S (86.2 g/m^2). The lowest weed dry biomass was recorded with TPR-CT-ZT (47.9 g/m^2) with 48.8% WCE. Rests of the treatments were between these, yet their effect was less pertaining to TPR. Lower weed dry biomass and higher WCE helped in harvesting higher grain and straw yield in TPR (4.23 and 6.91 t/ha, respectively) followed by DSR CT+R+S (2.91 and 4.74 t/ha, respectively). The lowest grain and straw yield recorded in DSR ZT+S (2.57 and 4.19 t/ha, respectively).

Among weed management practices, the lowest weed dry biomass and the highest WCE was recorded in herbicide rotation cyhalofop+ pinoxsulam 135 g/ha (16.26 g/m^2 and 90.3%, respectively) followed by continuous bispyribac sodium 25 g/ha (35.59 g/m^2 and 78.7%, respectively). Continuous application of bispyribac was the next best treatment, as it controls the wide range of weeds, but some of the weeds could not be controlled, which offered competition to the crop. The highest weed dry biomass was recorded with a weedy check (167.3 g/m^2). The higher grain and straw yield was recorded with cyhalofop+ pinoxsulam135 g/ha (3.82 and 6.56 t/ha respectively) followed by bispyribac sodium 25 g/ha than a weedy check.

Higher yield in TPR helped to obtain highest net return (Rs 41396/ha) followed by ZT DSR+R+S (Rs 27871/ha), whereas, the B: C was the highest with DSR+R+S (2.26) followed by TPR (2.23). The lowest net return and B: C recorded with CT DSR+S (Rs 16264/ha and 1.50 respectively). Rests of the treatments were between these, yet their effect was less pertaining to TPR. Among weed management practices, the highest net return and B: C was recorded in cyhalofop+ pinoxsulam 135 g/ha (Rs 39887/ha and 2.42 respectively) followed by bispyribac sodium 25 g/ha over the weedy check (**Table 4**).

During the study, it was recorded that dry spells for more than 15 days have formed the soil cracks and it was shorter, narrower, shallow in ZT with previous crop residues were retained. However, in CT without crop residues plots had longer, wider and deeper soil cracks. Once soil cracks were formed the water requirement significantly increased. In transplanted rice, due to puddling, hard pan was formed below plow zone, which restricted the further down ward movement of water and with minimum irrigation/rainfall thin layer of water could be maintained resulted minimum soil cracks (**Plate 1**).

Table 4. Weed density, dry biomass, weed control efficiency, grain and straw yield and economics as influenced by crop establishment methods and weed management practices on rice in rice-wheat-greengram cropping system under CA

Treatments	Total weed density (g/m^2)	Total weed dry weight (g/m^2)	WCE (%)	Grain yield (kg/ha)	Straw yield (kg/ha)	Net Return (Rs/ha)	B:C
Crop establishment methods							
CT DSR+S	6.94(63.44)	8.20(86.24)	7.8	2758.3	4495.3	16264	1.50
CT DSR+R+S	6.44(54.44)	7.70(74.46)	20.4	2911.1	4739.0	18968	1.58
ZT DSR+S	6.85(62.89)	8.56(93.49)		2572.2	4185.0	23535	2.07
ZT DSR+R+S	5.73(41.56)	7.08(63.17)	32.4	2816.7	4588.2	27871	2.26
TPR	4.89(27.56)	6.27(47.90)	48.8	4227.8	6910.7	41396	2.23
LSD (p=0.05)	0.92**	1.39*		182.12**	299.29**		
Weed management							
Weedy check	10.76(119.07)	12.84(167.30)		1816.7	2725.0	10012	1.45
Bispyribac 25 g/ha	4.56(20.73)	5.90(35.59)	78.7	3539.0	5662.4	34640	2.24
Cyhalofop + pinoxsulam 135 g/ha	3.18(10.13)	3.95(16.26)	90.3	3816.0	6563.5	39887	2.42
LSD (p=0.05)	0.50**	0.72**		169.31**	278.43**		
Interaction (TxW)	1.13**	NS		378.58**	622.60**		

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; **TPRCT:** Transplanted rice followed by CT in wheat; **S:** Sesbania as brown manure. Weed data subjected to SQRT transformation (x+0.5); original values are given in parentheses; **WCE**: weed control efficiency

ZT-DSR+R+S **Transplanted rice**

Plate 1. Soil cracks as influenced by crop establishment and weed management practices in rice

Table 5. Energy consumption and energy output for rice cultivation under different tillage and weed management practices

Treatments	Energy Input (MJ/ha)	Energy Output (MJ/ha)	Net Energy (MJ/ha)	Energy Use Efficiency	Energy Productivity (kg/MJ)	Total CO_2 equivalent emission (kg/ ha)
CT-DSR:W1	16377.19	54077.50	37700.31	3.30	0.10	211.13
CT-DSR+S:W2	60663.45	113179.83	52516.38	1.87	0.05	221.88
CT-DSR+S:W3	60693.92	122959.33	62265.41	2.03	0.06	221.48
CT-DSR+R:W1	53861.51	59652.50	5790.99	1.11	0.03	211.13

CT-DSR+R+S:W2	98163.45	119136.67	20973.22	1.21	0.03	221.88
CT-DSR+R+S: W3	98193.92	127303.33	29109.41	1.30	0.04	221.48
ZT-DSR:W1	11547.34	54077.50	42530.16	4.68	0.14	100.06
ZT-DSR+S:W2	57614.65	104678.33	47063.68	1.82	0.05	110.81
ZT-DSR+S:W3	55849.60	111616.67	55767.06	2.00	0.06	110.41
ZT-DSR+R:W1	49143.62	57980.00	8836.38	1.18	0.04	111.81
ZT-DSR+S+R:W2	95463.48	112196.67	16733.19	1.18	0.03	143.68
ZT-DSR+S+R:W3	95493.95	126096.67	30602.72	1.32	0.04	122.16
TPR:W1	16802.20	78050.00	61247.80	4.65	0.14	240.83
TPR:W2	16860.01	164825.00	147964.99	9.78	0.28	242.02
TPR:W3	16890.48	202720.00	185829.52	12.00	0.33	241.62

W_1: Weedy check; W_2: Bispyribac-Na at 25 g/ha; W_3: Cyhalofop+Penoxsulam at 135 g/ha

The long term impact of herbicides in rice under different tillage practices was conducted during *Kharif,* 2018. The highest energy productivity (0.33 kg/MJ), energy output (202720 MJ/ha), net energy (185829.52 MJ/ha) and energy use efficiency (12.0) was obtained in TPR – cyhalofop+penoxsulam at 135 g/ha followed by TPR – bispyribac-Na at 25 g/ha. Further, the highest greenhouse gas emission equivalent to CO_2 emission (t/ha) was observed in TPR – bispyribac-Na at 25 g/ha followed by TPR – cyhalofop+penoxsulam at 135 g/ha. The least performance of the treatment for energy management was observed in CT-DSR+R-weedy plots and for least greenhouse gas emission was observed in ZT DSR – weedy plots (**Table 5).**

Experiment 2 Weed management in rice - maize/mustard/pea - greengram based cropping system under conservation agriculture

Study on weed management in long term rice - maize/mustard/pea - greengram cropping system under conservation agriculture was conducted, under the study following major findings were recorded

In winter season,

In pea

During the study, the study area comprised with *Medicago polymorpha, Chenopodium album* and *Rumex dentatus* were major broadleaved weeds, *Avena fatua, Phalaris minor* and *Dinebra retroflexa* were major grassy weeds. **Table 6** illustrated that the weed density and dry biomass was recorded highest in TPR-CT (93 no./m^2 and 159.9 g/m^2, respectively) followed by ZT DSR+S-ZT-ZT (87.4 no./m^2 and 147.9 g/m^2, respectively). However, the lowest weed parameters were obtained in ZT DSR+R+S-ZTR+ZTR (49.2 no./m^2 and 82.9 g/m^2, respectively). However the lowest weed density and dry biomass was observed in CT (9.73/m^2 and 11.44 g/m^2, respectively). It clearly illustrated that ZT DSR+R+S-ZTR+ZTR has 48.2% WCE over TPR-CT. It was noticed that weed dry biomass reduction in residue retained plots was 35.6% over residue removal plots. Among weed management practices, pendimethalin *fb* hand weeding recorded lower weed parameters (23.1 no./m^2 and 39.8 g/m^2, respectively) followed by pendimethalin alone (40.7 no./m^2 and 69.9 g/m^2, respectively). Whereas, the highest weed density and dry biomass was recorded in weedy check plots (157.3 no./m^2 and 267.4 g/m^2, respectively). Weed control efficiency was recorded highest in ZT DSR+R+S-ZTR-ZTR (69%) followed by CT DSR+R+S-CTR-ZTR (62.4%) and lowest with TPR-CT (40.2%). Pendimethalin *fb* hand weeding significantly reduced the multiple flush of weeds resulted lower weed population and higher weed control efficiency (85.1%) followed by pendimethalin (73.9%) over weedy check.

Crop establishment method influenced the yield attributes and yield of pea (**Table 6**), pods/plant was recorded the highest with ZT DSR+R+S-ZTR-ZTR (21.1 pods/plant), however, rest of the crop establishment method were statistically comparable. Higher yield attributes leads to better seed yield, the highest yield recorded in ZT DSR+R+S-ZTR-ZTR (1.54 t/ha) which was 40.3% higher than ZT DSR+S-ZT-ZT (1.10 t/ha), this has lowest seed yield of pea. CT DSR+R+S-CTR-ZTR (25.6%) and CT DSR+S-CT-ZT (15.9%) are other crop establishment which gave competitive yield to ZT DSR+R+S-ZTR-ZTR. Similarly, haulm yield was followed the trend of seed yield and higher haulm yield with ZT DSR+R+S-ZTR-ZTR (3.83 t/ha) followed by CT DSR+R+S-CTR-ZTR (3.37 t/ha) and the lowest haulm yield recorded with ZT DSR+S-ZT-ZT (2.24 t/ha). Among the weed management practices, application of pendimethalin 1.0 kg/ha *fb* hand weeding increased the pods/plant by 17.3% and seed yield by 174% over weed check. Pendimethalin 1.0 kg/ha also noticed considerable increase in pods/plant (14.5%) and seed yield (136%).

The energy use pattern was studied during *Rabi,* 2017-18 under long term impact of weed control measures in DSR-based cropping system under conservation agriculture in pea. The highest grain yield (2.2 t/ha) was obtained with the ZT+R along with pendimethalin at 1.0 kg/ha PE *fb* one hand weeding at 25 DAS. Similarly, energy output (77708.9 MJ/ha), net energy (67405.4 MJ/ha) and energy use efficiency (7.5) was highest in CT along with pendimethalin at 1.0 kg/ha PE *fb* one hand weeding at 25 DAS. But the energy productivity (0.21 kg/MJ) was highest in ZT along with pendimethalin at 1.0 kg/ha PE *fb* one hand weeding at 25 DAS. The least performance of the treatment was observed in CT+R along with weedy check plots (**Table 7**).

Table 6. Weed and yield parameters as influenced by crop establishment and weed management practices in pea

Treatment	Weed density (no./m^2)	Weed dry biomass (g/m^2)	WCE (%)	Pods/ plant	Grain yield (kg/ha)	Straw yield (kg/ha)
Crop establishment methods						
CT DSR+S-CT-ZT	8.17^b(79.2)	10.61^b(137.1)	48.7	19.6^b	1274.4^{bc}	3452.1^b
CT DSR+R+S-CTR-ZTR	7.04^c(59.6)	9.24^c(100.5)	62.4	19.9^b	1381.1^b	3368.4^b
ZT DSR+S-ZT-ZT	8.68^{ab}(87.4)	11.10^{ab}(147.9)	44.7	19.2^b	1100.0^d	2237.7^d
ZT DSR+R+S-ZTR-ZTR	6.27^d(49.2)	8.29^c(82.9)	69.0	21.1^a	1543.3^a	3833.2^a
TPR-CT	9.06^a(93.0)	11.86^a(159.9)	40.2	19.2^b	1213.3^c	2997.3^c
LSD (p=0.05)	0.61	1.04		1.08	108.48	271.51
Weed management						
Weedy check	12.49^a(157.3)	16.25^a(267.4)	-	17.9^b	640.0^c	1810.9^c
Pendimethalin	6.33^b(40.7)	8.28^b(69.9)	73.9	20.5^a	1511.3^b	3479.4^b
Pendimethalin *fb* HW	4.71^c(23.1)	6.13^c(39.8)	85.1	21.0^a	1756.0^a	4242.9^a
LSD (p=0.05)	0.90	1.27		1.00	144.87	508.75

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; **TPRCT:** Transplanted rice followed by CT in Pea; **S:** Sesbania. Weed data subjected to SQRT transformation; original values are in parentheses

Table 7. Energy consumption and energy output as influenced by crop establishment and weed management practices in pea

Treatments	Energy input (MJ/ha)	Yield (kg/ha)	Energy output (MJ/ha)	Net energy (MJ/ha)	Energy use efficiency	Energy productivity (kg/MJ)
CT-Pea:W1	9673.8	616.7	11326.2	1652.4	1.2	0.06
CT-Pea (TPR):W1	9673.8	633.3	34037.8	24363.9	3.5	0.07
CT-Pea:W2	9989.9	1460.0	26815.4	16825.5	2.7	0.15
CT-Pea (TPR):W2	9989.9	1506.7	60368.9	50379.0	6.0	0.15
CT-Pea:W3	10303.5	1746.7	32080.5	21777.0	3.1	0.17
CT-Pea (TPR):W3	10303.5	1500.0	77708.9	67405.4	7.5	0.15
CT-Pea+R:W1	84673.8	650.0	11938.4	-72735.5	0.1	0.01
CT-Pea+R:W2	84989.9	1583.3	29080.5	-55909.3	0.3	0.02
CT-Pea+R:W3	85303.5	1910.0	35080.4	-50223.1	0.4	0.02
ZT-Pea:W1	6677.5	500.0	9183.4	2505.8	1.4	0.07
ZT-Pea:W2	6993.5	1283.3	23570.5	16577.0	3.4	0.18

ZT-Pea:W3	7307.1	1516.7	27856.2	20549.1	3.8	0.21
ZT-Pea+R:W1	81677.5	800.0	14693.4	-66984.2	0.2	0.01
ZT-Pea+R:W2	81993.5	1723.3	31651.8	-50341.8	0.4	0.02
ZT-Pea+R:W3	82307.1	2106.7	38692.5	-43614.7	0.5	0.03

W1: Weedy check; W2: Pendimethalin at 1.0 kg/ha PE; W3: Pendimethalin at 1.0 kg/ha PE *fb* 1 HW at 25 DAS

In mustard

Crop establishment method and weed management practices significantly reduced the weed density and weed dry biomass (**Table 8**). The lowest values of weed parameters was recorded in ZT DSR+R+S-ZTR-ZTR (63.3 no./m^2 and 94.1 g/m^2, respectively) followed by CT DSR+R+S-ZTR-ZTR (72 no./m^2 and 108.6 g/m^2, respectively), whereas, the highest weed parameters was obtained in TPR-CT (110.3 no./m^2 and 175.1 g/m^2, respectively). The reduction in weed density and dry biomass recorded the better weed control. ZT DSR+R+S-ZTR-ZTR has recorded higher weed control efficiency (68.8%) followed by CT DSR+R+S-CTR-ZTR (64%) and lowest with TPR-CT (41.9%). It was observed that retention of crop residues significantly reduced the weed density and dry biomass in ZT and CT. Application of pre-emergence of pendimethalin *fb* hand weeding recorded lower weed density (23.4 no./m^2) and weed dry weight (41.4 g/m^2) followed by pendimethalin alone (43.7 no./m^2 and 74.3 g/m^2, respectively). The highest density and dry biomass was recorded in weedy check plots. Pendimethalin *fb* hand weeding recorded highest weed control efficiency (86.3%) followed by pendmethalin alone (75.3%) over weedy check.

Crop establishment method has significant effect on yield attributes and yield of mustard (**Table 8**). The highest number of siliqua was recorded in ZT DSR+R+S-ZTR-ZTR (190.6/plant) followed by CT DSR+R+S-CTR-ZTR (181.7/plant). The lowest siliqua was recorded in ZT DSR+S-ZT-ZT (179.9/plant). It was recorded that among the crop establishment methods, siliqua/plant was statistically comparable except ZT DSR+R+S-ZTR-ZTR. Seed yield was recorded the highest with ZT DSR+R+S-ZTR-ZTR (1.62 t/ha) and lowest with ZT DSR+S-ZT-ZT (1.21 t/ha). It was noticed that seed yield was 33.8% higher over ZT DSR+S-ZT-ZT. Similarly, CT DSR+R+S-CTR-ZTR recorded 21.6% and CT DSR+S-CT-ZT (14.8%) higher over ZT DSR+S-ZT-ZT. The establishment, growth and development of yield attributes were poor when it was sown in ZT-ZT-ZT system, whereas there was further improvement with TPR-CT. However, ZT and CT with placement of previous crop residues significantly suppressed emergence of weeds hence, obtained better yield attributes and higher seed yield. Straw yield also followed the trend of seed yield.

Among the weed management practices, siliqua/plant was highest with pendimethalin *fb* hand weeding (195.2/plant) followed by pendimethalin (185.5/siliqua). The lowest siliqua was recorded with weedy check (167.9/siliqua). Higher yield attributes led to obtain higher seed yield in pendimethalin *fb* hand weeding (1.89 t/ha) which was 1.76 times higher than weedy check (0.67 t/ha). Pendimethalin alone has also recorded significant reduction in initial flush of weeds resulted 1.36 times higher seed yield than weedy check. Pendimethalin *fb* one hand weeding has better weed control, this might be due to suppression of initial flush of weeds through pendimethalin and subsequent flush are being taken care by implying one additional hand weeding. Straw yield followed the trend of seed yield and highest was recorded with pendimethalin *fb* hand weeding (4.45 t/ha) followed by pendimethalin (3.75 t/ha), whereas, the lowest straw yield with weedy check (1.85 t/ha).

The long term impact of crop establishment and weed control measures in DSR-based cropping system under conservation agriculture in mustard was conducted during *Rabi,* 2017-18. The highest seed yield (2.3 t/ha) and energy output (67375 MJ/ha) was obtained with the ZT+R along with pendimethalin at 1.0 kg/ha PE *fb* one hand weeding at 25 DAS. However, this treatment showed the negative net energy return (-18184.2 MJ/ha) and least other parameters. The highest energy use efficiency (4.4), energy productivity (0.15 kg/MJ) and net energy return (36107.4 MJ/ha) was obtained in ZT along with pendimethalin at 1.0 kg/ha PE *fb* one hand weeding at 25 DAS. The least performance of the treatment was observed in CT+R along with weedy check plots (**Table 9**).

Table 8. Weed and yield parameters as influenced by crop establishment and weed management practices in mustard

Treatment	Weed density (no./m^2)	Weed dry biomass (g/m^2)	WCE (%)	No. of siliqua /plant	No. of seeds/siliqua	Seed yield (kg/ha)	Straw yield (kg/ha)
Crop establishment methods							
CT DSR+S-CT-ZT	8.80^{b}(95.2)	11.08^{b}(151.8)	49.6	181.1^{b}	14.1^{a}	1390.0^{bc}	3326.2^{bc}

CT DSR+R+S-CTR-ZTR	7.54^{c}(72.0)	9.47^{c}(108.6)	64.0	181.7^{b}	13.6^{a}	1472.2^{b}	3518.5^{b}
ZT DSR+S-ZT-ZT	9.44^{a}(105.8)	11.81^{ab}(165.5)	45.1	179.9^{b}	13.5^{a}	1211.1^{d}	2897.0^{d}
ZT DSR+R+S-ZTR-ZTR	7.87^{d}(63.3)	8.66^{c}(94.1)	68.8	190.6^{a}	13.8^{a}	1620.0^{a}	3872.7^{a}
TPR-CT	9.72^{a}(110.3)	12.34^{a}(175.1)	41.9	181.0^{b}	13.5^{a}	1311.1^{cd}	3138.4^{cd}
LSD (p=0.05)	0.38	0.86		7.14	1.09	128.9	307.38
Weed management							
Weedy check	14.14^{a}(200.9)	17.27^{a}(301.3)	-	167.9^{c}	13.6^{a}	686.7^{c}	1854.0^{c}
Pendimethalin	6.54^{b}(43.7)	8.51^{b}(74.3)	75.3	185.5^{b}	13.8^{a}	1623.3^{b}	3749.9^{b}
Pendimethalin fb HW	4.75^{c}(23.4)	6.25^{c}(41.4)	86.3	195.2^{a}	13.7^{a}	1892.7^{a}	4447.8^{a}
LSD (p=0.05)	0.91	1.32		5.16	NS	154.46	366.25

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; **TPRCT:** Transplanted rice followed by CT mustard **S:** Sesbania. Weed data subjected to SQRT transformation; original values are in parentheses

Table 9. Energy consumption and energy output for as influenced by crop establishment and weed management practices in mustard

Treatments	Energy input (MJ/ha)	Yield (kg/ha)	Energy output (MJ/ha)	Net energy (MJ/ha)	Energy use efficiency	Energy productivity (kg/MJ)
CT-Mustard:W1	12925.9	700.0	20416.6	7490.7	1.6	0.05
CT-Mustard (TPR):W1	12925.9	666.7	19444.4	6518.6	1.5	0.05
CT-Mustard:W2	13241.9	1650.0	48125.0	34883.1	3.6	0.12
CT-Mustard (TPR):W2	13241.9	1533.3	44722.2	31480.3	3.4	0.12
CT-Mustard:W3	13555.5	1820.0	53083.4	39527.9	3.9	0.13
CT-Mustard (TPR):W3	13555.5	1733.3	50555.6	37000.1	3.7	0.13
CT-Mustard+R:W1	87925.9	700.0	20416.6	-67509.3	0.2	0.01
CT-Mustard+R:W2	88241.9	1716.7	50069.5	-38172.4	0.6	0.02
CT-Mustard+R:W3	88555.5	2000.0	58333.4	-30222.1	0.7	0.02
ZT-Mustard:W1	9929.6	600.0	17500.0	7570.4	1.8	0.06
ZT-Mustard:W2	10245.6	1433.3	41805.5	31559.9	4.1	0.14
ZT-Mustard:W3	10559.2	1600.0	46666.6	36107.4	4.4	0.15
ZT-Mustard+R:W1	84929.6	766.7	22361.3	-62568.3	0.3	0.01
ZT-Mustard+R:W2	85245.6	1783.3	52013.8	-33231.8	0.6	0.02

ZT-Mustard+R:W3	85559.2	2310.0	67375.0	-18184.2	0.8	0.03

W1: Weedy check; W2: Pendimethalin at 1.0 kg/ha PE; W3: Pendimethalin at 1.0 kg/ha PE *fb* 1 HW at 25 DAS; *TPR: transplanted rice in *kharif* plot.

In maize

Medicago polymorpha, Avena ludoviciana and Rumex dentatus was abundant weed species in maize. Other weeds such as *Chenopodium album*, *Physalis minima*, *Sonchus* sp. and *Lathyrus sativus* were also presented in experimental field however, their abundance was less. Weed density was higher in ZT compared to the CT and TPR-CT. *Rumex dentatus* was present only in weedy checks.

Shannon diversity index was higher and comparable in CT, CTR and CTTPR, whereas lowest in the ZT and ZTR (**Fig. 2**). Diversity in weedy check was much higher as compared to the weed management treatments. Pendimethalin + atrazine *fb* on hand weeding effectively controlled the weeds, hence lowest weed diversity was recorded. Although, ZT plots have higher weed densities but have lower weed diversity, this mainly because of dominancy of a single weed species *i.e. Medicago polymorpha*.

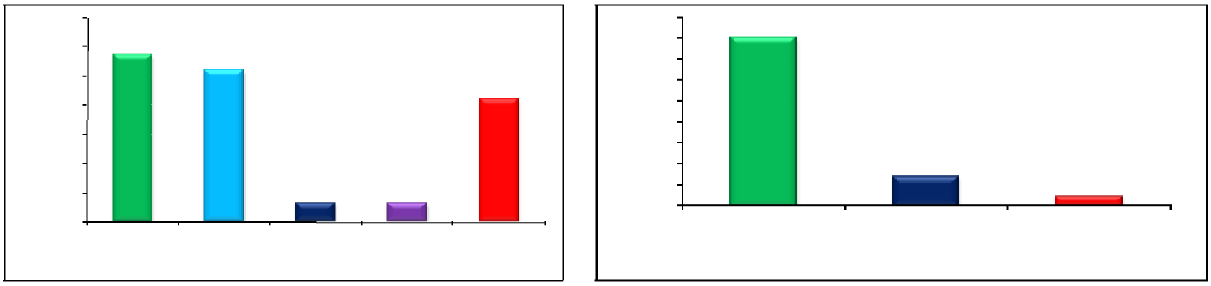


Fig. 2. Effect of weed diversity as influenced by tillage practices (A) and weed management (B) in maize

Seed bank study indicate that, in maize there is a decreasing trend of *Medicago polymorpha* (ZT and ZTR)*, Cheopodium album* (ZTR) and *Rumex dentatus* (CTR, ZT and ZTR) emergence with the depth. *Medicago polymorpha* was substantially distributed in all three soil layers. Whereas, *Chenopodium album* germination was higher in CT, ZTR and CTTPR compared to the CTR and ZTR in all three layers. Conversely, CTR and ZT have higher germination of the *Rumex dentatus* in all three layers.

Crop establishment method and weed management practices significantly influenced the weed parameters at 60 DAS (**Table 10**). It was recorded that the lowest weed density and dry biomass was recorded in ZT DSR+R+S-ZTR-ZTR (61.9 no./m^2 and 92.9 g/m^2, respectively) followed by CT DSR+R+S-ZTR-ZTR (73.2 no./m^2 and 110.7 g/m^2, respectively) and highest with TPR-CT (114.3 no./m^2 and 178.5 g/m^2, respectively). Reduction in weed density and dry biomass recorded higher WCE in ZT DSR+R+S-ZTR-ZTR (69.9%) followed by CT DSR+R+S-ZTR-ZTR (64.1%). Among weed management practices, higher weed density and dry biomass recorded in weedy check (210.5 no./m^2 and 308.4 g/m^2, respectively). The lowest density and dry biomass was recorded in pendimethalin + atrazin *fb* hand weeding (23.1 no./m^2 and 40.8 g/m^2, respectively) followed by pendimethalin + atrazin as pre-emergence *fb* 2,4-D (42.6 no./m^2 and 74.2 g/m^2, respectively). This leads to achieving higher weed control efficiency in pendimethalin + atrazin *fb* hand weeding (86.8%) and pendimethalin + atrazin *fb* 2, 4-D (74.2%) over weedy check. establishment methods and weed management practices significantly influenced the yield attributes and yield of maize under conservation agriculture (**Table 10**). Cobs/plant was higher in ZT DSR+R+S-ZTR-ZTR (2.4) which was followed by TPR-CT (2.2), whereas, cobs/plant under rest of crop establishment were statistically comparable. Whereas, grains/cob was lowest in TPR-CT (280.2 no./cob) followed by ZT DSR+S-ZT-ZT (287.3 no./cob) and CT DSR+S-CT-ZT (304.6 no./cob). Grain yield was recorded the highest with ZT DSR+R+S-ZTR-ZTR (3.58 t/ha) followed by CT DSR+R+S-CTR-ZTR (3.27 t/ha) and the lowest yield with TPR-CT (2.98 t/ha). The higher yield in ZT DSR+R+S-CTR-ZTR and CT DSR+R+S-CTR-ZTR was due to placement of previous crop residues on soil surface, hampered the emergence and establishment of weeds, resulted lower competition for available resources. Stover yield followed the trend of grain yield and recorded higher stover yield with ZT DSR+R+S-CTR-ZTR followed by CT DSR+R+S-CTR-ZTR.

Maize is a wider spaced crop, during winter, the growth and development was slow in initial stage this prompts weeds to establish and proliferate. However, imposition of weed management practices significantly reduced the weed biomass led to better formation of yield attributes and further grain and stover yield. Application of pre-emergence herbicides pendimethalin + atrazin *fb* hand weeding recorded more number of cobs/plant and grains/cob (2.5 cobs/plant and 377.7 no./cob, respectively) followed by pendimethalin+ atrazin *fb* 2,4-D (2.3

cobs/plant and 344.7 grains/cob, respectively) and lowest with weedy check (1.7 cobs/plant). Similarly, grain and stover yield was recorded highest with pendimethalin + atrazin *fb* hand weeding (4.32 and 7.56 t/ha, respectively) followed by pendimethalin+ atrazin *fb* 2,4-D (3.35 and 5.69 t/ha, respectively), whereas the lowest yields were obtained weedy check (1.95 and 2.11 t/ha respectively). Pendimethalin+ atrazin *fb* hand weeding recorded 122% higher grain yield followed by pendimethalin+ atrazin *fb* 2,4-D (71.9%) over weedy check.

Among the cropping system, maize was badly infested with weeds, this may be due to wider row spacing and initial slow growth, whereas, mustard and pea had better suppression of weeds during winter season. However, their effect was not significant. Among the weed management practice, it was noticed that application of pre-emergence herbicides *fb* one hand weeding significantly reduced the weed dry weight followed by pre-emergence herbicide alone. The highest weed density and weed dry biomass was recorded with weedy check.

Table 10. Weed and yield parameters as influenced by crop establishment and weed management practices in maize

Treatment	Weed density (no./m^2)	Weed dry biomass (g/m^2)	WCE (%)	No. of cob /plant	Grains/cob	Grain yield (kg/ha)	Stover yield (kg/ha)
Crop establishment methods							
CT DSR+S-CT-ZT	8.95^{b} (100.3)	11.19^{b} (155.3)	49.6	2.1^{ab}	304.6^{abc}	3122.2^{bc}	5315.0^{bc}
CT DSR+R+S-CTR-ZTR	7.60^{c} (73.2)	9.63^{c} (110.7)	64.1	2.0^{b}	330.7^{ab}	3266.7^{b}	5562.8^{b}
ZT DSR+S-ZT-ZT	9.45^{a} (110.6)	11.79^{ab} (168.2)	45.5	1.9^{b}	287.3^{bc}	3077.8^{bc}	5239.4^{bc}
ZT DSR+R+S-ZTR-ZTR	6.85^{d}(61.9)	8.74^{d}(92.9)	69.9	2.4^{a}	337.3^{a}	3577.8^{a}	6085.6^{a}
TPR-CT	9.80^{a}(114.3)	12.34^{a}(178.5)	42.1	2.2^{ab}	280.2^{c}	2977.8^{c}	5070.6^{c}
LSD (p=0.05)	0.37	0.76		0.43	46.43	272.67	453.54
Weed management							
Weedy check	14.45^{a}(210.5)	17.43^{a}(308.4)	-	1.7^{b}	201.7^{b}	1946.7^{c}	3114.7^{c}
Pendimethalin + atrazin *fb* 2,4-D	6.47^{b}(42.6)	8.55^{b}(74.2)	76.0	2.3^{a}	344.7^{a}	3346.7^{b}	5689.3^{b}
Pendimethalin+ atrazin *fb* HW	4.73^{c}(23.1)	6.24^{c}(40.8)	86.8	2.5^{a}	377.7^{a}	4320.0^{a}	7560.0^{a}
LSD (p=0.05)	0.95	1.31		0.45	41.55	262.23	441.34

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; **TPRCT:** Transplanted rice followed by CT Maize; S:Sesbania. Weed data subjected to SQRT transformation; original va are in parentheses

The long term impact of crop establishment and weed control measures in DSR-based cropping system under conservation agriculture in maize was conducted during *Rabi,* 2017-18. The highest seed yield (4.7 t/ha) and energy output (91195.5 MJ/ha) was obtained with the ZT+R along with pendimethalin + atrazine (0.5+0.5 kg/ha PE) *fb* one hand weeding at 25 DAS. However, net energy, energy use efficiency and energy productivity are lower. The highest energy use efficiency (6.2), energy productivity (0.32 kg/MJ) and net energy return (67421.2 MJ/ha) was obtained in ZT along with pendimethalin + atrazine (0.5+0.5 kg/ha PE) *fb* one hand weeding at 25 DAS. The least performance of the treatment was observed in CT (TPR) along with weedy check plots (**Table 11).**

Table 11. Energy consumption and energy output as influenced by crop establishment and weed management practices in maize

Treatments	Energy input (MJ/ha)	Yield (kg/ha)	Energy output (MJ/ha)	Net energy (MJ/ha)	Energy use efficiency	Energy productivity (kg/MJ)
CT-Maize:W1	15223.3	1900.0	36606.6	21383.3	2.4	0.12
CT-Maize (TPR):W1	15223.3	1766.7	11632.2	-3591.2	0.8	0.12
CT-Maize:W2	90223.3	3233.3	62295.5	-27927.8	0.7	0.04
CT-Maize (TPR):W2	90223.3	3133.3	27672.5	-62550.9	0.3	0.03
CT-Maize:W3	15223.3	4233.3	81562.2	66338.8	5.4	0.28
CT-Maize (TPR):W3	15223.3	4033.3	27550.0	12326.7	1.8	0.26
CT-Maize+R:W1	90223.3	1933.3	37248.8	-52974.6	0.4	0.02
CT-Maize+R:W2	90786.1	3433.3	66148.8	-24637.3	0.7	0.04
CT-Maize+R:W3	90853.0	4433.3	85415.5	-5437.4	0.9	0.05
ZT-Maize:W1	12227.0	1866.7	35964.5	23737.4	2.9	0.15
ZT-Maize:W2	12789.8	3200.0	61653.4	48863.6	4.8	0.25
ZT-Maize:W3	12856.6	4166.7	80277.8	67421.2	6.2	0.32
ZT-Maize+R:W1	87227.0	2266.7	43671.2	-43555.8	0.5	0.03
ZT-Maize+R:W2	87789.8	3733.3	71928.8	-15861.0	0.8	0.04
ZT-Maize+R:W3	87856.6	4733.3	91195.5	3338.9	1.0	0.05

W1: Weedy check; W2 Pendimethalin + atrazine (0.5+0.5 kg/ha PE) *fb* 2,4-D (0.75 kg/ha) at 25 DAS; W3:Pendimethalin + atrazine (0.5+0.5 kg/ha PE) *fb* 1 HW at 25 DAS; *TPR: transplanted rice in *kharif* plot.

In greengram 2018,

At 45 DAS, the study area comprised of weeds i.e. *Echinochloa colona, Cyperus rotundus, Euphorbia geniculata, Paspalidium flavidum, Commelina communis* and *Convolvulus arvensis*. The highest weed density was recorded in DSR CT+S-CT-ZT (73.6 no./m^2) followed by TPR-CT-CT (69.9 no./m^2), whereas the lowest weed density was recorded with DSR ZT+R+S-ZTR-ZTR (47.2 no./m^2). The lower weed density in DSR ZT+R+S-ZTR-ZTR was mainly due to the retention of previous crop residues created an obstacle for germination and emergence of weeds, which was not present in CT and ZT without crop residues. This treatment has lesser weed density resulted in lower weed seed rain, which further lowered the establishment of weeds. Among weed management practices, weedy check recorded the highest weed density (145.1 no./m^2), whereas the lowest weed density was recorded with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (7.6 no./m^2). Application of pendimethalin at 678 g/ha has considerably suppressed the weed density (30.4 no./m^2), yet their effect was less pertaining to pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (**Table 12**).
Similar to weed density, weed dry biomass was recorded the highest in DSR CT+S-CT-ZT (47.2 g/m^2) followed by TPR-CT-CT (40.5 g/m^2), whereas the lowest weed density was recorded with DSR ZT+R+S-ZTR-ZTR (27.5 g/m^2). Weed dry biomass in rest of the tillage treatments were significantly lower, yet their effect was less pertinent to DSR CT+S-CT-ZT. This resulted in the highest WCE with DSR ZT+R+S-ZTR-ZTR (41.7%) over DSR CT+S-CT-ZT. The higher WCE in DSR ZT+R+S-ZTR-ZTR recorded higher seed and stover yield (1.11 and 2.38 t/ha, respectively) followed by DSR CT+R+S-CTR-ZTR. The lowest seed and stover yield was recorded with DSR ZT+S-ZT-ZT (0.96 and 1.86 t/ha, respectively). It was recorded that the seed and stover yield increment in DSR ZT+R+S-ZTR-ZTR was 15.8 and 27.6%, respectively higher followed by DSR CT+R+S-CTR-ZTR over the DSR ZT+S-ZT-ZT (**Table 12**).

Among weed management practices, weedy check has the highest weed dry biomass (87.5 g/m^2) and lowest with pendimethalin 678 g/ha *fb* hand weeding (5.1 g/m^2) with the highest WCE (94.2%). The grain and stover yield was highest with pendimethalin 678 g/ha *fb* hand weeding (1.37 and 2.79 t/ha, respectively) followed by pendimethalin 678 g/ha (1.24 and 2.49 t/ha, respectively). The seed and stover yield was recorded 229.7 and 224%, respectively higher in pendimethalin 678 g/ha *fb* HW at 30 DAS followed by pendimethalin 678 g/ha over the weedy check.

Table 12. Weed density, dry biomass, weed control efficiency, grain and straw yield as influenced by crop establishment methods and weed management practices in greengram

Treatments	Total weed density (g/m²)	Total weed dry weight (g/m²)	WCE (%)	Yield (kg/ha)	% increase	Straw (kg/ha)	% increase
Crop establishment methods							
DSR CT+S-CT-ZT	7.6(73.6)	6.1(47.2)		957.8	0.3	1980.48	6.3
DSR CT+R+S-CTR-ZTR	6.1(50.7)	4.9(32.8)	30.5	1040.6	9.0	2005.31	7.6
DSR ZT+S-ZT-ZT	6.9(63.9)	5.4(38.4)	18.6	955.0	-	1863.72	
DSR ZT+R+S-ZTR-ZTR	5.8(47.2)	4.5(27.5)	41.7	1106.1	15.8	2377.86	27.6
TPR-CT	7.3(69.9)	5.6(40.5)	14.2	971.7	1.7	1929.63	3.5
LSD (p=0.05)	0.61	0.42		NS		293.13	
Weed management							
Weedy check	12.0(145.1)	9.3(87.5)		414.33		809.55	
Pendimethalin 678 g/ha	5.5(30.4)	4.4(19.2)	78.1	1238.33	198.9	2494.35	208.1
Pendimethalin 678 g/ha *fb* HW at 30 DAS	2.6(7.6)	2.2(5.1)	94.2	1366	229.7	2790.3	224.7
LSD (p=0.05)	0.51	0.41		89.06		179.73	

In rice 2018,

Rice field was severely infested with a wide range of weeds, at 60 DAS, *Cyperus iria* and *Echinochloa colona* were the major weeds, with the progress of time, the weed like *Alternanthera sessilis, Caesulia axillaris, Dinebra retroflexa* and *Ludwigia parviflora* were become dominant along with *C. iria* and *E. colona*. In DSR, *Phyllanthus urinaria, Physallis minima, Commelina benghalensis* and *Digera arvensis* were other weeds but with lower density. All the field except weedy check of all the treatments and puddle transplanted rice (TPR) were sown with 30 kg/ha of *sesbania* (S) and this was knock down by applying 2,4 D 500 g/ha at 32 DAS.

The highest weed density was recorded in CT DSR+S (93.44 no./m^2) followed by ZT DSR+S (88.11 no./m^2), whereas the lowest weed density was recorded with TPR (37.78 no./m^2). The lower weed density in TPR was mainly due to churning of the field where existing weeds were incorporated and transplanting of 21 days old seedlings and also with the maintenance of thin water layer since the beginning, which was not the case with CT and ZT with and without crop residues. Among weed management practices, weedy check recorded the highest weed density (153.13 no./m^2), whereas the lowest weed density was recorded with herbicide rotation and application of cyhalofop+ penoxsulam 135 g/ha (23.13 no./m^2). Continuous application of bispyribac sodium 25 g/ha in rice recorded 38.40 no./m^2, this was considerably lower than the weedy check, yet their effect was less pertinent to cyhalofop+ penoxsulam 135 g/ha. The higher weed density in continuous bispyribac was due to poor control of grasses and some of the broadleaved weeds (**Table 13**).

The highest weed dry biomass was recorded with DSR ZT+S (123.77 g/m^2) followed by DSR CT+S (122.1 g/m^2). The lowest weed dry biomass was recorded with TPR-CT-ZT (60.8 g/m^2) which resulted to record the WCE to the tune of 50.9%. Rests of the treatments considerably reduced the weed dry biomass, yet their effect was less pertaining to TPR-CT-ZT. The lowest weed parameters and better yield attribute helped to harvest higher grain and straw yield in TPR (4.11 and 6.68 t/ha, respectively) followed by DSR CT+R+S (2.95 and 4.82 t/ha, respectively). The lowest grain and straw yield was recorded in DSR ZT+S (2.95 and 4.82 t/ha, respectively) (**Table 13**).

Among weed management practices in rice, the lowest weed dry biomass and the highest WCE was recorded in herbicide rotation cyhalofop+ penoxsulam 135 g/ha (43.87 g/m^2 and 77.6%, respectively) followed by continuous bispyribac sodium 25 g/ha (63.47 g/m^2 and 67.6%, respectively). The highest weed dry biomass was recorded with a weedy check (195.8 g/m^2). This mainly due to obtained congenial condition for the weeds to germinate and flourish, resulted in enrichment in the seed bank, this offered the maximum competition to the rice crop. The higher grain and straw yield was recorded with cyhalofop+ penoxsulam 135 g/ha (4.17 and 7.17 t/ha, respectively) followed by bispyribac sodium 25 g/ha over the weedy check.

Higher yield in TPR helped to obtain highest net return (Rs 39207/ha) followed by ZT DSR+R+S (Rs 36260/ha), whereas, the B: C was the highest with ZT DSR+R+S (2.64) followed by ZT DSR+S (2.38). The lowest net return and B: C recorded with CT DSR+S (Rs 24504/ha and 1.75 respectively). Rests of the treatments were between these, yet their effect was less pertaining to ZT DSR+R+S. Among weed management practices, the highest net return and B: C was recorded in cyhalofop+ penoxsulam 135 g/ha (Rs 46172/ha and 2.65 respectively) followed by bispyribac sodium 25 g/ha over the weedy check (**Table 13**).

The long term impact of weed control measures in DSR-based cropping system under conservation agriculture in rice was conducted during *Kharif,* 2018. The highest energy productivity (0.30 kg/MJ) and energy use efficiency (10.76) was obtained in ZT DSR+S – Cyhalofop + penoxsulam 135 g/ha. Whereas, the highest energy output (182086 MJ/ha) and net energy (164819.57 MJ/ha) and energy use efficiency (12.0) was obtained in TPR – Cyhalofop + penoxsulam 135 g/ha. The least performance of the treatment for energy management was observed in CT DSR +R – Weedy plots and for least greenhouse gas emission was observed in ZT DSR – weedy plots (**Table 14**).

Table 13. Weed density, dry biomass, weed control efficiency, grain and straw yield and economics as influenced by crop establishment methods and weed management practices in rice

Treatments	Total weed density (g/m^2)	Total weed dry weight (g/m^2)	WCE (%)	Grain yield (kg/ha)	Straw yield (kg/ha)	Net Return (Rs/ha)	B:C
Crop establishment methods							
CT DSR+S	8.80(93.44)	10.29(122.09)	1.4	3223.3	5251.7	24504	1.75
CT DSR+R+S	8.14(79.11)	9.70(107.58)	13.1	3378.9	5501.5	27258	1.84
ZT DSR+S	8.47(88.11)	10.17(123.77)		2954.4	4820.9	30319	2.38
ZT DSR+R+S	7.11(59.33)	8.80(91.07)	26.4	3290.0	5359.9	36260	2.64
TPR	5.68(37.78)	7.10(60.78)	50.9	4105.6	6680.5	39207	2.17
LSD (p=0.05)	1.50**	1.90*		96.85**	159.45**		
Weed management							
Weedy check	12.21(153.13)	13.86(195.83)		2057.3	3086.0	14254	1.65
Bispyribac 25 g/ha	6.09(38.40)	7.64(63.47)	67.6	3944.7	6311.5	41821	2.49
Cyhalofop + penoxsulam 135 g/ha	4.62(23.13)	6.13(43.87)	77.6	4169.3	7171.3	46172	2.65
LSD (p=0.05)	0.78**	1.06**		172.91**	269.37**		
Interaction	NS	NS		NS	NS		

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; **TPRCT:** Transplanted rice followed by CT in wheat; **S:** Sesbania as brown manure. Weed data subjected to SQRT transformation (x+0.5); original values are given in parentheses; **WCE**: weed control efficiency

Table 14. Energy consumption and energy output for rice cultivation

Treatments	Energy Input (MJ)	Output Energy (MJ)	Net Energy (MJ)	Energy Use Efficiency	Energy Productivity (kg/MJ)	Total CO_2 equivalent emission (kg/ha)
CT DSR W1	16367.75	64670.00	48302.25	3.95	0.12	211.13
CT DSR+S W2	60969.60	130703.33	69733.73	2.14	0.06	223.27
CT DSR+S W3	61108.10	143714.00	82605.90	2.35	0.06	232.82
CT DSR +R W1	53867.75	69130.00	15262.25	1.28	0.04	211.13
CT DSR+R+S W2	98208.71	137643.33	39434.63	1.40	0.04	222.60

CT DSR+R+S W3	98608.10	164067.68	65459.58	1.66	0.04	232.82
ZT DSR W1	13313.51	54635.00	41321.49	4.10	0.12	100.06
ZT DSR+S W2	57654.47	122259.67	64605.20	2.12	0.06	111.53
ZT DSR+S W3	12466.37	134181.33	121714.97	10.76	0.30	121.76
ZT DSR +R W1	51162.82	65785.00	14622.18	1.29	0.04	111.81
ZT DSR+R+S W2	95503.78	134173.33	38669.55	1.40	0.04	123.28
ZT DSR+R+S W3	95903.18	146127.33	50224.15	1.52	0.04	133.51
TPR W1	16809.22	89869.00	73059.78	5.35	0.16	240.83
TPR W2	16867.03	159620.00	142752.97	9.46	0.27	242.02
TPR W3	17266.43	182086.00	164819.57	10.55	0.29	252.25

W1: Weedy check; W2: Bispyribac-Na at 25 g/ha; W3: Cyhalofop + penoxsulam 135 g/ha

Experiment 3 Weed management in soybean-wheat-greengram cropping system under conservation agriculture

Study on weed management in long term soybean - wheat - greengram cropping system under conservation agriculture was conducted, under the study following major findings were recorded.

In wheat 2017-18,

In wheat, major weed flora *Medicago polymorpha, Chenopodium album, Vicia sativa*, *Euphorbia geniculata*, *Sonchus oleraceus, Convolvulus arvensis* and *Physalis minima* were major broadleaved weeds, whereas, *Avena ludoviciana Paspaladium flavidium Digitaria sanguinalis, Dinebra retroflexa* and *Phalaris minor* were major grassy weeds present. However, it was noticed that majority of Sonchus, Physalis, Euphorbia and Paspaladium, Digitaria and Dinebra were emerged late in wheat.

The weed density, dry biomass and wed control efficiency was significantly influenced by crop establishment methods and weed management practices in wheat (**Table 15**). It was recorded that among crop establishment methods the lowest weed density and dry biomass was recorded with ZTWR-ZTGR-ZTSR (41.6 no./m^2 and 39.3 g/m ^{2}, respectively) followed by weed density with ZTWR-ZTGR-ZT (42.2 no./m^2) and weed dry biomass with ZTWR-ZT-ZTSR (42.74 g/m^2) and the highest weed density was recorded in CT-CT-CT (50.5 g/m^2). Whereas, weed dry biomass was more in ZT-ZT-ZT and ZT-CT-ZT (48.1 g/m^2), this was mainly due to more weed biomass accumulation on leftover weeds of previous season, however, the density was less. The highest weed control efficiency was recorded when wheat was sown with ZTWR-ZTGR-ZTSR (71.3%) followed by ZTWR-ZT-ZTSR (68.8%), whereas the lowest weed control efficiency was recorded with ZT-CT-ZT and ZT-ZT-ZT (64.9%). Yield attributes and yield was significantly influenced by crop establishment method and weed management practice (**Table 15**). Grains/spike was highest in ZTWR-ZTGR-ZTSR (41.3) followed by ZTWR-ZT-ZTSR (39.6 no./spike), whereas, the lowest grain/spike was recorded in CT-CT-CT (35.8 no./spike). This helped in achieving higher grain yield and resulted highest grain and straw yield with ZTWR-ZTGR-ZTSR (3.88 and 5.64 t/ha, respectively) followed by ZTWR-ZT-ZTSR (3.71 and 5.41 t/ha, respectively), whereas, the lowest yield obtained in CT-CT-CT (3.32 and 4.78 t/ha, respectively). It clearly illustrated that ZTWR-ZTGR-ZTSR has recorded 16% additional seed yield of wheat over CT-CT-CT.

Among the weed management practices, pre-mix application of clodinafop+metsulfuron at 64 g/ha has recorded the lowest weed density and dry biomass (3.78 no./m^2 and 1.78 g/m^2, respectively) followed by mesosulfuron + iodosulfuron at 14.4 g/ha (11.4 no./m^2 and 5.28 g/m^2, respectively), whereas the highest weed density and dry biomass was recorded in weedy check (130.5 no./m^2 and 136.9 g/m^2, respectively). Application of sulfosulfuron at 25 g/ha also considerably suppressed the weed density and dry biomass (37.2 no./m^2 and 35.0 g/m^2, respectively), yet, their effect was less pertaining to clodinofop+metsulfuron and iodosulfuron+mesosulfuron. This clearly illustrate that above herbicides has special ability to kill the wide range of weed flora during the season. Clodinafop+metsulfuron has better ability and controlled almost all the weeds, whereas mesosulfuron + iodosulfuron was little weak on grasses, but was strong on broad leaved weeds. Sulfosulfuron alone at 25 g/ha controlled the initial weed flora but has less persistency and was not so effective for controlling grassy and broad leaved weeds at later stages. This leads to highest weed control efficiency in plots where ready mix of clodinafop+metsulfuron at 64 g/ha was applied (98.7%) followed by mesosulfuron + iodosulfuron at 14.4 g/ha (96.1%) over weedy check. It was also recorded that sulfosulfuron at 25 g/ha was weak on many of the weeds and resulted considerably poor weed control efficiency of 74.4% over weedy check. Weed management practices significantly controlled the weeds which reduced the competition among wheat plants for resources resulted more grains/spike and further helped in higher grain and straw yield in clodinafop+metsulfuron at 64 g/ha (5.01 and 7.20 t/ha, respectively) followed by mesosulfuron + iodosulfuron at 14.4 g/ha (4.75 and 6.58 t/ha, respectively), where sulfosulfuron at 25 g/ha has 3.10 and 4.66 t/ha, respectively. The lowest grain and straw yield was recorded in weedy check (1.36 and 2.15 t/ha, respectively. Application of clodinafop+metsulfuron recorded 2.69 times more wheat yield followed by 2.5 times in mesosulfuron + iodosulfuron.

Table 15. Weed and crop parameters as influenced by crop establishment and weed management practices in wheat

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	WCE (%)	Grains/ spike	Grain yield (kg/ha)	Straw yield (kg/ha)
Crop establishment methods						
CT-CT-CT	6.40^a(50.50)	6.84^a(46.22)	66.2	35.8^c	3316.7^d	4782.9^d
ZT-CT-ZT	5.75^c(45.33)	6.97^{ab}(48.10)	64.9	36.8b^c	3432.5^{cd}	4953.5^d
ZTWR-ZTGR-ZT	5.46^d(42.17)	6.68^b(44.06)	67.8	37.8^{bc}	3532.5^c	5170.4^c
ZTWR-ZT-ZTSR	5.51^{cd}(45.25)	6.58^c(42.74)	68.8	39.6^{ab}	3709.2^b	5405.2^b
ZTWR-ZTGR-ZTSR	5.46^d(41.58)	6.31^c(39.28)	71.3	41.3^a	3878.3^a	5644.0^a
ZT-ZT-ZT	6.13^d(49.42)	6.97^{ab}(48.10)	64.9	37.2^{bc}	3465.8^c	4920.5^d
LSD (p=0.05)	0.25	1.01		3.39	143.66	210.04
Weed management						
Sulfosulfuron 25 g/ha	6.08^b(37.17)	5.96^b(35.01)	74.4	34.4^b	3102.8^c	4661.3^c
Iodosulfuron+mesosul furon 14.4 g/ha	3.38^c(11.39)	2.40^c(5.28)	96.1	47.5^a	4751.7^b	6581.8^b
Clodinafop+metsulfur on 64 g/ha	1.97^d(3.78)	1.51^c(1.78)	98.7	50.1^a	5010.6^a	7195.6^a
Weedy check	11.44^a(130.50)	11.72^a(136.91)	-	20.3^c	1358.3^d	2145.8^d
LSD (p=0.05)	0.46	2.03		3.04	162.66	279.21

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; Weed data subjected to SQRT transformation; original values are in parentheses

In greengram 2018,

At 45 DAS, the study area comprised of weeds i.e. *Echinochloa colona, Cyperus rotundus, Euphorbia geniculata, Amaranthus viridis, Paspalidium flavidum, Commelina communis* and *Convolvulus arvensis*. The highest weed density was recorded in CT-CT-CT (86.3 no./m^2) followed by CT-ZT-ZT (74.2 no./m^2), whereas the lowest weed density was recorded with ZTGR-ZTSR-ZTWR (46.3 no./m^2). The lower weed density in ZTGR-ZTSR-ZTWR was mainly due to the retention of previous crop residues created an obstacle for germination and emergence of weeds, which was not the case in CT and ZT without crop residues. This treatment has fewer weed density resulted in lower weed seed rain, which further lowered the establishment of weeds. Among weed management practices, weedy check recorded the highest weed density (136.2 no./m^2), whereas the lowest weed density was recorded with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (22.8 no./m^2). Application of pendimethalin at 678 g/ha has considerably suppress the weed density (36.9 no./m^2), yet their effect was less pertaining to pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (**Table 16**).

Similar to weed density, the highest weed dry biomass was recorded with CT-CT-CT (43.80 g/m^2); whereas the lowest weed dry biomass was recorded in ZTGR-ZTSR-ZTWR (20.7 g/m^2). Weed dry biomass in other tillage treatments was in between above two; however, their weed suppression effects were less pertinent to ZTGR-ZTSR-ZTWR. This resulted to achieve higher WCE in ZTGR-ZTSR-ZTWR (52.7%) over CT-CT-CT. Lower weed parameters and higher WCE helped in the synthesis of more number of branches, higher pods/plants and seeds/pod resulted in higher seed and stover yield in ZTGR-ZTSR-ZTWR (1.03 and 2.13 t/ha, respectively) followed by ZT-ZTSR-ZTWR. The lowest seed and stover yield has recorded with CT-CT-CT (0.89 and 1.74 t/ha, respectively). The seed yield improvement was 52.7% higher in ZTGR-ZTSR-ZTWR followed by ZT-ZTSR-ZTWR 44.3% over CT-CT-CT (**Table 16**).

Among weed management practices, weedy check plots have the highest weedy dry biomass (64.56 g/m^2) and lowest with pendimethalin 678 g/ha *fb* hand weeding (10.99 g/m^2). The highest WCE was recorded with pendimethalin 678 g/ha *fb* hand weeding (83%) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha

(73.5%). Application of pendimethalin 678 g/ha alone recorded 53.4% WCE over the weedy check. The better weed suppression and higher weed control efficiency helped in synthesis of more number of branches, pods/plant and seeds/pod, thus, resulted the highest grain and stover yield in pendimethalin 678 g/ha *fb* hand weeding (1.32 and 2.72 t/ha, respectively) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha (1.20 and 2.72 t/ha, respectively). The lowest yield was recorded with a weedy check (0.39 and 0.79 t/ha, respectively).

Table 16. Weed density, dry biomass, weed control efficiency, grain and straw yield as influenced by crop establishment methods and weed management practices in greengram under soybean-wheat-greengram cropping system

Treatments	Total weed density (g/m^2)	Total weed dry weight (g/m^2)	WCE (%)	Yield (kg/ha)	% increase	Straw (kg/ha)	% increase
Crop establishment methods							
CT-CT-CT	8.95(86.3)	6.40(43.80)		889.0		1739.6	
CT-ZT-ZT	8.31(74.2)	5.93(37.55)	14.3	911.5	2.5	1821.3	4.7
ZTGR-ZT-ZTWR	7.20(57.7)	4.83(25.67)	41.4	969.8	9.1	1895.0	8.9
ZT-ZTSR-ZTWR	6.76(52.9)	4.62(24.41)	44.3	1000.7	12.6	1995.4	14.7
ZTGR-ZTSR-ZTWR	6.07(46.3)	4.11(20.70)	52.7	1030.7	15.9	2125.8	22.2
ZT-ZT-ZT	7.86(68.2)	5.40(32.04)	26.8	927.3	4.3	1852.3	6.5
LSD (p=0.05)	0.48	0.32		56.55		115.16	..
Weed management							
Pendimethalin 678 g/ha	7.76(61.1)	5.46(30.08)	53.4	907.2	31.0	1763.3	22.9
Pendimethalin 678 g/ha *fb* imazethapyr 80 g/ha	6.03(36.9)	4.12(17.14)	73.5	1200.2	105.6	2341.8	96.1
Pendimethalin 678 g/ha *fb* HW at 30 DAS	4.64(22.8)	3.25(10.99)	83.0	1319.1	135.8	2723.6	144.4
Weedy check	11.66(136.2)	8.03(64.56)		392.8		790.9	
LSD (p=0.05)	0.31	0.26		52.67		103.88	

In soybean 2018,

The experimental field comprised with *Echinochloa colona, Cyperus iria, Commelina banghalensis,Phyllanthus niruri, Mecardonia procumbens, Digitaria sanguinalis,Tridex procumbens, Dinebra retroflexa, Eclipta alba* and *Mullago pentaphylla*. Among these weeds, Grassy weeds were more with ZT and it was further reduced with ZT+R. However, the density of grassy weeds was lower with CT and CT+R. Shannon diversity index (H) is commonly used to characterize species diversity in a community. Shannon's index accounts for both abundance and evenness of the species present.

$$\text{Shannon index } (H') = -\sum_{i=1}^{S}(Pi\ln(Pi))$$

where, S = total number of species in a community; *Pi* = proportion of species *i*; *ni* = number of individuals in specie *i*; N = total number of individual in a treatment

Shannon diversity index worked out for different crop establishment methods using the weed density at 60 DAS. In soybean, ZT-ZT-ZT has higher diversity due to the more number of species present and evenly distributed compare to the CT-CT-CT and ZT+GR-ZT+SR-ZT+WR. Among weed management practices, weedy check (W_4) has the highest diversity of weeds followed by imazethapyr+imazamox 70 g/ha (W_2). The lowest diversity was recorded with metribuzine 500 g/ha *fb* HW at 30 DAS (W_3) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha (W_2).

The study area was heavily infested with sedges like *Cyperus iria,* and *Cyperus rotundus,* grassy weeds like *Echinochloa colona, Dinebra retroflexa,Cynodon dactylon* whereas broadleaved weeds *viz. Alternanthera paronychioides, Physalis minima, Caesulia axillaris, Phyllanthus urinaria,* and *Commelina banghalensis* were other major weed flora.

The highest weed density was recorded in CT-CT-CT (92.04 no./m^2) followed by ZT-ZT-CT (87.50 no./m^2), whereas the lowest weed density was recorded with ZTSR-ZTSR-ZTGR (57.38 no./m^2). The lower weed density in ZTSR-ZTSR-ZTGR was mainly due to the retention of previous season crop residues, which acted as mulch and created an obstacle for germination and emergence of weeds. But, in CT and ZT without crop residues, the said advantages were not noticed. ZTSR-ZTSR-ZTGR has fewer weed density this significantly reduced the weed seed rain, which further lowered the establishment of weeds. Among weed management practices, weedy check recorded the highest weed density (161.46 no./m^2), whereas the lowest weed density was recorded with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (20.76 no./m^2). Application of pendimethalin at 678 g/ha has considerably suppressed the weed density (47.37 no./m^2), yet their effect was less pertaining to pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (**Table 17**). Similar to weed density, weed dry biomass accumulation was recorded the highest with CT-CT-CT (72.29 g/m^2) followed by ZT-ZT-CT (68.64 g/m^2). The lowest weed dry biomass was recorded in ZTSR-ZTSR-ZTGR (30.12 g/m2). Rest of the treatments were between these treatments, however, their effect was les pertaining to ZTSR-ZTSR-ZTGR. These helped to achieve higher WCE (58.3%) followed by ZT-ZTWR-ZTGR (54.6%) over CT-CT-CT. Weed management practices has the lowest weed dry biomass and the highest WCE (11.58 g/m^2 and 90.2%, respectively) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha (27.73 g/m^2 and 76.4%, respectively), whereas, these values were vice versa with weedy check (117.74 g/m^2).

Among crop establishment methods, the highest seed and stover yield was recorded with ZTSR-ZTSR-ZTGR (1.17 and 2.84 t/ha, respectively) followed by ZT-ZTWR-ZTGR (1.15 and 2.77 t/ha, respectively) the lowest seed and stover yield was recorded with ZT-ZT-CT (1.00 and 2.41 t/ha, respectively). Among weed management practices, the highest seed and stover yield was recorded with metribuzin 500 g/ha *fb* HW (1.56 and 4.06 t/ha, respectively) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha (1.33 and 3.20 t/ha, respectively). Rest of the treatments was between 500 g/ha *fb* HW and weedy check. Yet their effect was considerably better than a weedy check.

Among crop establishment method, the highest net return and B: C ratio was recorded in ZTSR-ZTSR-ZTGR (Rs. 24348/ha and 2.39, respectively) followed by ZTSR-ZTSR-ZT, whereas, the lowest net return and B:C ratio was recorded in ZT-ZT-CT (Rs 12344 and 1.53, respectively). Among weed management practices, metribuzin 500 g/ha *fb* HW obtained net return and B: C ratio (Rs 35583/ha and 2.74, respectively) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha, whereas negative return (Rs 5912/ha) with 0.69 B:C ratio recorded in weedy check.

In soybean- wheat- greengram cropping system chemical properties of soil i.e. nitrogen (N) phosphorus (P) potassium (K) and organic carbon (OC) were significantly influenced by crop establishment methods and weed management practices. At 0-5 cm soil depth, the available N, P, K and OC were significantly higher in ZTR -ZTR- ZTR (443.8, 19.6 428.5kg/ha and 0.82%, respectively) followed by ZTR-ZT-ZTR (426.3, 17.3, 390.1kg/ha and 0.74%, respectively). The lowest values were recorded in CT-CT-CT (362.7, 13.8, 276.3kg/ha and 0.66%, respectively). Similar trend was recorded at 5-10cm, 10-15cm and 15-20 cm soil depths. However, there was decrease trend of available N, P, K and OC found with increase in soil depths. In contrary to these, pH was higher in CT-CT-CT (7.72) followed by ZT-ZT-ZT (7.41), whereas, the lowest value was recorded in ZTR -ZTR- ZTR (7.13).

Among the weed management practices, the availability of N, P and K, OC and pH were almost comparable to each other. However, at 0-5 cm soil depths, these were recorded higher in imazethapyr + imazamox 70 g/ha (W_1; 413.8, 16.7, 356.3, 7.57 and 0.74% respectively) and lowest in weedy check plots (W_4; 408.4, 16.2, 352.9, 7.13 and 0.71%, respectively).

Table 17. Weed density, dry biomass, weed control efficiency, grain and straw yield as influenced by crop establishment methods and weed management practices in soybean under soybean-wheat-greengram cropping system

Treatments	Total weed density (g/m^2)	Total weed dry weight (g/m^2)	WCE (%)	Seed yield (kg/ha)	Stover yield (kg/ha)	Net Return (Rs/ha)	B:C
Crop establishment methods							
CT-CT-CT	9.13(92.04)	7.92(72.29)		1005.2	2407.5	12407	1.53
ZT-ZT-CT	8.83(87.50)	7.68(68.64)	5.1	1002.9	2413.3	12344	1.53

ZT-ZTWR-ZTGR	7.38(62.27)	5.28(32.81)	54.6	1148.7	2774.0	23425	2.34
ZTSR-ZTSR-ZT	7.93(71.54)	6.12(44.19)	38.9	1136.5	2737.3	22978	2.31
ZTSR-ZTSR-ZTGR	6.94(57.38)	4.99(30.12)	58.3	1174.6	2837.9	24348	2.39
ZT-ZT-ZT	8.26(76.14)	6.52(49.02)	32.2	1111.5	2670.4	22078	2.26
LSD (p=0.05)	0.55**	0.64**		55.13**	134.04**		
Weed management							
Imazethapyr +imazamox 70 g/ha	8.23(68.31)	6.33(41.00)	65.2	1123.9	2528.8	19326	1.95
Pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha	6.86(47.37)	5.21(27.73)	76.4	1334.5	3202.8	27076	2.33
Metribuzin 500 g/ha *fb* HW	4.54(20.76)	3.40(11.58)	90.2	1560.3	4056.8	35583	2.74
Weedy check	12.68(161.46)	10.74(117.74)		367.6	771.9	-5912	0.69
LSD (p=0.05)	0.40**	0.32**		25.15**	62.40**		
TxW	NS	0.79**		61.59**	152.85**		

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; Weed data subjected to SQRT transformation; original values are in parentheses

Experiment 4 Weed management in maize-wheat-greengram cropping system under conservation agriculture

In wheat 2017-18,

Among crop establishment methods, the lowest weed density and dry biomass, and highest WCE were recorded with ZTWR-ZTGR-ZTMR (25.2 no/m^2, 19.0 g/m^2 and 61.2%, respectively) followed by in ZTWR-ZTGR-ZT and ZTWR-ZT-ZTSR. The highest weed density and weed dry biomass were recorded in ZT-ZT-ZT, followed by CT-CT-CT with lower WCE (20.7%). Better yield attributes helped in harvesting higher grain and straw yield with ZTWR-ZTGR-ZTMR (3.61 and 4.91 t/ha, respectively) followed by ZTWR-ZT-ZTMR, whereas, the lowest yield obtained in CT-CT-CT (2.95 and 4.20 t/ha, respectively).

Among weed management practices, sulfosulfuron + metsulfuron 32 g/ha has the lowest weed density and dry biomass (6.6 no/m^2 and 3.4 g/m^2, respectively) followed by mesosulfuron + iodosulfuron 14.4 g/ha, whereas the highest weed density and dry biomass was recorded in weedy check (94.8 no/m^2 and 90.8 g/m^2, respectively). Application of clodinafop 50 g/ha *fb* 2,4-D 500 g/ha also considerably suppressed the weed density and dry biomass, but *Medicago polymorpha, Sonchus oleraceus* and *Euphorbia geniculata* could not be controlled appropriętely. Lower density and dry biomass leads to highest WCE in sulfosulfuron + metsulfuron 32 g/ha (96.3%) followed by mesosulfuron + iodosulfuron 14.4 g/ha (91.7%) over the weedy check. Lower weed parameters in sulfosulfuron + metsulfuron 32 g/ha helped for better yield attributes resulted in higher grain and straw yield (4.64 and 6.46 t/ha, respectively) followed by mesosulfuron + iodosulfuron 14.4 g/ha (4.42 and 6.05 t/ha, respectively). The lowest grain and straw yield was recorded in the weedy check (**Table 18**).

Table 18. Weed and crop parameters as influenced by crop establishment and weed management practices in wheat

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	WCE (%)	Grain yield (kg/ha)	Straw yield (kg/ha)
Crop establishment methods					
CT-CT-CT	6.11(44.3)	5.44(38.8)	20.7	2950.0	4204.92
ZT-CT-ZT	5.87(43.0)	6.16(35.9)	26.6	3174.2	4228.98
ZTWR-ZTGR-ZT	5.33(35.5)	4.79(30.6)	37.5	3257.5	4652.65

ZTWR-ZT-ZTMR	5.23(32.8)	4.69(28.0)	42.8	3446.7	4795.94
ZTWR-ZTGR-ZTMR	4.50(25.2)	3.80(19.0)	61.2	3611.7	4907.00
ZT-ZT-ZT	6.27(50.5)	5.91(48.9)	-	3132.5	4448.13
LSD (p=0.05)	0.36**	0.30**		380.80*	NS
Weed management					
Clodinafop 60 g/ha *fb* 2,4-D 580 g/ha	6.34(40.4)	5.67(32.4)	64.3	2919.4	4093.14
Sulfosulfuron+metsulfuron 32 g/ha	2.62(6.6)	1.93(3.4)	96.3	4643.9	6463.37
Mesosulfuron+iodosulfuron 14.4 g/ha	3.55(12.3)	2.82(7.6)	91.7	4418.3	6049.06
Weedy check	9.70(94.8)	9.44(90.8)	-	1066.7	1552.84
LSD (p=0.05)	0.22**	0.20**		200.44**	274.60**
TxW	0.54**	0.49**		NS	NS

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; Weed data subjected to SQRT transformation; original values are in parentheses

In greengram 2018

At 45 DAS, the highest weed density was recorded in CT-CT-CT (68.80 no./m^2) followed by CT-ZT-ZT (59.89 no./m^2), whereas the lowest weed density was recorded with ZTGR-ZTSR-ZTWR (37.70 no./m^2). The lower weed density in ZTGR-ZTSR-ZTWR was mainly due to retention of previous crop residues lowered the germination and emergence of weed seeds, thus resulted lower weed densities in the system, whereas, in CT and ZT without crop residues, weed seeds get favourable conditions for germination, emergence and establishment as most of the weed seeds were present in surface of the soil. ZTGR-ZTSR-ZTWR had lower weed density resulted in lower weed seed rain, which further lowered the establishment of weeds. Among weed management practices, weedy check recorded the highest weed density (108.62 no./m^2), whereas the lowest weed density was recorded with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (19.10 no./m^2). Application of pendimethalin at 678 g/ha has considerably suppressed the weed density (30.58 no./m^2), yet their effect was less pertaining to pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (**Table 19**).

Among the crop establishment methods, the lowest weed dry biomass was recorded in ZTGR-ZTMR-ZTWR (17.51 g/m^2) which was followed by ZT-ZTSR-ZTWR, whereas, maximum weed dry biomass was recorded with CT-CT-CT (37.24 g/m^2). Rest of the crop establishment methods had weed dry biomass between these; however, their effect was less pertaining to ZTGR-ZTMR-ZTWR. Lower weed dry biomass helped in achieving higher WCE to the tune of 53.0% in ZTGR-ZTMR-ZTWR followed by ZT-ZTSR-ZTWR (44.4%) over CT-CT-CT. Lower weed parameters helped in the formation of more number of branches/plant, pods/plant and seeds/pod resulted in higher seed and stover yield. The highest seed and stover yield was recorded with ZTGR-ZTMR-ZTWR (1.05 and 2.16 t/ha, respectively) followed by ZT-ZTSR-ZTWR (1.02 and 2.03 t/ha, respectively). The lowest seed and stover yield was recorded with CT-CT-CT (0.90 and 1.77 t/ha, respectively). Rest of the treatments out yielded, yet their effect was less pertinent to ZTGR-ZTMR-ZTWR. The seed and stover yield improvement was 15.7 and 22.0%, respectively higher in ZTGR-ZTMR-ZTWR over CT-CT-CT.

Among weed management practices, the lowest weed dry biomass and the highest WCE was recorded in pendimethalin 678 g/ha *fb* HW (9.55 g/m^2 and 82.5%, respectively) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha (14.79 g/m^2 and 72.9%, respectively). Application of pendimethalin 678 g/ha alone could control the weed by 53.4% over the weedy check. The seed and stover yield was highest with pendimethalin 678 g/ha *fb* hand weeding (1.33 and 2.76 t/ha, respectively) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha (1.22 and 2.38 t/ha, respectively). Other weed management practices also gave better seed and stover yield than a weedy check. The seed and stover yield improvement was 226.8 and 235.1%, respectively higher in pendimethalin 678 g/ha *fb* hand weeding over Weedy check.

Table 19. Weed density, dry biomass, weed control efficiency, grain and straw yield as influenced by crop establishment methods and weed management practices in greengram under maize-wheat-greengram cropping system

Treatments	Total weed density	Total weed dry	WCE (%)	Yield (kg/ha)	% increase	Straw (kg/ha)	% increase

	(g/m^2)	weight (g/m^2)					
Crop establishment methods							
CT-CT-CT	8.02(68.80)	5.92(37.24)		904.83		1770.61	
CT-ZT-ZT	7.49(59.89)	5.50(32.13)	0.137	932.33	3.0	1863.26	5.2
ZTGR-ZT-ZTWR	6.51(46.75)	4.46(21.71)	0.417	988.17	9.2	1930.8	9.0
ZT-ZTSR-ZTWR	6.15(43.12)	4.28(20.72)	0.444	1017.33	12.4	2028.92	14.6
ZTGR-ZTSR-ZTWR	5.54(37.70)	3.80(17.51)	0.530	1047.33	15.7	2159.83	22.0
ZT-ZT-ZT	7.08(55.01)	4.98(27.07)	0.273	944	4.3	1885.59	6.5
LSD (p=0.05)	0.37	0.25		56.57**		114.23**	
Weed management							
Pendimethalin 678 g/ha	6.97(49.21)	5.02(25.39)	0.534	923.89	125.6	1795.66	117.8
Pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha	5.50(30.58)	3.84(14.79)	0.729	1218	197.5	2376.52	188.3
Pendimethalin 678 g/ha *fb* hand weeding	4.29(19.10)	3.05(9.55)	0.825	1338	226.8	2762.71	235.1
Weedy check	10.42(108.62)	7.38(54.52)		409.44		824.44	
LSD (p=0.05)	0.27	0.24		52.49**		103.58**	

In maize 2018,

The study area was heavily infested with sedges like *Cyperus iria,* and *Cyperus rotundus,* grassy weeds like *Echinochloa colona, Dinebra retroflexa, Paspaladium flavidum* whereas broadleaved weeds *viz. Alternanthera paronychioides, Physalis minima, Caesulia axillaris, Phyllanthus urinaria, Commelina communis* and *Commelina banghalensis* were major weed flora.

The highest weed density was recorded in CT-CT-CT (78.67 no./m^2) followed by ZT-ZT-CT (74.67 no./m^2), whereas the lowest weed density was recorded with ZTMR-ZTWR-ZTGR (57.38 no./m^2). The lower weed density in ZTSR-ZTSR-ZTGR was mainly due to the retention of previous season crop residues, which acted as mulch and created an obstacle for germination and emergence of weeds. But, in CT and ZT without crop residues, the said advantages were not noticed. ZTSR-ZTSR-ZTGR has fewer weed density this significantly reduced the weed seed rain, which further lowered the establishment of weeds. Among weed management practices, weedy check recorded the highest weed density (148.56 no./m^2), whereas the lowest weed density was recorded with atrazine 1000 g/ha *fb* hand weeding at 30 DAS (20.76 no./m^2). Application of atrazine + topramezone (500+25.2 g/ha) has considerably suppressed the weed density (29.33 no./m^2) followed by atrazine + tembotrione (500+120 g/ha), yet their effect was less pertaining to atrazine 1000 g/ha *fb* hand weeding at 30 DAS (**Table 20**). Similar to weed density, weed dry biomass accumulation was recorded the highest with CT-CT-CT (82.76 g/m^2) followed by ZT-ZT-CT (76.08 g/m^2). The lowest weed dry biomass was recorded in ZTMR-ZTWR-ZTGR (31.51 g/m^2). Rest of the treatments were between these treatments, however, their effect was less pertaining to ZTMR-ZTWR-ZTGR. These helped to achieve higher WCE (61.9%) followed by ZT-ZTWR-ZTGR (58.1%) over CT-CT-CT. The lower weed dry biomass under ZTMR-ZTWR-ZTGR recorded the highest WCE (61.9%) followed by ZT-ZTWR-ZTGR (58.1%). Reduction in weed parameters improved the yield attributes, resulting in the highest grain and straw yield in ZTMR-ZTWR-ZTGR (3.41 and 6.70 t/ha, respectively) followed by ZT-ZTWR-ZTGR (3.27 and 6.43 t/ha, respectively). The lowest grain and straw yield was recorded in CT-CT-CT (2.73 and 5.36 t/ha, respectively). Other tillage practice had also recorded better grain and straw yield, yet their effect was less pertinent to ZTMR-ZTWR-ZTGR.

Among weed management practices, the lowest weed dry biomass and the highest WCE was recorded with atrazine 500 g/ha *fb* HW (15.09 g/m^2 and 89.1%, respectively) which was almost at par to atrazine+topramezone 500+25.2 g/ha (22.38 g/m^2 and 83.8%, respectively) over the weedy check. Atrazine+tembotrione 500+120 g/ha had also recorded considerable reduction in weed dry biomass and higher WCE over the weedy-check, yet the effect was less pertaining to atrazine 500 g/ha *fb* HW and atrazine + topramezone 500 + 25.2 g/ha. Better weed control helped to harvest the highest grain and straw yield in atrazine 500 g/ha *fb* HW (4.13 and 8.56 t/ha, respectively) followed by atrazine + topramezone 500+25.2 g/ha (3.86 and 7.72 t/ha, respectively). The lowest grain and straw yield was recorded with a weedy check (0.98 and 1.77 t/ha, respectively).

Among crop establishment method, the highest net return and B: C ratio was recorded in ZTMR-ZTWR-ZTGR (Rs. 47900/ha and 4.18, respectively) followed by ZT-ZTWR-ZTGR, whereas, the lowest net return and B:C ratio was recorded in CT-CT-CT (Rs 28792 and 2.33, respectively). Among weed management practices, atrazine 500 g/ha *fb* HW obtained net return and B: C ratio (Rs 50311/ha and 2.90, respectively) followed by atrazine + topramezone 500 + 25.2 g/ha, whereas negative return (Rs 6505/ha) with 0.73 B: C ratio recorded in weedy check.

In maize- wheat- greengram cropping system, chemical properties of soil i.e. nitrogen (N) phosphorus (P) potassium (K) and organic carbon (OC) were significantly influenced by crop establishment methods and weed management practices. At 0-5 cm soil depth, the available N, P, K and OC were significantly higher in ZTR -ZTR- ZTR (430.6, 16.3, 421.6 kg/ha and 0.78%, respectively) followed by ZTR-ZT-ZTR (413.1, 13.3, 383.2 kg/ha and 0.70%, respectively). The lowest values were recorded in CT-CT-CT (349.6, 10.8, 269.4 kg/ha and 0.62%, respectively). Similarly, at 5-10 cm, 10-15 cm and 15-20 cm soil depthsthe trend of 0-5 cm soil depth was followed. However, it was recorded that with increase in soil depths the availability of N, P, K, and OC were decreased. The pH of the soil was significant higher in CT-CT-CT (7.50) followed by ZT-ZT-ZT (6.91), whereas, the lowest value was recorded in ZTR -ZTR- ZTR (7.13).
Among the weed management practices, the available N, P, K, pH and OC were highest at 0-5 cm soil depths with clodinafop 50 g/ha *fb* 2,4-D 50 g/ha (W_1; 398.8, 13.6, 349.4, 7.35and 0.70%, respectively) and lowest in weedy check plots(W_4; 392.7, 12.8,342.7, 6.93 and 0.67%, respectively). Similar to crop establishment methods, at deeper soil layer these values were decreased and difference was narrow down.

Table 20. Weed density, dry biomass, weed control efficiency, grain and straw yield and economics as influenced by crop establishment methods and weed management practices in maize under maize-wheat-greengram cropping system

Treatments	Total weed density (g/m^2)	Total weed dry weight (g/m^2)	WCE (%)	Seed yield (kg/ha)	Stover yield (kg/ha)	Net Return (Rs/ha)	B:C
Crop establishment methods							
CT-CT-CT	8.29(78.67)	8.32(82.76)		2727	5359.9	28792	2.33
ZT-ZT-CT	8.00(74.67)	7.86(76.08)	8.1	3133	6162.0	36294	2.68
ZT-ZTWR-ZTGR	6.68(51.25)	5.41(34.71)	58.1	3268	6428.2	45278	4.00
ZTMR-ZTWR-ZT	7.04(57.67)	6.12(45.52)	45.0	3162	6222.4	43328	3.88
ZTMR-ZTWR-ZTGR	6.20(46.08)	5.07(31.51)	61.9	3410	6699.7	47900	4.18
ZT-ZT-ZT	7.39(62.08)	6.58(50.82)	38.6	3131	6163.0	42759	3.84
LSD (p=0.05)	0.29**	0.31**		70.92**	131.95**		
Weed management							
Atrazine+tembotrione (500+120 g/ha)	6.92(47.89)	6.14(38.41)	72.2	3576	6641.5	39531	2.51
Atrazine+topramezone (500+25.2 g/ha)	5.42(29.33)	4.68(22.38)	83.8	3862	7724.9	45338	2.74
Atrazine 500 g/ha *fb* HW at 30 DAS	4.60(21.17)	3.86(15.09)	89.1	4132	8558.2	50311	2.90
Weedy check	12.13(148.56)	11.57(138.39		985	1765.4	-6505	0.73
LSD (p=0.05)	0.40**	0.39**		84.54**	159.75**		
TxW	NS	0.94**		207.07**	391.29**		

Experiment 5 Long term impact of tillage and chemical weed control in maize-mustard-greengram cropping system under conservation agriculture

Study on weed management in permanent beds long term maize–mustard - greengram cropping system under conservation agriculture was conducted, under the study following major findings were recorded-

In mustard 2017-18,

In mustard, crop establishment method and weed management significantly influenced the weed dynamics and yield of mustard (**Table 21**). Weed density and dry biomass lowest in ZTMsR-ZTGR-ZTMR (94.6 no./m^2 and 69.4 g/m^2, respectively) followed by ZTMsR-ZT-ZTMR (97.3 no./m^2 and 85.4 g/m^2, respectively), whereas the highest was recorded with CT-CT-CT (118.5 no./m^2 and 122.7 g/m^2, respectively) and ZT-ZT-ZT (112.7 no./m^2 and 107.3 g/m^2, respectively). This helped in achieving more weed control efficiency in ZTMsR-ZTGR-ZTMR (60.8%) followed by ZTMsR-ZT-ZTMR (51.8%). More no. of seeds/siliqua was with ZTMsR-ZTGR-ZTMR (18.2), higher yield attributes helped in harvesting of more seed and straw yield (1665.8 and 3717.7 kg/ha, respectively) followed by ZTMsR-ZT-ZTMR (1566.7 and 3495.8 kg/ha, respectively) and lowest with CT-CT-CT (1383.3 and 3091.6 kg/ha, respectively).

Application of pendimethalin 0.75 kg/ha *fb* one hand weeding significantly suppressed the initial and subsequent flush of weeds resulted lower weed density and dry biomass (48 no./m^2 and 41.6 g/m^2, respectively) followed by pendimethalin *fb* isoproturon (90.4 no./m ^{2} and 77 g/m^2, respectively). The highest weed density and dry biomass recorded with weedy check (176.1 no./m^2 and 177.1 g/m^2, respectively). Pendimethalin *fb* hand weeding managed the weeds more efficiently resulting maximum weed control efficiency (76.5%) and more number of seeds/siliqua (19.9) which resulted highest seed yield (2045.6 kg/ha) and straw yield (4745.7 kg/ha) followed by pendimethalin *fb* isoproturon. It was recorded that isoproturon alone was not that effective to control weeds, hence this may be only applied with pre-emergence herbicides or subsequently one hand weeding may be adopted. The lowest seed and straw yield was recorded with weedy check (738.9 and 1514.7 kg/ha, respectively).

Table 21. Weed and crop parameters as influenced by crop establishment and weed management practice in mustard

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	WCE (%)	No. of seed/ siliqua	Grain yield (kg/ha)	Straw yield (kg/ha)
Crop establishment methods						
CT-CT-CT	10.60^{a}(118.54)	10.77^{a}(122.66)	30.8	14.92^{b}	1383.3^{d}	3091.6^{d}
ZT-CT-ZT	10.37^{a}(112.92)	10.11^{b}(108.75)	38.6	15.53^{ab}	1435.8^{cd}	3200.8^{cd}
ZTMsR-ZTGR-ZT	10.26^{a}(111.08)	9.68^{c}(101.00)	43.0	16.25^{ab}	1508.3^{bc}	3365.3^{bc}
ZTMsR-ZT-ZTMR	9.67^{b}(97.33)	8.99^{d}(85.37)	51.8	17.25^{ab}	1566.7^{ab}	3495.8^{ab}
ZTMsR-ZTGR-ZTMR	9.53^{b}(94.58)	8.09^{e}(69.39)	60.8	18.24^{a}	1665.8^{a}	3717.7^{a}
ZT-ZT-ZT	10.35^{a}(112.67)	10.04^{bc}(107.29)	39.4	15.69^{ab}	1402.5^{cd}	3123.4^{cd}
LSD (p=0.05)	0.44	0.40		2.81	113.56	251.66
Weed management						
Isoproturon	10.80^{b}(116.89)	10.01^{b}(100.65)	43.2	16.06^{b}	1345.0^{c}	2824.5^{c}
pendimethalin *fb* isoproturon	9.50^{c}(90.39)	8.74^{c}(76.96)	56.6	18.46^{a}	1845.6^{b}	4244.8^{b}
Pendimethalin *fb* hand weeding	6.96^{d}(48.00)	6.44^{d}(41.55)	76.5	19.90^{a}	2045.6^{a}	4745.7^{a}
Weedy check	13.26^{a}(176.14)	13.26^{a}(177.14)	-	10.83^{c}	738.9^{d}	1514.7^{d}
LSD (p=0.05)	0.53	0.72		1.99	107.03	239.75

CT: Conventional tillage; **CTR:** Conventional tillage with residue incorporation; **ZT:** Zero tillage; **ZTR:** Zero tillage with residue; Weed data subjected to SQRT transformation; original values are in parentheses

In greengram 2018

At 45 DAS, the highest weed density was recorded in CT-CT-CT (59.83 no./m^2) followed by CT-ZT-ZT (49.33 no./m^2), whereas the lowest weed density was recorded with ZTGR-ZTUR-ZTMsR (27.25 no./m^2). The lower weed density in ZTGR-ZTUR-ZTMsR was mainly due to retention of previous crop residues lowered the germination and emergence of weed seeds, thus resulted lower weed densities in the system, whereas, in CT and ZT without crop residues, weed seeds get favourable conditions for germination, emergence and establishment as most of the weed seeds were present on the surface of the soil. ZTGR-ZTUR-ZTMsR had lower weed density resulted in lower weed seed rain, which further lowered the establishment of weeds. Among weed management practices, weedy check recorded the highest weed density (94.11 no./m^2), whereas the lowest weed density was recorded with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (10.22 no./m^2). Application of pendimethalin 678 g/ha *fb* quizalofop 50 g/ha and pendimethalin at 678 g/ha has considerably suppressed the weed density, yet their effect was less pertaining to pendimethalin 678 g/ha *fb* hand weeding at 30 DAS.

Among crop establishment methods, the highest weed dry biomass was recorded in CT-CT-CT (29.39 g/m^2), whereas the lowest weed dry biomass was recorded in ZTGR-ZTUR-ZTMsR (14.34 g/m^2). Rest of crop establishment treatments were between these two, yet their effect was less pertaining to ZTGR-ZTUR-ZTMsR. Lower weed density and weed dry biomass in ZTGR-ZTUR-ZTMsR recorded the highest WCE by 51.2%. The highest WCE and lower weed dry biomass with ZTGR-ZTUR-ZTMsR helped in the synthesis of more number of branches, pods/plant and seeds/pod resulted in higher seed and stover yield (0.99 and 2.04 t/ha, respectively) followed by ZT-ZTUR-ZTMsR. The lowest seed and stover yield was recorded with CT-CT-CT (0.86 and 1.67 t/ha, respectively).

Among weed management practices, weedy check has the highest weedy dry biomass (49.73 g/m^2) and lowest with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (5.6 g/ha). The highest WCE was recorded with pendimethalin 678 g/ha *fb* hand weeding (88.7%) followed by pendimethalin 678 g/ha *fb* quizalofop 50 g/ha (78.2%) and pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha (55.5%) over the weedy check. The grain and stover yield was highest with pendimethalin 678 g/ha *fb* hand weeding (1.28 and 2.64 t/ha, respectively) followed by pendimethalin 678 g/ha *fb* quizalofop 50 g/ha (1.17 and 2.28 t/ha, respectively).

In maize 2018,

The study area comprised with *Echinochloa colona, Digitaria sanguinalis, Dinebra retroflexa, Cynodon dactylon, Cyperus iria, Commelina benghalensis, Phyllanthus urinaria, Merrimia emerginata, Oplisemenus* sp., *Eclipta alba, Euphorbia geniculata* and *Alternanthera sesilis*. Shannon diversity index worked out for different crop establishment methods using the weed density at 60 DAS. In maize, ZT-ZT-ZT has higher diversity due to the more number of species present and evenly distributed compare to the ZT+GR-ZT+SR-ZT+WR. Among weed management practices, weedy check (W_4) has the highest diversity of weeds followed by atrazine 1000 g/ha *fb* 2, 4-D 580 g/ha (W_1). The lowest diversity was recorded with integrated weed management of atrazine 500 g/ha + topramezone 25.2 g/ha *fb* HW at 40 DAS (W_3) followed by atrazine 500 g/ha + topramezone 25.2 g/ha (W_2).

Weed seed bank study were conducted by taking soil sample of 10 cm diameter core at 0-5, 5-10 and 10-15 cm depth in each plot of all the crop establishment methods. In maize, the soil comprised mainly with *Echinochloa colona, Phyllanthus urinaria* and *Dinebra retroflexa*, apart from *these Cyperus iria, Ammania baccifera, Mecardonia procumbens* and *Euphorbia heterophylla* were minor weeds. It has been found that, there is decreasing trend for *Echinochloa colona, Phyllanthus urinaria* and *Dinebra retroflexa* with the decreasing soil depth. However, *Echinochloa colona* was highest with ZT-ZT-ZT+MsR at 0-5 cm and at deeper layer CT-CT-Ct has more seeds, similarly *Phyllanthus urinaria* and *Dinebra retroflexa* had followed the trend of *Echinochloa colona*. In deeper soil layer, retention of crop residues reduced the weed seed bank in maize under maize-mustard-greengram cropping.

The study area was heavily infested with grassy weeds like *Echinochloa colona, Dinebra retroflexa, Paspaladium flavidum* and *Cynodon dactylon* whereas broadleaved weeds *viz. Alternanthera paronychioides, Physalis minima, Caesulia axillaris, Phyllanthus urinaria, Commelina communis* and *Commelina banghalensis* and *Cyperus iria* was only sedge present.

The highest weed density was recorded in ZT-ZT-ZT (53.42 no./m^2) followed by ZT-ZT-CT (48.83 no./m^2), whereas the lowest weed density was recorded with ZTMR-ZTMsR-ZTGR (29.75 no./m^2). The lower weed density in ZTMR-ZTMsR-ZTGR was mainly due to the retention of previous season crop residues, which acted as mulch and created an obstacle for germination and emergence of weeds. But, in CT and ZT without crop residues, the said advantages were not noticed. ZTMR-ZTMsR-ZTGR has fewer weed density this significantly reduced the weed seed rain, which further lowered the establishment of weeds. Among weed management practices, weedy check recorded the highest weed density (89.61 no./m^2), whereas the lowest weed density was recorded with atrazine + topramezone (500+25.2 g/ha) *fb* HW at 40 DAS (13.56 no./m^2). Application of atrazine + topramezone (500+25.2 g/ha) has considerably suppressed the weed density (21.78 no./m^2) followed by atrazine + tembotrione (500+120 g/ha), yet their effect was less pertaining to atrazine + topramezone (500+25.2 g/ha) *fb* HW at 40 DAS (**Table 22**).

However, weed dry biomass accumulation was recorded the highest with ZT-ZT-CT (56.92 g/m^2) followed by CT-CT-CT (52.37 g/m^2) and ZT-ZT-ZT (50.91 g/m ^{2}). The lowest weed dry biomass was recorded in ZTMR-ZTMsR-ZTGR (24.08 g/m^2). Rest of the treatments were between these treatments, however, their effect was less pertaining to ZTMR-ZTMsR-ZTGR. These helped to achieve higher WCE (57.7%) followed by ZT-ZTMsR-ZTGR (54.05%) over ZT-ZT-CT. Application of atrazine + topramezone (500+25.2 g/ha) *fb* HW at 40 DAS recorded lowest weed dry biomass and the highest WCE (10.54 g/m^2 and 88.29%) followed by atrazine + topramezone (500+25.2 g/ha). Reduction in weed parameters improved the yield attributes, resulting in highest grain and straw yield was recorded in ZTMR-ZTMsR-ZTGR (3.36 and 7.07 t/ha, respectively) followed by ZT-ZTMsR-ZTGR (3.22 and 6.78 t/ha, respectively). The lowest grain and straw yield was recorded in ZT-CT-ZT (2.90 and 6.14 t/ha, respectively). Among weed management practices, the highest grain and straw yield was recorded with atrazine + topramezone (500+25.2 g/ha) *fb* HW at 40 DAS (3.81 and 8.51 t/ha, respectively) followed by atrazine + topramezone (500+25.2 g/ha) (3.66 and 7.87 t/ha, respectively). However, the lowest grain and straw yield was recorded with a weedy check (1.57 and 3.02 t/ha, respectively).
Among crop establishment method, the highest net return and B: C ratio was recorded in ZTMR-ZTMsR-ZTGR (Rs. 47509/ha and 4.15, respectively) followed by ZT-ZTMsR-ZTGR, whereas, the lowest net return and B:C ratio was recorded in ZT-ZT-CT (Rs 32448 and 2.50, respectively). Among weed management practices, atrazine + topramezone (500+25.2 g/ha) *fb* HW at 40 DAS obtained net return and B: C ratio (Rs 45002/ha and 2.70, respectively) followed by atrazine + topramezone (500+25.2 g/ha), whereas the lowest return (Rs 4339/ha) with 1.18 B: C ratio recorded in weedy check.

Table 22. Weed density, dry biomass, weed control efficiency, grain and straw yield and economics as influenced by crop establishment methods and weed management practices in maize under maize-mustard-greengram cropping system

Treatments	Total weed density (g/m^2)	Total weed dry weight (g/m^2)	WCE (%)	Seed yield (kg/ha)	Stover yield (kg/ha)	Net Return (Rs/ha)	B:C
Crop establishment methods							
CT-CT-CT	6.08(41.33)	10.51(52.37)	8.00	3012	6340.1	34461	2.60
ZT-ZT-CT	6.69(48.83)	9.96(56.92)		2902	6140.9	32448	2.50
ZT-ZTMsR-ZTGR	5.60(34.83)	6.58(26.16)	54.05	3224	6782.0	44902	3.98
ZTMR-ZTMsrR-ZT	6.41(46.17)	7.44(42.86)	24.71	3189	6702.7	44253	3.94
ZTMR-ZTMsR-ZTGR	5.17(29.75)	6.23(24.86)	57.69	3364	7072.7	47509	4.15
ZT-ZT-ZT	6.84(53.42)	7.85(50.91)	10.56	2932	6205.6	39505	3.62
LSD (p=0.05)	0.27**	0.43**		108.95**	226.43**		
Weed management							
Atrazine 1.0 kg/ha *fb* 2,4-D 580 g/ha	6.69(44.61)	8.51(49.47)	45.04	3380	6759.9	36411	2.39
Atrazine 500 g/ha +							

Topramezone 25.2 g/ha	4.70(21.78)	5.61(18.87)	79.04	3656	7873.7	42074	2.61
Atrazine 500 g/ha + Topramezone 25.2 g/ha *fb* HW at 40 DAS	3.72(13.56)	4.35(10.54)	88.29	3813	8505.9	45002	2.70
Weedy check	9.43(89.61)	13.92(90.00)		1566	3023.0	4339	1.18
LSD (p=0.05)	0.22**	0.27**		66.27**	137.53**		
TxW	0.54**	0.65**		162.34**	336.88**		

In maize/blackgram- mustard- greengram cropping system chemical properties of soil i.e. nitrogen (N) phosphorus (P) potassium (K) and organic carbon (OC) were significantly influenced by crop establishment methods and weed management practices. At 0-5 cm soil depth, the available N, P, K and OC were significantly higher in ZTR -ZTR- ZTR (439.8, 17.8, 425.2 kg/ha and 0.80%, respectively) followed by ZTR-ZT-ZTR (422.2, 14.9, 386.8 kg/ha and 0.72%, respectively). The lowest values were recorded in CT-CT-CT (358.7, 11.6, 273.0 kg/ha and 0.64%, respectively). Similarly, at 5-10 cm, 10-15 cm and 15-20 cm soil depths the trend of 0-5 cm soil depth was followed. However, it was found that with increase in soil depths the availability of N, P, K, and OC were decreased. The pH of the soil was significant higher in CT-CT-CT (7.59) followed by ZT-ZT-ZT (7.31), but the lowest value was recorded in ZTR -ZTR-ZTR (7.00).

Among the weed management practices,the available N, P, K, pH and OC were highest at 0-5 cm soil depths with atrazine 500 g/ha *fb* 2,4-D 500 g/ha (W_1; 409.6,15.4, 352.3, 7.44and 0.72%, respectively) and lowest in weedy check plots(W_4; 400.0, 14.0, 332.9, 7.02and 0.69%, respectively). Similar to crop establishment methods, at deeper soil layer these values were decreased.

Exploratory trial

Experiment 6 Effect of crop residue load and spray volume with pendimethalin on weed control

During winter 2017-18, it was recorded that retention of crop residue load significantly reduces the weed density to the tune of 46.9 to 100% over bare soil, where broadleaved weeds were suppressed better than the grassy weeds. Suppression of weed dry biomass was highest with 8 t/ha and it reduced with reduction in crop residue load. Similar to crop residue load, spray volume has significantly reduced the weeds from 250 to 750 L/ha spray volume over control. The control of weed density was ranged from 65-92.5%, and weed dry biomass (67.6-93.9%). The highest control obtained with 750 L/ha and the lowest with 250 L/ha.

During summer 2018, the suppression of weed density was ranged from 41.2-100% and weed dry biomass from 40.6-100% with crop residue load, the highest suppression recorded in 8 t/ha and lowest with bare soil. Similarly, spray volume suppressed weed density to the tune of 58.8-93.6% and wed dry biomass by 60.2-94.6% over control. Increase in crop residue load and spray volume considerably improve the weed control efficiency.

During rainy season 2018, the highest weed density and dry biomass were recorded with bare soil and without herbicide. The suppression of weed density was ranged from 23.4-100% and weed dry biomass from 30.1-95.4% with crop residue load, the highest suppression recorded in 8 t/ha and lowest with bare soil. Similarly, spray volume suppressed weed density to the tune of 80.8-93.4% and weed dry biomass by 88-96.3% over control. During the rainy season, the effect of spray volume was at par to each other.

It was noticed that the increase in crop residue load significantly reduced the weed density and dry biomass of weed; however, with progress in time, the emergence of weeds noticed in crop residue applied plots. The weed emergence was more in 4 t/ha and low in 8 t/ha. This was mainly due to exposure of soils and non-reaching of herbicides to the soils. This was more prominent during summer and winter. However, during rainy season no such observations were recorded. These might be due to high rainfall and cloudy weather helped to reach the herbicide to the soils and also least loss due to photodegradation of pendimethalin 38.7%.

IARI

Weed management in CA based cropping system

A)Nitrogen and herbicide interaction for better weed control in CA-based maize under maize-wheat-green gram system

Under a long-term conservation agriculture (CA)-based experiment in maize–wheat – greengram cropping system (Table 6), weed and nitrogen management were evaluated in maize. Treatments comprised of zero tillage (ZT) with residue retention (R) 50% RDN (ZT+R+50%N), ZT+R+75%N, ZT+R+100%N and conventional tillage (CT) with residue incorporation (R) + 100% RDN (CT+R+100%N), superimposed with the tank-mix of atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha as pre-emergence (ATR+PMT), atrazine 1.0 kg/ha as pre-emergence *fb* tembotrione 100 g/ha at 25 DAS (ATR-TEM), atrazine 1.0 kg/ha as pre-emergence *fb* hand pulling at 25 DAS (ATR-HP) and unweeded control (UWC).

The density of total weeds at 40 DAS due to tillage, residue and nitrogen, and weed management practices were significantly affected in maize (Table 23). The ZT-based systems resulted in lower weed density than the CT. Among the ZT-based systems, ZT+R+100%N was most efficient for controlling weeds. This ZT+R+100%N gave highest maize grain yield (Figure 3). This result shows that ZT-based systems were able to reduce the weed seed bank build-up in soil over the years. Among the herbicide treatments, the tank-mix application of ATR+PMT reduced considerably the total weeds density than the sequential applications of ATR-TEM and ATR-HP, resulting into higher weed control efficiency and ultimately higher grain yield.

Fig. 3. ZT-based maize with 75%N (left) and 100%N (right)

Table 23. Effect of various weed and nitrogen management practices on weed and maize

Treatment	Weed density (no./m2)	Yield (t/ha)
Tillage, residue and nitrogen		
ZT+R+50%N	27	5.30
ZT+R+75%N	26	5.70
ZT+R+100%N	19	5.91
CT+R+100%N	41	5.77
LSD (P=0.05)	8.0	0.13
Weed management		
ATR + PMT	19	5.67
ATR-TEM	24	5.52
ATR-HP	28	5.21
UWC	42	4.50
LSD (P=0.05)	11	0.19

B)**Sequential herbicides for efficient weed management in CA-based direct seeded rice**

A study was carried out on weed management in rice under a 10 year old conservation agriculture (CA) based rice-wheat system. The main plot treatments constituted of six tillage and residue (TR) practices (Table 7): ZT DSR (Zero-till direct-seeded rice) – ZTW (Zero-till wheat), WR (wheat residue) + ZT DSR – RR (rice residue) + ZTW, WR+ ZT DSR + BM – RR + ZTW, ZT DSR – ZTW – ZT mungbean (ZTMB), mungbean residue + ZT DSR – RR + ZTW – WR + ZTMB and TPR (Transplanted puddled rice)– CTW (Conventional till wheat). Four weed control treatments were unweeded control (W1), pendimethalin 1.50 kg/ha at 1 DAS *fb* bispyribac-Na 0.025 kg/ha at 25 DAS (W2), pyrazosulfuron-ethyl 0.025 kg/ha at 1 DAS *fb* tank-mixture of cyhalofop-butyl 0.100 kg/ha + bispyribac-Na 0.025 kg/ha at 25 DAS (W3) and pyrazosulfuron-ethyl 0.025 at 1 DAS *fb* cyhalofop-butyl 0.100 kg/ha at 20 DAS *fb* bispyribac-Na 0.025 kg/ha at 25 DAS (W4). The rice yield was significantly higher in TPR over DSR treatments, but, the second highest yield (6.33 t/ha) was recorded in the MB + ZTDSR – RR + ZTW – WR + ZTMB (Table 24). Weed control treatment that comprised of pyrazosulfuron-ethyl 0.025 at 1 DAS *fb* cyhalofop-butyl 0.100 kg/ha at 20 DAS *fb* bispyribac-Na 0.025 kg/ha at 25 DAS was most efficient in controlling weeds and obtaining higher rice yield. This treatment (~7.18 t/ha) gave

2.2 times higher yield over UWC (~3.19 t/ha) (Figures 4a and 4b). Interaction showed that the MB + ZTDSR – RR + ZTW – WR + ZTMB practice combined with the sequential application of pyrazosulfuron-ethyl 0.025 at 1 DAS *fb* cyhalofop-butyl 0.100 kg/ha at 20 DAS *fb* bispyribac-Na 0.025 kg/ha at 25 DAS could result in highest rice yield among the DSR treatments. At the same level of weed management, however, it was slightly inferior to TPR–CTW system on rice yield. Thus, the sequential application of herbicides in direct-seeded rice could efficiently manage weeds and increased yield considerably.

Table 24. Tillage, crop establishment methods and weed management interaction effect on grain yield of rice

Treatment	Weed management (WM)				Mean
Tillage and residue practices (TR)	W1	W2	W3	W4	
ZTDSR– ZTW	2.62	7.18	6.53	7.47	5.95
WR + ZTDSR – RR + ZTW	1.70	6.55	5.68	6.75	5.17
WR+ ZTDSR + BM – RR + ZTW	2.80	6.05	5.55	6.35	5.19
ZTDSR – ZTW – ZTMB	3.30	5.93	5.25	6.43	5.23
MB + ZTDSR – RR + ZTW – WR + ZTMB	3.67	7.22	6.68	7.78	6.33
TPR– CTW	5.05	7.85	7.28	8.29	7.12
Mean	3.19	6.80	6.16	7.18	
LSD ($P \leq 0.05$) (TCE)	0.44				
LSD ($P \leq 0.05$) (WM)	0.21				
LSD ($P \leq 0.05$) (TCE) X (WM)	0.22				

Fig. 4a. Pyrazosulfuron-ethyl 1 DAS fb **Fig. 4b. Unweeded control cyhalofop-butyl at 20**
DAS fb bispyribac-Na at 25 DAS

2.1.1.4 Water Management

RCER

Daily root zone water balance was simulated for growing seasons of *Kharif, Rabi* and summer using a daily time step water balance model. Model accounted for root zone processes considering inputs (rainfall/evaporation), outputs (deep drainage, evaporation, transpiration and runoff) and soil moisture storage. Crop water uptake from root zone was estimated using Penman-Montieth approach. Time series field observed data on root zone soil moisture content was used to validate the model. Deep percolation rate was varied from 1 to 6 mm/day to arrive at calibrated value of 3mm/day for puddled paddy fields and 4 mm/day from non-puddled paddy and other crops (mustard and greengram). Simulations were carried out for farmers practice (FP) and CA practices separately.Results showed that, CA practices of DSR recorded higher evaporation loss of 504 mm as against 410 and 399 mm observed in FP and ZTT (Table 1). The practice of puddling in FP reduced deep percolation loss by 27 and 17% compared to DSR and ZTT. Adoption of CA practices in mustard required only five irrigations (275 mm) against 6 irrigations (330 mm) in farmers practice. In mustard the evaporation loss was reduced by ~10%. In case of summer mungbean, there was no difference in amount water to be applied, as both treatments required four irrigation. Evaporation loss under CA practices was 6.8% lower as compared to farmers practice.

Table 1. Seasonal water balance of crops under CA practices

Crop	Treatment	DOS	Inflow ↓		Outflow ↑			Seasonal moisture gain/loss (mm)
			RF (mm)	Irrigation (mm)	Evop. Loss (mm)	Runoff (mm)	Percolation loss (mm)	
Paddy	FP	25/07/2016	510	0	410	78	218.2	-202
	DSR	05/07/2016	705	0	504	45	300	-81
	ZTT	25/07/2016	510	0	399	45	264	-204
Mustard	FP	15/12/2016	62.5	330	408	0.0	0.0	-14.5
	CA	15/12/2016	62.5	275	367	0	0	-29

Green	FP	05/04/2017	254.7	240	321.6	0.0	0.0	177.1
gram	CA	05/04/2017	254.7	240	299.8	0.0	0.0	198.1

*Water balance for 90 cm root zone depth


Transplanting of paddy


Transplanted view of paddy


Weeding in paddy plots


Field view at Jharkhand


Threshing of paddy


Pre-emergence herbicide application


Field view of mustard


Field view of linseed

Experimental site: Chene, Namkum, Ranchi, Jharkhand


Paddy crop at maturity


Rabi crop land preparation


Water harvesting pond

Experimental site: Kandora, Jashpur, Chhattisgarh

CSSRI

1) Irrigation system in rice crop

Data are given in Table 2 for the comparison of different irrigation methods in rice crop. Results of micro irrigation methods and surface irrigation methods are discussed below as:

a) Mini sprinkler irrigation method in rice crop

Results on irrigation through mini sprinkler irrigation method shows (Table 2) that 6.10 tha^{-1} grain yield was obtained in DSR+50% reduce tillage+33% wheat residue incorporation during 2018. Lower grain yield of direct seeded rice under mini-sprinkler irrigation was recorded in comparison to transplanted rice. The grain yield of DSR-RT under mini-sprinkler irrigation method was lower than DSR-RT under surface irrigation method. Mini-sprinkler in DSR-RT saved 70.1% irrigation water and 59.9% electricity as compared to transplanted rice. Mini sprinkler fertigation method in rice saved 29.1% nitrogen of recommend dose (45 kg) and increase nitrogen use efficiency from 54.43 to 55.71 kg grain kg^{-1} nitrogen compared to TPR. Irrigation water productivity ranged from 2.917 to 2.985 kg m^{-3}.

Wheat sowing using happy seed drill in rice residue under mini sprinkler irrigation method.

Table 2: Effect of irrigation methods on rice grain yield (Arize 6129), irrigation water requirement, water productivity, saving of water and electricity, and nitrogen use efficiency during *kharif* 2018

RCTs	TPR	DSR+RT	DSR+RT	DSR+RT	DSR +WR incorporation
Mode of irrigation	Surface T_1	Surface T_8	Drip T_7	Mini – Sprinkler T_9	Mini –Sprinkler T_{10}
Irrigation criteria	1DADPW	Small soil cracks with surface dryness	(Previous 3days CPE) Alternate day	(Previous 2days CPE) Alternate day	(Previous 2 days CPE) Alternate day
Years	2018	2018	2018	2018	2018
Grain yield (tha^{-1})	6.66	6.81	7.17	5.96	6.10
Total crop productivity (tha^{-1})	15.25	15.80	16.80	13.93	14.32
Total irrigation water (ha-cm)	68.27	45.0	13.0	20.0	20.0
Total irrigation water (m^{3}ha^{-1})	6826	4496	1306	2043	2043
Crop water productivity (kg m^{-3})	2.234	3.51	12.86	6.82	7.01
Grain water productivity (kg m^{-3})	0.98	1.52	5.49	2.92	2.99
Irrigation water saving (%)	-	34.14	80.91	70.1	70.1
Electricity saving (%)	-	34.15	82.34	72.32	72.32
NUE (kg grain kg^{-1} nitrogen) 40 kg N saving	43.11	45.4	47.8	54.43	55.71
Rainfall received =1005.4 mm and Pan evaporation =539.9 mm during June, 2018 to September 2018, CPE= cumulative pan evaporation criteria used for irrigation through mini sprinkler system, CD (0.05) for grain yield=0.35 and NUE=Nitrogen use efficiency					

b)Drip irrigation in rice crop

Data shows (Table 7) that production of 7.17 tha^{-1} grain yield, where rice was sown under 50% reduce tillage with zero tillage seed drill machine saved 80.1% irrigation water along with 5.49 kg m^{-3} irrigation water productivity, 82.34% electricity and 47.8 kg grain kg^{-1} N NUE. During this year (2018) rice grain yield under drip irrigation system recorded 7.66% higher than under TPR.

Surface irrigation method in rice crop required huge amount of irrigation water in comparison to the drip irrigation in rice crop.

Surface irrigation in rice crop

Result shows (Table 2) that DSR under surface irrigation method produced grain yield 6.81 tha^{-1}. Grain yields in DSR under surface irrigation method were higher than mini sprinkler irrigation system with 1.52 kg m^{-3} irrigation water productivity. Likewise, NUE was 35.51 kg grain kg^{-1} N in 2018 under surface irrigation method.

2) Irrigation system in wheat crop

The results of micro irrigation system in wheat crop during 2018-19 discussed in Table 8 as given below:

a) Mini sprinkler irrigation in wheat

Results shows (Table 3) that wheat in zero tillage with 100% rice straw mulch produced higher grain yield of 6.46 to 6.50 tha^{-1} under mini sprinkler irrigation method and 6.54 tha^{-1} under surface irrigation method. Sprinkler irrigation system in wheat saved 38% irrigation water over the surface irrigation method. Mini-sprinkler method may be feasible for wheat crop.

b) Drip irrigation method in wheat

- Drip irrigation system was installed during *rabi* 2016-17. It was laid in 1000 m^2 field area. The discharge of dripper was 4 litres/hour and 14824 litres/1000m^2/hr. The criterion of irrigation scheduling was CPE ratio of previous 7 days with 0.8 volume of water of total irrigation water computed and applied.
- Results on the irrigation methods as given in Table 8 indicate that pressurized irrigation methods are water saver in comparison to surface irrigation method in partially reclaimed sodic soil with sandy loam texture.
- The grain yield of wheat under drip irrigation was 6.08 tha^{-1}, which was statistically significant to conventional irrigation method. Saving of irrigation water under drip irrigation was 50.40% compared to conventional method. It saved 12.4% more irrigation with water productivity of 4.54 kg m^{-3} as compared to mini-sprinkler irrigation method.
-

c) Surface irrigation method in wheat

- Evaluating different rice residue management techniques in wheat crop with different irrigation methods and observed that 100% rice residue management with turbo happy seed drill machine for wheat sown is feasible as rice residue is hassle free which is good for plant stand, higher crop growth and yield.
- Surface irrigation system in wheat with 100% rice residue mulch produced grain yield of 6.54 tha^{-1} with saving of irrigation water 33.74% compared to without crop residue techniques under surface irrigation method. Rice mulch in wheat crop saved one irrigation that due to mulching, reduced the evaporation losses during crop growth period.
- Rice crop residue maintained favourable soil temperature and moisture to facilitate better germination, growth and yield during the crop growth period.
-

d) Nitrogen use efficiency under different irrigation methods

Data on nitrogen use efficiency for wheat crop (Table 3) shows that application of nitrogen fertilizer by using leaf colour chart, always maintained at LCC No 4/5. The nitrogen through urea applied via fertilizer tank @ 2.5 kg with irrigation water on scheduled day.

i. **Nitrogen use efficiency vs Mini sprinkler irrigation system**

Nitrogen use efficiency in mini sprinkler irrigation system varied from 75.43 to 75.98 kg grain kg^{-1} and saved 43.32% nitrogen of recommended dose (85.02 kg N ha^{-1} and 140 kg urea ha^{-1}) as compared to conventional surface irrigation method in crop season 2018-2019 (Table 3). NUE in mini sprinkler irrigation system was calculated 75.98 to 76.45 kg grain kg^{-1} N.

Table 3: Effect of surface and mini sprinkler irrigation method on wheat yield, irrigation water requirement, water productivity, saving of water and electricity during 2018-19

RCTs	Conventional wheat sowing	Wheat sowing in Zero tillage with100% rice mulch/DSR	Wheat sowing in Zero tillage with 100% rice mulch/DSR	Wheat sowing in Zero tillage with 100% rice mulch/DSR with WRI	Wheat sowing in Zero tillage with 100% rice mulch/DSR
Mode of irrigation	**Surface T_1**	**Drip Irrigation- T_7**	**Surface T_8**	**Mini –Sprinkler T_9**	**Mini – Sprinkler T_{10}**
Irrigation criteria	**Growth stages**	**(Previous 7days CPE)**	**Growth stages**	**(previous 7 days CPE)**	**(7 days CPE)**
years	2018-19	2018-19	2018-19	2018-19	2018-19
Grain yield (tha^{-1})	5.52	6.08	6.54	6.46	6.50
Total crop productivity (tha^{-1})	14.12	14.65	16.81	17.41	17.38
Total irrigation water (ha-cm)	27.0	13.39	17.94	16.74	16.74
Total irrigation water ($m^3 ha^{-1}$)	2704.34	1339.4	1794.2	1674.1	1674.1
Crop water productivity($kg\ m^{-3}$)	5.22	10.94	9.37	10.40	10.38
Grain water productivity($kg\ m^{-3}$)	2.04	4.54	3.65	3.86	3.88
Irrigation water saving (%)	-	50.40	33.74	38.0	38.0
Electricity saving (%)	-	22.98	33.66	3.73	3.73
NUE (kg grain kg^{-1} nitrogen)	36.8	52.23	49.58	75.98	76.45
% saving of N	-	22.4	12.1	43.32	43.32
Saving of urea(Kg/ha)	-	72.41	39.1	140	140

Rainfall received=46.2 mm and Pan evaporation=257.1 mm during November 2018 to March 2019. CPE=cumulative pan evaporation of 7 days used for irrigation through mini sprinkler system, CD (0.05) =0.35 (2018-19) and NUE= nitrogen use efficiency. Wheat cv. HD 2967.

Nitrogen use efficiency vs Drip irrigation method in wheat crop

Nitrogen use efficiency in drip irrigation system was 52.23 kg grain kg^{-1} N in wheat sown by Turbo/happy seeder in 100% rice crop residue mulch, where nitrogen applied through Leaf colour chart which is used for the determination of nitrogen requirement during the crop growth period.

ii. **Nitrogen use efficiency vs surface irrigation method in wheat crop**

Under surface irrigation method nitrogen use efficiency was 49.58 kg grain kg^{-1} N in wheat sown by Turbo/happy seeder in 100% rice crop residue mulch, where nitrogen applied through Leaf colour chart which is used for the determination of nitrogen requirement during the crop growth period. NUE increased with increasing grain yield and reducing nitrogen requirement.

e) Electricity consumption under different irrigation methods in wheat crop

The lowest electricity consumption was computed under drip irrigation system (Table 3). It was 22.98% in comparison to conventional surface irrigation method. 3.73% more electricity saved in mini sprinkler irrigation method as compare to surface irrigation method with conventional method of wheat sowing. There for, results (Table 8) revealed that electricity was saved in pressurized irrigation system compared to surface irrigation system.

f) Economic analysis of wheat crop under different irrigation methods during 2018-19-

The economic analyses of wheat crop during 2018-19 (Table 4) shows that B:C ratio varied from 2.32 to 3.91 under different wheat crop establishment techniques and irrigation methods. Maximum B:C ratio (3.91) was computed under zero tilled wheat with rice residue mulch under surface irrigation system. Similarly, B:C ratio of sprinkler irrigation system varied from 3.06 to 3.08. More than 23%, net income was observed under mini sprinkler irrigation system as compare to the surface irrigation system (T8) and drip irrigation system. There for, results indicated that micro irrigation system in wheat crop performed better with saving of inputs. Also found that micro irrigation system is feasible economically and sustainable, when organic matter was added to the soil through rice residue or root system. Among the tillage system, wheat sown by zero tillage was found more profitable than CV and RT tillage practices.

Table 4: Economic analysis of wheat crop under different irrigation method

RCTs	Wheat 2018-19 (HD2967)						
	Operation Cost (B1-cost)	Grain yields, tha^{-1}	Gross Income with straw (Rs./ha)	Net Income (Rs./ha)	B:C	Differences & % Net income over CV	
CV wheat-T_1	36578	5.52	121568	84990	2.32	-	-
ZT+100%RR- T_7	33839	6.08	131872	98033	2.89	20554	24.18
ZT+100%RR T_8	28578	6.54	140336	111758	3.91	26768	31.50
ZT+100%RR T_9	34215	6.46	138864	104649	3.06	19659	23.13
ZT+100%RR T_{10}	34215	6.50	139600	105385	3.08	20395	23.99

Whereas, MSP @1840/q in 2018-2019 and straw @ Rs.20,000.0 ha^{-1}; CV=conventional wheat sowing; RR= rice residue; RT= reduced tillage; ZT=zero tillage; B:C=Net income/Cost

It was observed that cost of cultivation of wheat crop was lower in zero tillage wheat as compared to CV tillage practices. Zero tillage wheat sowing will improve soil heath, check air pollution and improves crop productivity.

The result shows that grain yield of wheat increased under different irrigation methods with *in-situ* management of rice residue. ZT with rice residue mulch was relatively better than CV method of wheat sowing. It may be due to optimum soil moisture and favorable temperature regulation under residue management to facilitate better seed germination and crop growth as compared to non-residue practice.

"Zero tillage wheat with rice residue mulch under micro irrigation system was found better option for sustainable, profitable and eco-friendly cropping system for those region where scarcity of water for agriculture"

Feasibility of sprinkler irrigation system in rice–wheat cropping system

The feasibility of sprinkler irrigation system in rice-wheat cropping sequence was worked out with the help of hydraulic parameters (Table 5). The results on characterization of hydraulic parameters of installed sprinkler irrigation system shows that out of three operating pressure i.e. 1.6, 1.8, and 2.0 (kg cm^{-2}), uniformity coefficient (CU %) at start was not much affected but water distribution at end was much affected and reached maximum 90.00% in 2012 and 88.07% in 2013. Similarly DU (%) and wetted radius (m) also increased with operating pressure and wetted radius reached maximum (9.69 m) at operating pressure of 2.0 kg cm^{-2}.

Table 5: Effects of different operating pressure on hydraulic characterization of installed sprinkler irrigation system

Operating pressure (kg cm^{-2})	Hydraulic parameters of installed sprinkler system								
	CU (%)		DU (%)		CV (%)		Wetted radius (m)	Average discharge (lh^{-1})	
	Start	End	Start	End	Start	End	-	Start	End
1.6	84.43	82.53	79.47	74.37	19.78	25.05	6.26	-	-
1.8	85.02	81.20	80.22	75.89	18.58	25.34	8.03	323.0	312.0
2.0	84.96	88.07	82.45	84.05	17.84	15.46	9.69	471.7	396.3

Coefficient of variation (CV %) of the system was inversely related to operating pressure and recorded minimum at operating pressure of 2.0 kg cm^{-2}. Hydraulic parameters shows relatively better performance of the system at operating pressure of 2.0 kg cm^{-2}, therefore system operated as such in both rice and wheat crops. The data given in Table 7&8 shows that yield of rice and wheat under mini-sprinkler irrigation was statistically at par with that of under conventional practice. Thus, mini-sprinkler irrigation system in rice and wheat crops may be successful with saving of natural resources considerably in higher magnitudes, which may be utilized for more area under cultivation and increasing production from the saved resources where water resource is scarce particularly.

Observations recorded under sprinkler irrigation method- The following observations recorded in rice crop at blooming stage

a) Sprinkler irrigation at the time of flowering reduced the grain setting.

b) Insecticides and pesticides should not be used through sprinkler system at grain formation stage because grains turn brownish black and at later lowers the quality and market price of crop.

c) Herbicide application in rice at 50 days after sowing badly affected its growth and plants become stunted. Also flowering got delayed which cause non-uniform maturity and irregular grains formation.

i) Highlight of sprinkler irrigation system's in rice-wheat cropping system

"Sprinkler irrigation system in DSR under reduced tillage with wheat residue incorporated or without crop residue followed by zero tilled wheat with rice residue mulched in is feasible, promising, sustainable and eco-friendly with lower inputs requirement relatively".

Feasibility of drip irrigation system in rice–wheat cropping system

(i) Rice with drip irrigation system-

that production of 7.17 tha^{-1} grain yield, where rice was sown under 50% reduce tillage with zero tillage seed drill machine saved 80.1% irrigation water along with 5.49 kg m^{-3} irrigation water productivity, 82.34% electricity and 47.8 kg grain kg^{-1} N NUE. During this year (2018) rice grain yield under drip irrigation system recorded 7.66% higher than under TPR. **Surface irrigation method in rice crop required huge amount of irrigation water in comparison to the drip irrigation in rice crop.**

(ii) Wheat with drip irrigation method

a) Drip irrigation system was installed during *rabi* 2016-17. It was laid in 1000 m^2 field area. The discharge of dripper was 4 litres/hour and 14824 litres/1000 m^2/hr. The criterion of irrigation scheduling was CPE ratio of previous 7 days with 0.8 volume of water of total irrigation water computed and applied.

b) Results on the irrigation methods as given in Table 8 indicates that pressurized irrigation methods are water saver in comparison to surface irrigation method in partially reclaimed sodic soil with sandy loam texture.

c) The grain yield of wheat under drip irrigation was 6.08 t ha^{-1}, which was statistically significant to conventional irrigation method. Saving of irrigation water under drip irrigation was 50.40% compared to conventional method. It saved 12.4% more irrigation water with water productivity of 4.54 kg m^{-3} as compared to mini-sprinkler irrigation method.

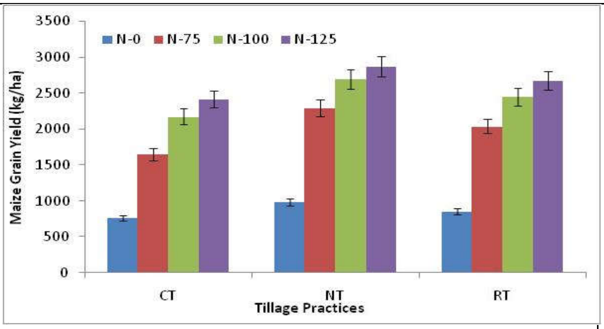
2.1.1.5 Nutrient Management

CRIDA

Nutrient management experiments were initiated in three cropping systems Maize-Pigeonpea, Pearlmillet-Horsegram and Cotton-pigeonpea**.**

1. Maize –Pigeonpea system

An experiment was initiated in 2012 to develop sustainable tillage and nitrogen management strategies to improve the soil physical properties of dryland farming system (maize-pigeonpea crop rotation) and farm productivity and profitability. The experiment was laid out with three tillage treatments as main plots and Nitrogen levels in sub plots. The result of the experiment has revealed that different tillage practices (CT, NT and RT) significantly influenced the maize grain yield. There was 26.4 and 14.6% higher grain yield in NT (2212.6 kg ha^{-1}) and RT (2005.4 kg ha^{-1})), respectively as compared to the CT (1750.2 kg ha^{-1}). In NT, 10.3% higher grain yield was recorded as compared to the RT (Fig. 1a). The nitrogen fertilizer application (N_{75}, N_{100} and N_{125}) significantly influenced the maize grain yield as compared to the N_0. There was 130.2, 181.4 and 206.3% higher grain yield in N_{75} (1995.5 kg ha^{-1}), N_{100} (2439.6 kg ha^{-1}) and N_{125} (2655.6 kg ha^{-1}), respectively as compared to the N_0 (866.9 kg ha^{-1}). 22.3 and 33.1% higher grain yield was observed in N_{100} and N_{125} as compared to the N_{75}; the yield increase was 8.9% in N_{125} over the $N_{100.}$ It was observed that NT (5169.2 kg ha^{-1}) and RT (4779.5 kg ha^{-1}),recorded 22.1 and 12.9% higher straw yield respectively as compared to the CT (4232.6 kg ha^{-1}). In NT, 8.2% higher straw yield was recorded as compared to the RT (Fig 1b). An increase of 117.1, 162.1 and 180.3% higher straw yield was observed in N_{75} (4775.6 kg ha^{-1}), N_{100} (5765.7 kg ha^{-1}) and N_{125} (6167.0 kg ha^{-1}), respectively as compared to the N_0 (2200.2 kg ha^{-1}). About 20.7 and 29.1% higher straw yield was observed in N_{100} and N_{125}, respectively as compared to the N_{75}; the yield increase was 7.0% in N_{125} over the N_{100}



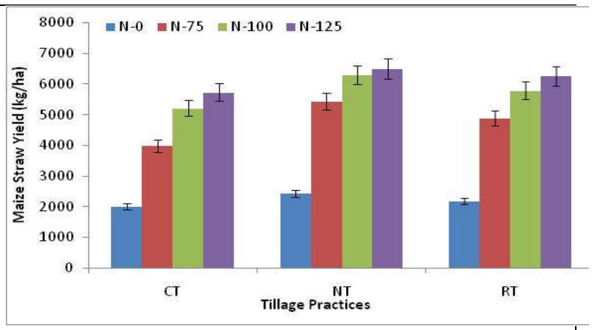


Fig. 1a. Effect of tillage practices and nitrogen levels on maize grain yield (kg/ha).	Fig. 1b. Effect of tillage practices and nitrogen levels on maize straw yield (kg/ha).

2. Pearlmillet – Horsegram/ Pigeonpea

Experiment was laid out in split plot design with three tillage treatments as main plots and nitrogen doses as subplots. The treatments were conventional Tillage (CT - one ploughing with disk plough, one harrowing and sowing), minimum Tillage (MT - One ploughing, sowing with 100% residue retention) and zero Tillage (ZT) - no till, direct seeded with 100% residue retention) as main plot treatments and three nutrient management practices of S_1 (75% RDF), S_2 (100% RDF) and S_3 (125% RDF) as sub plot treatments. MT recorded 53% higher pigeonpea yield as compared to CT (Fig 2). Among the fertilizer application 125% RDF recorded 39% higher yield as compared to 75% RDF. The interaction of tillage and nutrients was significant. MT with 125 % RDF (754 kg ha^{-1}) recorded significantly higher yield over other tillage practices (Plate 1).

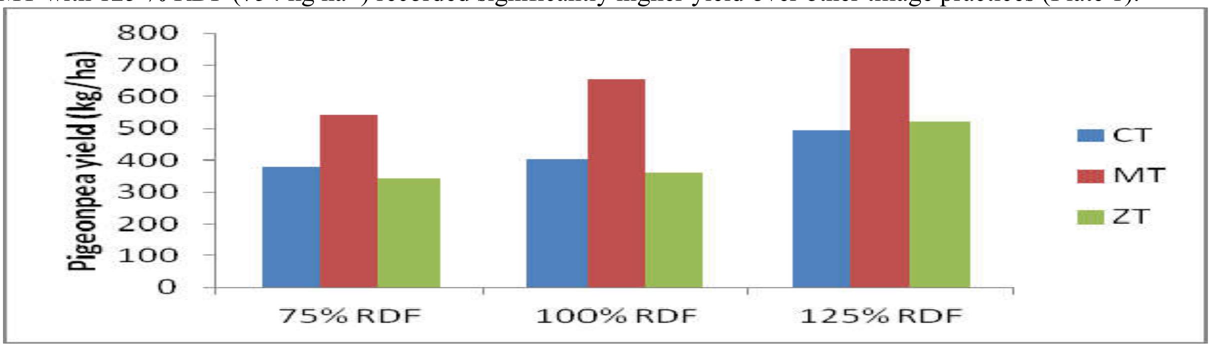


Fig. 2: Effect of CA and nutrient management on pigeonpea yield in pearlmillet-pigeonpea rotation

Plate 1: Pigeonpea grown in different recommended doses of fertilizers and tillage treatments

3. Cotton – Pigeonpea system

In cotton- pigeonpea system, seed cotton yield was not significantly influenced by tillage treatments but was influenced by the nutrient levels (Plate 2). The interaction between tillage and nutrient levels was found to be non-significant. Conventional tillage (298.7 kg/ha) recorded higher yield but this was par with minimum tillage (291.7 kg/ha) and zero tillage (252.4 kg/ha). Among the nutrient levels 125% RDF (303 kg/ha) recorded higher yield but this was on par 100% RDF (297.3 kg/ha) and significantly superior over 75% RDF (242.4 kg/ha) (Fig 3).

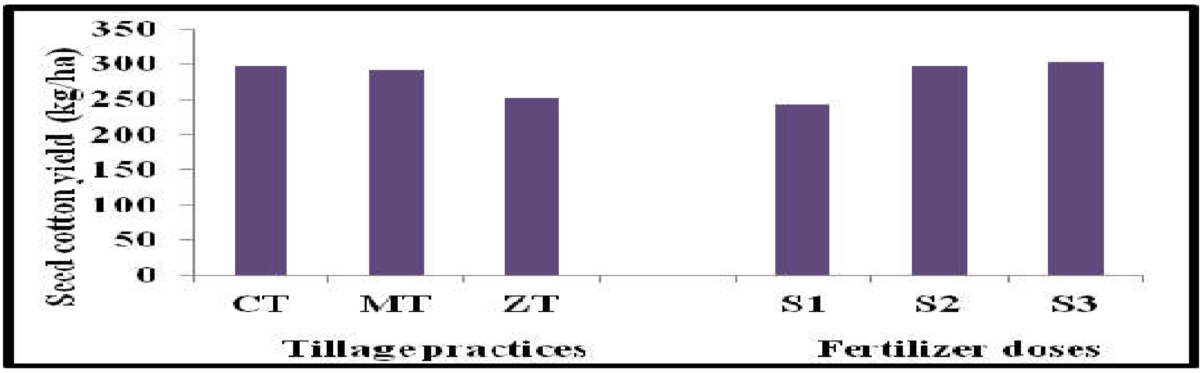


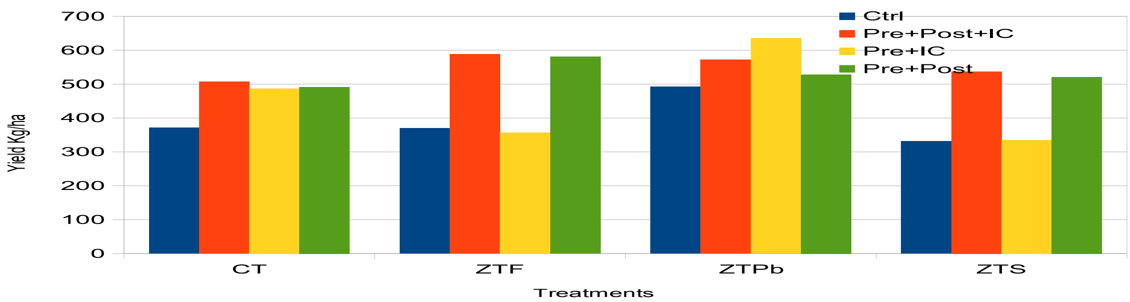
Fig 3: Effect of tillage and different recommended doses of fertilizers on seed cotton yield

Conventional tillage Minimum tillage Zero tillage Plate

Plate 2: Cotton crop grown in different recommended doses of fertilizers and tillage treatments.

Integration of in situ moisture conservation and weed control as IV principle in CA

An experiment was initiated at CRIDA with integration of in situ moisture conservation and weed control treatment along with CA practices. The permanent bed and furrow, permanent conservation furrow was tested against conventional tillage and zero tillage as main plots and weeds control treatments viz., were tested as subplots. In 2018 after harvest of maize daincha was sown with off season rainfall. In 2019 pigeonpea was



taken as test crop (Plate 3). This year the conservation agriculture treatments recorded higher pigeonpea yields as compared to conventional tillage. Among the CA practices integration of *in situ* moisture conservation with CA practices through permanent bed or conservation furrow recorded 20 and 25% higher seed yields of maize respectively, as compared to no moisture conservation practice (Fig 9). The weed control treatments increased the crop yield as compared to no weed control. Pre emergence+post emergence+ IC (removal of escape weeds) recorded higher yield as compared to other treatments.

Fig 4: Influence of different treatments on pigeonpea yield

a): Daincha as live mulch in the crop rows

Plate 3: Strategies to increase residue retention

RCER
Energy, Nutrient, Carbon and Water balance under CA practices in Jharkhand:

A. Energy:

Input and output energy in rice cultivation under FPs was 9783 and 152435 MJ, respectively (Table 1). Under CA practice input and output energy was higher in DSR (8906 and 138970 MJ/ha), respectively. The highest input-output energy ratio was recorded in DSR (15.6). The winter mustard and summer greemgram after rice had the highest input-out energy ratio in CA practice (2.21 and 1.89, respectively) as compared to farmers practice (1.41 and 1.48, respectively).

Table 1. Energy auditing in rice-mustard-green gram systems under CA

Particular	Paddy			Mustard		Greengram	
	FP	DSR	ZTT	FP	CA	FP	CA
Total energy input (MJ/ha)	9783	8906	8526	7159	6430	5658	4856
Grain yield (kg/ha)	5840	4947	4367	192	283	211	236
Straw yield (kg/ha)	5327	5300	3357	422	570	421	456
Total output energy (MJ/ha)	152435	138970	106157	10075	14200	8364	9169
Output-input energy ratio	15.58	15.60	12.45	1.41	2.21	1.48	1.89

Nitrogen balance: During 2016-17, farmer practice and DSR showed negative N balance in post-harvest rice soil, while ZTT practice had positive N balance (9.1 kg ha^{-1}) with an increase of 4.3% over initial soil N status (Table 2). All the CA practices and farmer practice showed negative N balance in post harvest soil of mustard crop, and the DSR practice found the best with 9% loss of N. During 2017-18, all the CA practices along with farmer practice showed negative N balance in rice soil in *Kharif*. N balance was positive in farmer practice and ZTT, which resulted in 4.4 and 3.6% increase over initial status in winter crop of mustard grown after rice. In summer crop of greengram, soil N balance showed positive, and the highest positive N balance was recorded in farmers' practice (35.9 kg ha^{-1}) followed by ZTT (33 kg ha^{-1}).

Table 2. Nitrogen balance (gain/loss), kg/ha in post harvest soil under CA practices Value in parentheses indicates the percent gain or loss.

CA practices	2016-17		2017-2018		
	Rice	Mustard	Rice	Mustard	Greengram
FP	-0.4 (-0.19)	-25 (-11.9)	-13.6 (-7.3)	7.6 (4.4)	35.9 (20)
DSR	-2.5 (-1.18)	-18.8 (-9.0)	-25.1 (-13.2)	-5.1 (-3.1)	26.4 (16.6)
ZTT	9.1 (4.3)	-28.8 (-13.1)	-16.8 (-8.8)	6.2 (3.6)	33 (18.3)

Phosphorus balance: Different CA practices showed negative P balance in the post-harvest *Kharif* rice soil during 2016-17 and the lowest P loss was observed in ZTT and farmers' practice with a corresponding loss of 10.5 and 11%, respectively over the initial status (Table 3). The winter crop mustard grown after rice showed positive P balance in all CA practices along with farmer practice. The *Kharif* rice during 2017-18 showed negative P balance in all the CA practices along with farmer practice, while ZTT and DSR showed the lowest P loss of 4.9 and 6.2%, respectively over initial status. Winter crop mustard showed the lowest P loss in ZTT (-0.24 kg ha^{-1}) as compared to the other practices.

Table 3. Phosphorus balance (gain/loss) in post-harvest soil under CA practice

CA practices	2016-17		2017-2018		
	Rice	Mustard	Rice	Mustard	Greengram
FP	-1.8 (-11)	1.1 (7.6)	-2.1 (-13.5)	-2.7 (20)	2.5 (23.1)
DSR	-2.6 (-15.8)	0.87 (6.3)	-0.9 (-6.2)	-2.6 (19)	0.55 (5)
ZTT	-1.7 (-10.5)	0.91 (6.2)	-0.76 (-4.9)	-0.24 (1.6)	0.4 (2.8)

Value in parentheses indicates the percent gain or loss

Potassium balance: The *Kharif* rice during 2016-17 showed positive soil K balance in all the CA practices along with farmers' practice, and varied from 25.2 to 29.8% increase over the initial status (Table 4). The mustard crop grown after rice showed negative K balance in all the CA practices with the least K loss in farmer practice. During 2017-18, *Kharif* rice showed negative K balance in all CA practices along with farmer practice and DSR observed the lowest K loss (7.4 kg ha^{-1}) with 4.2% soil K loss over the initial status. The winter crop mustard grown after rice showed negative K balance in all the CA practices along with farmer practice and lowest K loss of 9% over the initial status was recorded in ZTT. The K balance in the summer crop of greengram was negative in all the CA practices along with farmer practice and DSR observed the lowest K loss (17.9 kg ha^{-1}).

Table 4. Potassium balance (gain/loss) in post harvest soil under different CA practices

CA practices	2016-17		2017-2018		
	Rice	Mustard	Rice	Mustard	Green gram
FP	38.2 (26.7)	-0.1 (-0.06)	-45 (-24.8)	-15.4 (-11.3)	-22.4 (-18.5)
DSR	36.1 (25.2)	-1 (-0.56)	-7.4 (-4.2)	-34.3 (-20.1)	-17.9 (-13.1)
ZTT	42.7 (29.8)	-5.7 (-3.07)	-29.9 (-16.6)	-13.5 (-9.0)	-23.7 (-17.3)

Carbon foot print under different CA practices in Jharkhand

Soil organic carbon (SOC) in rice soil varied from 0.40 to 0.44% among different CA practices in 2016-17 (Table 5). Mustard crop grown after rice recorded higher SOC content of 0.43% in ZTT followed by DSR (0.42%). *Kharif* rice during 2017-18 showed higher SOC in ZTT (0.55%) followed by DSR (0.49%). SOC in winter crop of mustard soil varied from 0.59-0.66% among the different CA practices along with farmer practice.

Table 5. Organic carbon (%) in the post-harvest soil under different CA practice

CA practices	2016-17		2017-2018		
	Rice	Mustard	Rice	Mustard	Greengram
FP	0.40	0.37	0.42	0.59	0.51
DSR	0.43	0.42	0.49	0.62	0.55
ZTT	0.44	0.43	0.55	0.66	0.54

2.1.1.6 Resource Use Efficiency

Resource savings practices (IIFSR)

As indicated in the table 6 on an average 10% saving in irrigation water, 28% saving of labor and 16.8%saving of diesel and energy was recorded under CA practices as compared to conventional practices. Maximum saving of irrigation water (19.41%) and labor (31.7%) was recorded under sugarcane-ratoon-wheat and maize (cob)-pea (veg)-wheat- cowpea (pod) systems.

Table 6: **Resource saving under CA & CP in various cropping system.**

Cropping Systems	Irrigation (cm)			Labour (no.)			Diesel (ltr)			Energy (KMJ)		
	CP	CA	Saving (%)	CP	CA	Saving (%)	CP	CA	Saving (%)	CP	CA	Saving (%)
Rice- wheat- green gram	151.1	150.1	0.7	229.0	162.0	29.3	549.0	440.0	19.9	197.3	158.1	19.9
Rice- wheat- sesbania	172.1	170.1	1.2	177.0	127.0	28.2	617.0	489.0	20.7	221.7	175. 7	20.8
Maize (cob)- pea (veg)- wheat- cowpea (pod)	112.0	91.0	18.8	268.0	183.0	31.7	558.0	427.0	23.5	200.6	153.5	23.5
Sugarcane- ratoon- wheat	103.0	83.0	19.4	138.0	106.0	23.2	373.0	361.0	3.2	134.0	129.7	3.2
Average	134.6	123.6	10.0	203.0	144.5	28.1	524.3	429.3	16.8	188.4	154.2	16.8

Resource-Use Efficiency (IARI)

Resource savings in CA based cropping systems and monetisation

In CA based rice-wheat-mungbean system, maximum water saving to the tune of Rs 16,232 was observed followed by approximate savings of Rs 13390 in double zero till rice-wheat system (Table 7). In other wheat based systems (cotton-wheat, pigeonpea-wheat and maize-wheat), water savings of Rs 2881-4016 over CT was observed. The double ZT rice-wheat system proved superior in terms of labour savings of about 19.5%, which was monetized to approximately Rs 13390. Appreciable labour savings were exhibited by other CA based systems as well, with an average range of 3-10% across all the systems. Interestingly, 25% saving in N was found in both cotton-wheat, maize-wheat (amounting to 67.5 kg N/ha), rice-wheat (60 kg N/ha) under residue retention. 20% saving in wheat seed was observed under ZT sowing of wheat while 50% saving of rice seed was observed under machine-sown DSR. This has established the economic superiority of CA over CT in terms of resource savings and monetary benefits.

Table 7. Resource savings in CA based cropping systems as compared to corresponding CT treatment (R-W-M)

Cropping System	Water Saving (WS) (mm)	Labour Saving (LS) (%)	N saving (NS) (%)
Rice-wheat (with mung-bean)	794.4 (Rs 16,232)	3.2% (Rs 2320)	25% (Rs 750)
Rice-wheat (with-out mung-bean)	656.4 (Rs 13,390)	19.5% (Rs 13,920)	25% (Rs 750)
Cotton-wheat	198.0 (Rs 4,046)	8-15% (Rs 5,220)	25% (Rs 850)
Pigeon pea -wheat	151.0 (Rs 3,085)	10-18% (Rs 5,220)	-
Maize -wheat	141.0 (Rs 2,881)	5-12% (Rs 2,320)	25% (Rs 750)

Water savings and economization under different conservation agriculture practices and cropping systems

Under different cropping systems, i.e., rice-wheat, cotton-wheat, pigeonpea-wheat and maize-wheat irrigation water applied were measured by starflow meter and water savings were calculated w.r.t. transplanted rice-wheat cropping system. Water savings varied from 32 to 64% under different best treatments in respective cropping system (Table 8). Total water apllied and savings have been illustrated in Figure 5. The monetary value of water savings was calculated by taking into account the horsepower of pump and energy consumption due to drafting and withdrawal of water from tubewell with respect to transplanted rice-wheat and respective best treatments under different cropping systems (Table 5). Cost savings due to reduction in water use was highest in maize-wheat cropping system compared to transplanted rice-wheat system, but compared to individual cropping it is highest in rice-wheat followed by cotton-wheat system.

Table 8. Cost savings in different CA-based cropping systems

Treatment	Water savings (%) compared to TPR-CTW	Cost savings (Rs./ha/year) compared to TPR-CTW	Cost savings (Rs./ha/year) compared to respective CT
Rice-wheat (MBR+DSR-ZTW+RR –SMB+WR)	32.9	16232	16232
Cotton-wheat (ZT PBB+ R)	51.4	25371	4046
Pigeon pea- wheat (ZT PBB+ R)	58.6	28926	3085
Maize-wheat (ZT PBB+ R)	63.4	31143	2881

2.1.1.7 Copping Sequence

Evaluation of different cropping sequences for crop intensification under CA practices (IIFSR)

Effect of CA practices on yield and yield attributes of rice: As indicated in table 1 most of the attributing characters of rice were of higher order under conventional practices (transplanted rice) as compared to conservational practice (direct seeded rice) and hence plant height (106.5 cm), panicle length (26.13cm), grains/ panicle (109) as well as grain and straw yield were recorded higher under conventional practices (CP) than conservational practices (CA) (Fig1&2). However number of effective tillers (482) were more under CA condition as compared to CP practices.

Fig 1: Rice crop under CA conditions.

Fig 2: Rice crop under CP conditions.

Table 1:Yield and yield attributes of rice as influenced by CA and CP practices

Cropping Systems		Plant height (cm)	Tillers/m^2	Panicle length (cm)	Grains/ panicle	Grain yield (t/ha)	Straw yield (t/ha)
Rice-wheat-green gram	CA	96.87	512	24.53	84	4.44	8.33
	CP	107.60	369	25.73	111	5.07	11.39
Rice-wheat-sesbania	CA	97.00	452	23.40	88	3.66	7.92
	CP	105.40	415	26.53	107	4.24	10.31
Average	CA	96.93	482	23.97	86	4.05	8.13
	CP	106.50	392	26.13	109	4.65	10.85

Effect of CA practices on yield and yield attributes of maize:

Under maize crop as given in table 2, plant height (205cm) and number of the plant (6)/m^2 were higher under conventional practices (CP) as compared to conservational practices(CA).However cob weight was more under CA practices. Green cob yield was17.67% higher under conventional practices than conservational practices (7.19 t/ha). A view of maize crop in field is depicted in fig 3-5.

Table 2: Yield and yield attributes of maize as influenced by CA and CP practices

Cropping System		Plant height (cm)	Plants/ m^2	Weight/ cob (kg)	Green cob yield (t/ha)	Stower yield t/ha
Maize (cob)- pea (veg)-wheat-cowpea	CA	204.22	5	0.30	7.19	18.67
	CP	205.22	6	0.29	8.46	19.67

Fig03: Maize crop under maize (cob)-pea (veg)-wheat-cowpea in CA conditions.

Fig 04: Maize crop under maize (cob)-pea (veg)-wheat- cowpea in CP conditions.

Fig 05:Maize at 20 days after sowing

Effect of CA practices on yield and yield attributes of sugarcane: Sugarcane yield and yield attributes under sugarcane-ratoon-wheat cropping system were influenced due to tillage practices. SPAD value taken for greenness and single cane weight (1.30 kg) were recorded higher under CA practices. However brix value (21.14%), number of millable canes (63.33 thousands/ha) and cane yield (65.06 t/ha) were higher under conventional practice as compared to conservational practices (table 3).

Table 3: Yield and yield attributes of sugarcane as influenced by CA and CP practices (sugarcane-ratoon-wheat)

Cropping System		Spad	No. of internodes / plant	Plant height (cm)	Single Cane wt. (Kg)	Brix (%)	NMC (Thousand /ha)	Cane Yield (t/ha)	Straw Yield (t/ha)
Sugarcane-ratoon-wheat	CA	36.21	15.00	200.33	1.20	20.25	53.89	60.03	18.00
	CP	36.03	15.33	230.00	1.15	21.14	63.33	65.06	20.88
Average		36.12	15.17	215.17	1.17	20.70	58.61	62.54	19.44

Fig 06: Sugarcane (sugarcane-ratoon-wheat) under CP conditions.

Fig 07: Sugarcane (sugarcane-ratoon-wheat) under CA conditions.

Effect of CA practices on yield and yield attributes of wheat: On average basis and across the cropping systems plant height, numbers of tillers/meter square, ear length, grains/ear, and grain yield were recorded more under conservational practices (CA); however 1000 grain weight was higher under CP conditions.CA practices recorded about 7.86% higher grain yield as compared to conventional practices. Because of residue retention straw yield was recorded of lower order in CA practices as compared to CP conditions.A view of field crop under CA & CP (fig 08-15)

Table 4: Yield and yield attributes of wheat as influenced by CA and CP practices

Cropping Systems		Plant height (cm)	Tillers $/m^2$	Ear length (cm)	Grains/ ear	1000 grain wt.(g)	Grain yield (t/ha)	Straw yield (t/ha)
Rice- wheat- green gram	CA	99.67	611	8.70	43	41.9	5.39	9.46
	CP	99.80	614	8.69	41	43.1	4.77	10.63
Rice- wheat- sesbania	CA	101.60	634	9.27	44	42.2	5.33	8.14
	CP	102.20	593	8.81	40	43.4	4.50	11.16
Maize (cob)- pea (veg)-wheat-cowpea	CA	92.47	577	9.10	37	45.5	3.68	6.78
	CP	90.00	529	9.15	38	44.8	4.07	7.94
Average	CA	97.91	607	9.02	41	43.2	4.80	8.12
	CP	97.33	579	8.88	40	43.8	4.45	9.91

Effect of CA practices on yield of legumes (cowpea, green gram, veg. pea): Because of better control of secondary weeds in cowpea&green gram higher yields these cropsto the tune of 20.16 & 79.16% respectively were recorded under conventional practices as compared to conservational practices. CA practices recorded higher yield of vegetable pea as compared to CP practices which is mainly because of root infestation in vegetable pea.

Table 5: Yield of cowpea, green gram and vegetable pea as influenced by CA practices.

	Cow pea (green pod t/ha)	Green gram (grain yield t/ha)	Veg. Pea (green pod t/ha)
CA	6.71	0.48	3.2
CP	8.07	0.86	0.9

Fig 8: Green gram (rice-wheat-green gram) under CA conditions.

Fig 9: Green gram (rice-wheat-green gram) under CP conditions.

Fig 10: Cow pea (maize (cob)-pea (veg)-wheat- cowpea) under CA conditions.

Fig 11: Cow pea (maize (cob)-pea (veg)-wheat- cowpea) under CP conditions.

Fig 12: Sesbania (rice- wheat- sesbania) under CA conditions.

Fig 13: Sesbania (rice- wheat- sesbania) under CP conditions.

Fig 14:Pea crop under maize (cob)-pea (veg)-wheat- cowpea in CA conditions.

Fig 15:Pea crop under maize (cob)-pea (veg)-wheat- cowpea in CP conditions.

Effect of CA practices on WEY and net returns of various cropping systems: Maximum wheat equivalent yield (16.38 t/ha) was recorded under maize (cob)-pea (pod)- wheat- cowpea (pod)system followed by rice-wheat-green gram(16.30 t/ha). Both these systems remained at par statisticallyand showed significant superiority over rice-wheat-sesbania and sugarcane-ratoon-wheat systems.

Maximum net returns (Rs. 1.53 lakhs/ha) were recorded under rice-wheat-green gram system followed by maize (cob)- pea (veg)-wheat- cowpea (pod) cropping system. Lowest net returns (Rs0.95 lakhs/ha)were recorded by sugarcane-ratoon-wheat system because of considering only the plant crop of sugarcane for returns purposes.

Table 06: WEY& net returns ratio as influenced by CA and CP practices under different cropping systems

Cropping System	WEY (t/ha)			Gross Returns (lakhs/ha)			Net Terurns (lakhs/ha)		
	CA	CP	Av.	CA	CP	Av	CA	CP	
Rice- wheat- green gram	15.35	17.24	16.30	2.75	3.13	2.94	1.48	1.59	1.53
Rice- wheat- sesbania	12.06	12.58	12.32	2.19	2.34	2.27	1.08	0.99	1.04
Maize (cob)- pea (veg)- wheat- cowpea (pod)	16.57	16.18	16.38	3.05	2.98	3.01	1.44	1.00	1.22
Sugarcane-ratoon- wheat	11.09	12.10	11.59	2.04	2.23	2.13	0.91	1.00	0.95
Average	13.77	14.53	14.15	2.51	2.67	2.59	1.23	1.14	1.19
SEm +- Factor(A)		0.355			0.061			0.061	
Factor(B)		0.501			0.086			0.086	
Factor(A X B)		0.709			0.122			0.122	
CD (0.05P) Factor(B)*		1.54			0.264			0.264	

2.1.1.8 Establishment method

Effect of crop establishment methods and foliar nutrition on productivity of lentil in rice fallow system: (RCER)

A field experiment was conducted on clay loam soil (23.3% sand, 39.6% silt, 37.4% clay) during *rabi* season of 2018–19 at the ICAR Research Complex for Eastern Region Patna to evaluate the effect of crop establishment methods and foliar nutrition on productivity of lentil in rice–fallow system. Treatment consist of three crop establishment methods (*Utera*, ZT and CT) in main–plot and six foliar nutrition [(control (N1), seed priming+2% urea (N2), seed priming+2% DAP (N3), seed priming+0.5% KNO_3 (N4), seed priming+spray of 0.5% of 19: 19:19 NPK (N5) and seed priming+microbial treatment +2% urea at branching+2% DAP at flowering+0.5% KNO_3 at pod formation stages)] in sub–plot. Under *Utera* system, lentil seeds were broadcasted in standing crop of rice15 days before its harvest. Experiment was conducted in a split–plot design and replicated thrice. Results revealed that *Utera* system of lentil establishment produced grain yield (2.33 t/ha) at par to conventional tillage-CT (2.42 t/ha). The lowest yield was associated with ZT (2.19 t/ha). The combined application of seed priming+microbial treatments+2% urea at branching+2% DAP at flowering+0.5% KNO3 at pod formation stages had out yielded (2.82 t/ha) over rest of treatment combinations (Table 1). Hence, it may be concluded that growing of lentil in CT/*utera* along with combined application of seed priming+ microbial treatment+ 2% urea at branching+2% DAP at flowering+0.5% KNO_3 at pod formation stages is a viable option to the achieve the higher productivity for rice–fallow system in Eastern India.

Table 1. Seed yield (t/ha) of lentil as influenced by crop establishment methods and foliar nutrition

Treatment	Crop establishment methods			**Mean**
Foliar nutrition	*Utera*	ZT	CT	
Control (N1)	1.75	1.73	1.83	1.77
N1+2% Urea (N2)	2.16	1.90	2.16	2.07
N1+2% DAP (N3)	2.20	2.12	2.42	2.25
N1+0.5% KNO3 (N4)	2.38	2.21	2.53	2.37
N1+0.5% (19-19-19 NPK) (N5)	2.64	2.43	2.77	2.61
N1+N2+N3+N4+Microbes (N6)	2.87	2.74	2.84	2.82
Mean	2.33	2.19	2.42	2.32
LSD (P=0.05)	Crop establishment (E)		0.11	
	Foliar nutrition (N)		0.07	
	E×N		1.28	

1. Evaluation of crop establishment methods for improving the productivity of rice fallows:

A long-term study was initiated during the rainy season of 2016 at the ICAR RCER Patna to find out the most adaptable rice–winter crop rotations, appropriate crop establishment methods and residue management practices in rice–fallows. Treatment comprised of six levels of crop establishment methods and residue management (CERM) practices: zero–till direct seeded rice (ZTDSR), conventional–till DSR(CTDSR), puddle transplanted rice (PTR), ZTDSR with rice residue retention ($ZTDSR_{R+}$), CTDSR with rice residue retention ($CTDSR_{R+}$), PTR with rice residue retention (PTR_{R+}) and five post–rainy season crops *viz*. chickpea (Pusa 256), lentil (HUL 57), mustard (Proagro 5111), linseed (T 397) and safflower (PBNS 12) fitted in a split–plot design. Results revealed that pulses (lentil and chickpea) and safflower were the more productive over linseed and mustard in rainfed rice–fallows ecology. Average yield potential of winter crops were in the order of chickpea>lentil>safflower>mustard>linseed (Table 2 & 3). Rice productivity recorded the highest in PTR followed by CTDSR and lowest in ZTDSR irrespective of the residue management (Table 3). $ZTDSR_{R+}$ and ZTDSR treatments resulted in higher grain yield of all winter crops over PTR, being higher in chickpea, lentil and safflower.

Crop establishment and residue management (CERM) practices had significant ($p<0.05$) effect on productivity of winter crops. $ZTDSR_{R+}$ resulted in higher yields ($p<0.05$) of winter crops as compared to $ZTTR_{R+}$ and PTR_{R+}. Mean effect of CERM practices on winter crops followed the order $ZTDSR_{R+}$>ZTDSR>$CTDSR_{R+}$>CTDSR>PTR_{R+}>PTR. Effect of CERM treatment was most prominent on safflower followed by lentil, chickpea, and linseed; whereas the effect was marginal on mustard. $ZTDSR_{R+}$ increased productivity of chickpea, lentil, safflower, linseed and mustard by 70, 93, 191, 68 and 23 %, respectively, over PTR. Irrespective of winter crop, rice residue retention increased winter crop productivity by 12, 12 and 19 % in ZTDSR, CTDSR and PTR, respectively. Rice productivity was the highest in PTR system. Both CERM and winter crops treatments largely influenced the system productivity (SREY) in rice–fallow system (Table 4). $ZTDSR_{R+}$ in rice followed by chickpea, safflower and lentil led to higher system productivity, system production efficiency, and water productivity over CTDSR and PTR (with and without residue retention). Among CERM× winter crop treatments, the highest net returns was recorded in rice–safflower, rice–chickpea, and rice-lentil rotations with $ZTDSR_{R+}$ treatment over other CERM × winter crop combinations (Table 5).

Energy inflow was primarily influenced by CERM practices particularly with residue retentions. Conservation tillage treatments (ZTDSR) reduced energy, and maximum energy consumption was recorded with PTR_{R+} (79462–80124 MJ/ha). System net energy output (SNEO) was higher in non–residue retention treatments being higher in ZTDSR for rice–safflower (211241 MJ/ha) followed by rice–lentil (185443 MJ/ha) and rice–chickpea (180441 MJ/ha). A similar result was observed for system energy efficiency (Table 6).

Irrespective of CERM practices, a fast depletion of soil moisture content in 0–30 cm soil layer was observed up to 60 DAS and thereafter the rate of depletion of soil moisture content reduced. At the beginning of season, $ZTDSR_{R+}$ conserved 35 and 43 % higher soil moisture ($p<0.05$) than both $PTRZT_{R-}$ and $PTRZT_{R+}$, respectively; while it was at par with all other treatments. Trend was similar up to 90 DAS. After that difference in soil moisture content among treatments reduced drastically. $ZTDSR_{R+}$ and PTR_{R-} consistently had higher and lower moisture content, respectively, throughout the cropping period. Total soil moisture content from soil profile (0–30 cm) during crop growth period was significantly higher in treatments, where residues were retained and it was to tune of 4–5 % in 2017–2018 (Fig 1).

Table 2. Grain yield (t/ha) of winter crops (*Rabi* 2017–18) as influenced by crop establishment methods and residues management.

Establishment methods (E)	Winter crops (C)						LSD	
	Chickpea	Lentil	Safflower	Linseed	Mustard	Mean		
ZTDSR	1.66ab	1.61a	1.66b	0.80b	1.11a	1.37		
$ZTDSR_{R+}$	1.84a	1.76a	1.89a	1.04a	1.13a	1.53	E	0.11 (p<0.001)
CTDSR	1.28cd	1.14bc	0.95d	0.80b	0.95a	1.02	C	0.02 (p<0.001)
$CTDSR_{R+}$	1.46bc	1.17b	1.17c	0.86b	1.05a	1.14		
PTR	1.08d	0.91c	0.65e	0.62c	0.92a	0.83		
PTR_{R+}	1.21cd	1.05bc	0.75e	0.79b	1.14a	0.99		

Table 3.Grain yields of rice (t/ha) (*Kharif* 2018) as influenced by preceding crops (C), establishment methods 9E) and residues management (R)

Treatment	Winter crops (C)						LSD	
Establishment methods (E)	Chick pea	Lentil	Safflower	Linseed	Mustard	Mean		
ZTDSR-	3.58d	3.91bc	3.35c	3.57c	3.59c	3.60	E	0.50
ZTDSR+	3.75cd	3.64c	3.42c	3.55c	3.88bc	3.65	R	NS
CTDSR-	4.30bc	4.12bc	4.19b	3.97bc	3.77c	4.07	C	0.06
CTDSR+	4.48b	4.45b	4.24b	4.34b	4.47b	4.40		
PTR-	5.27a	5.48a	5.33a	4.99a	5.52a	5.32		
PTR+	5.65a	5.98a	5.85a	5.43a	5.86a	5.75		
Mean	4.50	4.60	4.40	4.31	4.51			

Table 4. System productivity and water productivity as influenced by crop establishment methods and residues management practices (2017-18)

Parameters	CERM practice	R–C	R–L	R–SF	R–Li	R–M	Mean	LSD (p=0.05)	
SREY (t/ha)	ZTDSR	9.26ab	9.07a	8.90b	7.34bc	7.41ab	8.40	E	0.46
	$ZTDSR_{R+}$	**9.97a**	**9.69a**	**9.79a**	**8.54a**	**7.81a**	**9.16**	C	0.12
	CTDSR	7.16d	6.84d	6.32d	6.55d	6.20c	6.61		
	$CTDSR_{R+}$	8.27c	7.79bc	7.37c	7.44bc	6.93bc	7.56		
	PTR	7.86cd	7.19cd	6.47d	6.94cd	7.17ab	7.13		
	PTR_{R+}	8.64bc	8.01b	7.25c	7.73b	7.83a	7.89		
	Mean	8.53	8.10	7.68	7.42	7.23			
SPE (kg/ha/day)									
	ZTDSR	25.00b	24.06b	20.44bc	20.26ab	7.41ab	19.43	E	1.21
	$ZTDSR_{R+}$	27.36a	26.40a	23.43a	21.60a	7.81a	21.32	C	0.35
	CTDSR	19.67d	18.71d	17.89d	17.01c	6.20c	15.90		
	$CTDSR_{R+}$	22.84bc	21.44c	19.98bc	18.77bc	6.93bc	17.99		
	PTR	21.50cd	19.32cd	18.76cd	19.38b	7.17ab	17.23		
	PTR_{R+}	23.14bc	21.07c	21.03b	21.87a	7.83a	18.99		
	Mean	23.25	21.83	20.26	19.81	7.23			
SWP (kg/ha/mm)									
	ZTDSR	5.78a	5.63a	5.58b	4.62a	4.62b	5.25	E	0.24
	$ZTDSR_{R+}$	6.07a	5.92a	6.02a	5.22a	4.83a	5.61	C	0.03
	CTDSR	4.37bc	4.03bc	3.69c	3.86bc	3.70d	3.93		
	$CTDSR_{R+}$	4.73b	4.24b	4.15c	4.09b	3.87c	4.22		
	PTR	3.71d	3.36d	3.01d	3.23c	3.30e	3.32		
	PTR_{R+}	3.87cd	3.65d	3.27cd	3.64bc	3.69e	3.63		
	Mean	4.75	4.47	4.29	4.11	4.00			

R–C: Rice–chickpea; R–L: Rice–lentil; R–SF: Rice–safflower; R–Li: Rice–Linseed, R–M: Rice–mustard, SREY: system rice equivalent yield, SPE: System production efficiency, SWP: system water productivity; E: crop establishment and residues management practices, C: winter crops. Different letters in column are significantly different at p < 0.05 according to DMRT.

Table 5. Production economics as influenced by crop establishment methods and residues management practices (2017-18)

Parameters	CERM practice	R–C	R–L	R–SF	R–Li	R–M	Mean	LSD (p = 0.05)	
SGR (000 ’	ZTDSR	164.15ab	151.342ab	153.5b	127.48bc	130.72ab	145.44	E	11.63

INR/ ha)	ZTDSR$_{R+}$	183.51a	169.018a	175.37a	150.38a	144.29a	164.51	C	1. 75
	CTDSR	137.71c	123.952d	115.43d	120.10c	116.19b	122.68		
	CTDSR $_{R+}$	149.23bc	134.018bcd	132.76c	126.45bc	122.03b	132.89		
	PTR	148.56bc	130.853cd	122.39cd	127.72bc	132.69ab	132.44		
	PTR $_{R+}$	155.05bc	143.725bc	130.12cd	142.43ab	141.95a	142.65		
	Mean	156.37	142.15	138.26	132.42	131.31			
SNR (000 ’ INR/ ha)	ZTDSR	100.97ab	96.73a	100.30b	74.38b	75.51ab	89.58	E	6. 20
	ZTDSR$_{R+}$	117.82a	110.70a	120.01a	92.95a	86.01a	105.50	C	1. 18
	CTDSR	68.70c	62.12b	55.88d	56.81c	52.77c	59.26		
	CTDSR $_{R+}$	78.21c	69.58b	71.18c	64.24bc	61.28bc	68.90		
	PTR	78.32c	70.24b	62.11cd	65.75bc	71.45ab	69.57		
	PTR $_{R+}$	84.86bc	78.74b	68.63cd	78.87ab	82.55a	78.73		
	Mean	88.15	81.35	79.69	72.17	71.60			
SBC R	ZTDSR	2.49a	2.56b	2.75b	2.28b	2.37ab	2.49	E	0. 18
	ZTDSR$_{R+}$	2.76a	2.87a	3.18a	2.73a	2.63a	2.84	C	0. 02
	CTDSR	1.84b	1.85d	1.83d	1.89c	1.83d	1.85		
	CTDSR $_{R+}$	2.07b	2.01cd	2.13c	2.06bc	2.01cd	2.05		
	PTR	2.07b	2.04cd	1.99cd	2.07bc	2.16bc	2.07		
	PTR $_{R+}$	2.15b	2.17c	2.10c	2.24b	2.35ab	2.20		
	Mean	2.23	2.25	2.33	2.21	2.23			

R–C: Rice–chickpea; R–L: Rice–lentil; R–SF: Rice–safflower; R–Li: Rice–Linseed, R–M: Rice–mustard; SGR: system gross returns; SNR: System net returns; SBCR: system benefit cost ratio, E: crop establishment and residues management practices, C: winter crops, Different letters in column are significantly different at *p* < 0.05 according to DMRT.

Table 6 Energy use efficiency as influenced by crop establishment methods and residues management practices (2017-18)

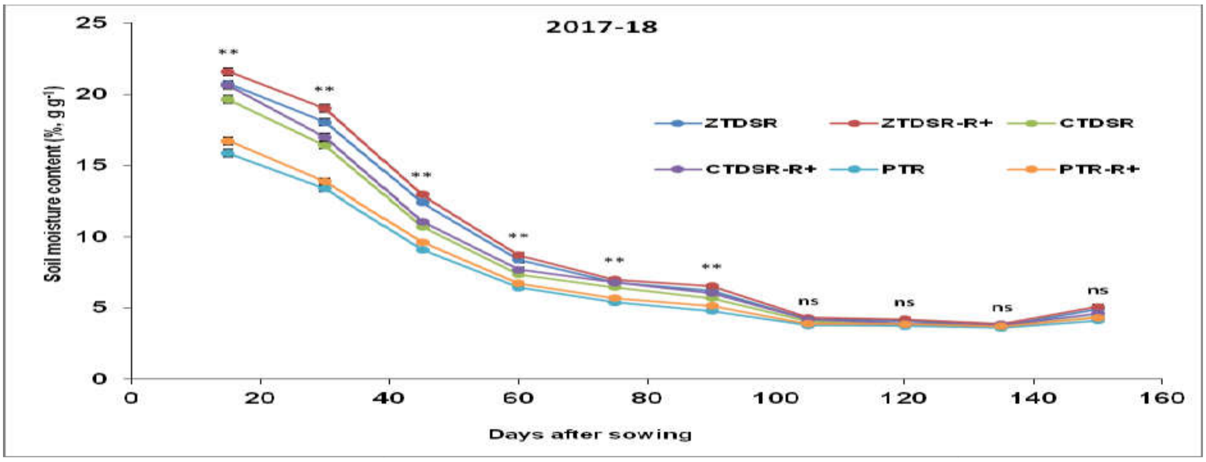
Para meter s	CERM practice	R–C	R–L	R–SF	R–Li	R–M	Mean	LSD (p =0.05)	
SEI (MJ/ ha)	ZTDSR	23117f	22455f	22491f	24064f	23109f	23047	E	NS
	ZTDSR$_{R+}$	68117b	67455b	67491b	69064b	68109b	68047	C	NS
	CTDSR	25768e	25106e	25142e	26715e	25760e	25698		
	CTDSR $_{R+}$	65768c	65106c	65142c	66715c	65760c	65698		
	PTR	28874d	28212d	28248d	29821d	28866d	28805		
	PTR $_{R+}$	**80124a**	**79462a**	**79498a**	**81071a**	**80116a**	**80055**		
	Mean	48628	47966	48002	49575	48620			
SEO MJ/h a)	ZTDSR	203558b	207898b	233732b	187279b	197820b	206058	E	150 23
	ZTDSR$_{R+}$	**229362a**	**230990a**	**262101a**	**215842a**	**221394a**	**231938**	C	206 3
	CTDSR	178390c	177498c	180716d	172809c	180573c	177997		
	CTDSR $_{R+}$	182116c	181296c	194883d	177542bc	186006bc	184369		
	PTR	217463ab	218229ab	214949c	205544a	218481a	214933		
	PTR $_{R+}$	219749a	218889ab	215081c	216703a	228649a	219814		
	Mean	205107	205800	216910	195953	205487			
SNE O (MJ/ ha)	ZTDSR	180441a	185443a	211241a	163215a	174711a	183010	E	150 23
	ZTDSR$_{R+}$	161245b	163535b	194610b	146778b	153285b	163891	C	206 3
	CTDSR	152622bc	152392bc	155574c	146094b	154813b	152299		
	CTDSR $_{R+}$	116348d	116190d	129741d	110827c	120246c	118670		
	PTR	**188589a**	**190017a**	**186700b**	**175722a**	**189614a**	**186129**		
	PTR $_{R+}$	139624c	139427c	135583d	135631b	148532b	139759		
	Mean	156478	157834	168908	146378	156867			

SER	**ZTDSR**	**8.81a**	**9.26a**	**10.39a**	**7.78a**	**8.56a**	**8.96**	E	0.42
	$ZTDSR_{R+}$	3.37d	3.42d	3.88c	3.13d	3.25d	3.41	C	0.07
	CTDSR	6.92c	7.07c	7.19b	6.47c	7.01c	6.93		
	$CTDSR_{R+}$	2.77e	2.78e	2.99d	2.66e	2.83e	2.81		
	PTR	7.53b	7.74b	7.61b	6.89b	7.57b	7.47		
	PTR_{R+}	2.74e	2.75e	2.71d	2.67e	2.85de	2.75		
	Mean	5.36	5.50	5.79	4.93	5.35			

R–C: **Rice–chickpea; R–L: Rice–lentil; R–SF: Rice–safflower; R–Li: Rice–Linseed, R–M: Rice–mustard; SEI: system energy input; SEO: system energy output; SNEO: system net energy output; SER: System energy ratio, E: crop establishment and residues management practices, C: winter crops, Different letters in column are significantly different at *p* < 0.05 according to DMRT.**

Fig. 1 Soil moisture content variation under various tillage and residue management practices during 2017–18; '' Denotes means of treatments are different at p<0.01 and 'ns' means non-significant**

Effect of different CA practices on yield of rice genotype



3 **Evaluation of CA practices under rice-fallow system of Eastern Region:**

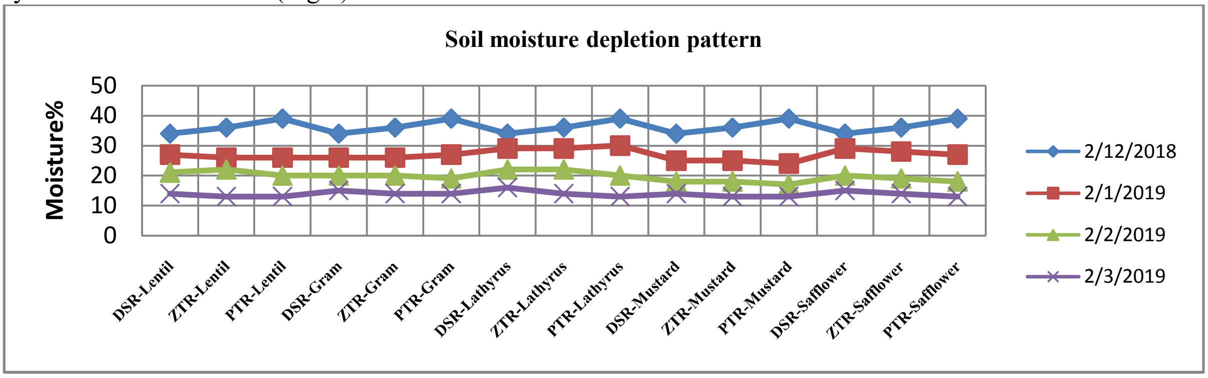
Three rice establishment methods *viz.* zero-till direct-seeded rice (ZT-DSR), ZT transplanting (ZT) and conventional (puddle) transplanting (CT) in main plot and five post–rainy season crops *viz.* lentil, chickpea, lathyrus, safflower and mustard in sub plot fitted in split–plot design were evaluated during 2018-19 at KVK Buxar, Bihar. Puddled transplanted rice produced higher grain yield of rice (5.16 t/ha) followed by zero till transplanted rice (4.83 kg/ha) and ZT-direct seeded rice (4.45 kg/ha). Rice equivalent yield (REY) had higher under ZT-DSR followed by ZT-ZTR and CT-PTR. System rice equivalent yield or system annual productivity was recorded maximum under CT-PTR (8.61 t/ha) followed by ZT-DSR and ZT-ZTR. In different crop grown under the systems safflower was produced maximum SEY (8.88 t/ha) and minimum under mustard (7.9 t/ha). Maximum net return and cost: benefit ratio was recorded under ZT-DSR. Among the winter crops, safflower had higher net return and cost: benefit ratio.

Table 7. Effect of crop establishment methods on rice equivalent yield, system equivalent yield and economics

Treatment	REY (t/ha)	SREY (t/ha)	Cost of cultivation (Rs/ha)	System net returns (Rs/ha)	System cost: benefit ratio
Crop establishment methods					
DSR	3.98	8.43	41420	106076	3.6
ZTR	3.59	8.42	45820	101548	3.2
PTR	3.45	8.61	47420	103327	3.2
LSD (P=0.05)	NS	NS	NS	NS	NS
Winter crops					
Lentil	3.25	8.07	45367	95774	3.12
Chickpea	3.99	8.80	50767	103229	3.04
Lathyrus	3.98	8.79	43267	110617	3.57
Mustard	3.09	7.90	41367	96907	3.35

Safflower	4.07	8.88	43667	111725	3.57
LSD (P=0.05)	0.15	0.33	1669	4063	0.13

Moisture depletion pattern: Moisture depletion pattern as influenced by different establishment methods and cropping system during the post rainy season. Maximum moisture depletion had recorded under PTR followed by ZT-TPR and ZT-DSR (Fig 2).



System equivalent yield

System equivalent yield (REL) recorded maximum under DSR-ZT safflower cropping system followed by DSR-ZT lathyrus and PTR-ZT chickpea. However minimum SEL was recorded under ZTR-ZT Mustard cropping system. Total net return was recorded maximum under DSR-ZT lathyrus followed by PTR-ZT safflower and DSR-ZT safflower cropping system. Minimum total net return (TNR) was recorded under ZTR-ZT lentil cropping system. CBR was recorded higher under DSR-ZT lathyrus cropping system.

Table 8. System equivalent yield and economics of different rice based cropping system

Cropping system	Actual yield (kg/ha)	Rabi season crop yield(kg/ha)	SEY (kg/ha)	Total net return (Rs/ha)	Cost benefit ratio
	Rice				
DSR-ZT Lentil	4450	1410	8055.6	99073	3.36
ZTR-ZT Lentil	4830	1215	7936.9	92596	3.00
PTR-ZT Lentil	5160	1190	8203.0	95653	3.00
DSR-ZT Chickpea	4450	1630	8753.2	105881	3.24
ZTR-ZT Chickpea	4830	1490	8763.6	101663	2.97
PTR-ZT Chickpea	5160	1410	8882.4	102142	2.92
DSR-ZT Lathyrus	4450	1785	8734.0	113045	3.84
ZTR-ZT Lathyrus	4830	1620	8718.0	108365	3.45
PTR-ZT Lathyrus	5160	1570	8928.0	110440	3.41
DSR-ZT Mustard	4450	1430	7882.0	100035	3.64
ZTR-ZT Mustard	4830	1250	7830.0	94725	3.24
PTR-ZT Mustard	5160	1180	7992.0	95960	3.19
DSR-ZT Safflower	4450	1510	8716.8	112345	3.79
ZTR-ZT Safflower	4830	1425	8856.6	110391	3.48
PTR-ZT Safflower	5160	1382	9065.1	112440	3.43
LSD (P=0.05)			942.0	11522.5	0.36

2.1.1.9 Crop Varities

Effect of different CA practices on yield of rice genotype (RCER)

Experimental Site 2: Kandora village, Kunkuri, Jashpur , Chhattisgarh

Results (Table 1) revealed that significantly the highest grain yield was recorded with the FPTR (3.07 t/ha) followed by ZTDSR–M (2.86 t/ha). Among rice genotypes, grain yield was significantly higher with Naveen (3.01 t/ha) closely followed by Lalat (3.00 t/ha).

Table 1. Effect of CA practices on yield attributes of rice in acid soils (*Kharif*)2018

Treatment	Panicles m^{-1} row (no.)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Harvest index
Rice establishment methods					
Farmer practice-PTR	41.75	3.07	3.17	6.24	0.49
ZTDSR–M	39.58	2.86	2.75	5.61	0.51
ZTDSR–NM	34.17	2.56	2.61	5.17	0.50
ZTTR–M	30.13	2.78	2.63	5.42	0.51
ZTTR–NM	26.50	2.64	2.55	5.18	0.51
SEm (±)	2.632	0.096	0.116	0.156	0.013

LSD (p≤0.05)	7.533	0.276	0.331	0.448	0.038
Genotypes					
Naveen	36.53	3.01	2.84	5.85	0.52
Lalat	34.30	3.00	2.83	5.82	0.51
IR 64	33.74	2.63	2.65	5.28	0.50
Sahabhagi dhan	33.12	2.49	2.65	5.14	0.48
SEm (±)	2.354	0.086	0.103	0.140	0.012
LSD (p≤0.05)	6.738	0.247	0.296	0.400	0.034

IIWBR

Screening of rice varieties for CA systems

Another experiment was conducted on evaluation of rice varieties suitable for CA system at two places at ICAR-IIWBR, research farm. Here two tillage crop establishment methods {P-TP (Puddling transplanting), ZT-TP (Zero tillage transpanting)} in main plot and twelve latest popular varieties of the area (HKR 47, HKR 48, HKR 128, Pusa 1509, NK 3325, Arize Swift Gold, Arize 6444 , CSR 30, PR 121, PR 126, PR 114 and S 786) in subplots replicated thrice were laid out during kharif season of 2018. The experiment was conducted in split plot design with a subplot size of 20 m^2. The transplanting of one month old seedling was done manually at a spacing of 20 cm x 15 cm. The fertilizer and irrigations were given as per the recommended practices and need of the crop. For control of weeds pre-emergence butachlor at 1250 g /ha and post emergence bispyribac sodium at 25 g/ha + ethoxysulfuron at 18 g/ha were applied.The crop was fertilized with 150 kg N, 60 kg P_2O_5 and 40 kg K_2O/ ha. Full P and K were applied as basal dose through 12:32:16 NPK mixture and muriate of potash. Whereas the remaining N was applied in two equal splits at 3 and 6 weeks after transplanting. The crop was irrigated as per the need.

The perusal of data in Fig revealed that the all the rice variety except basmati CSR 30 yielded less under ZT transplanting (ZT-TP) system compared to conventional puddle transplanting (P-TP) The overall mean rice yield of P-TP was 64.0 q/ha, whereas ZT-TP rice yield was 52.6 q/ha. If we see the individual performace of rice- varieties then the better yielder under both the system were Arize 6444 , Arize Swift Gold, HKR 128, PR 121, S 786 and PR 126. Among these two were hybrids (Arize 6444 and Arize Swift Gold). However, the genotypic differences were significant.

The results of the varietal evaluation suggest that there is need to breed and identify suitable varieties for aerobic system so as to fit in the rice-wheat system under CA.

Fig 1.Performance of rice varieties under puddle transplanting (P-TP) and Zero Tillage Transplanting (ZT-TP) conditions during 2018

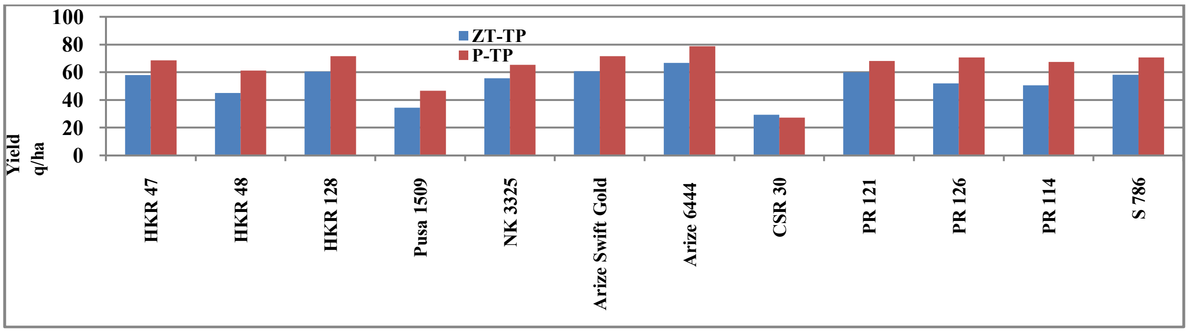
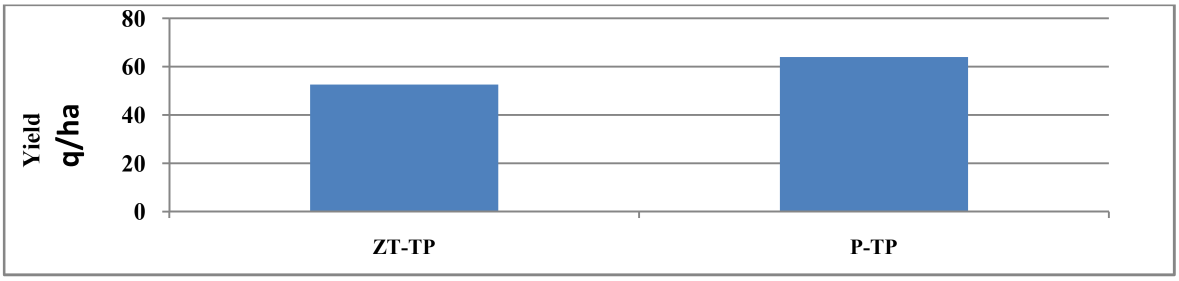


Fig 2.Performance rice under puddle transplanting (P-TP) and Zero Tillage Transplanting (ZT-TP) conditions during 2018



NRRI

Performance of promising rice varieties under conservation tillage vis-à-vis establishment methods
On-station experiment

A field experiment was started in 2017-18rabi (first year for rice variety identification under CA) to study the effect of different establishment methods on the promising rice varieties under conventional and zero/minimum tillage situations to identify and recommend suitable rice variety for conservation agriculture. The experiment was laid out in a split-factorial plot design with two establishment methods i.e. DSR and TPR, two tillage systems i.e. conventional (CT) and zero tillage (ZT) in main plots 1 and 2, respectively.The sub plot consisted of two residue management systems i.e. no residue incorporation and residue incorporation as sub-plot 1 and, 10 rice varieties as sub-plot 2. The varieties viz., CR Dhan 201, CR Dhan 202, CR Dhan 203, CR Dhan 204, CR Dhan 300, CR Dhan 303, CR Dhan 304, CR Dhan 305, Swarna and Naveen used in the experiment to study their relative performance.
The experiment was repeated in Kharif 2018. The yield under DSR was at par with TPR. The difference between ZT and CT was found to be non-significant. Also, no increase in yield was recorded due to residue incorporation compared to no residue incorporation. However, the difference among the varieties was significant. Rice variety 'Naveen' recorded maximum average yield (6.29 t/ha) followed by CR Dhan 203 (6.15 t/ha). CR Dhan 201 recorded lowest yield (5.3 t/ha). Swarna, CR Dhan 303, 304 and 305 recorded yields at par with 5.94, 5.93, 5.92, 5.91 t/ha, respectively. Under ZT treatments, CR Dhan203 recorded the highest yield (6.5 t/ha) in DSR, and Naveen recorded the highest yield (6.7 t/ha) in TPR among the varieties.

Activity: Performance evaluation of green gram varieties under conservation agriculture
On-station experiment

Field experiment was carried out to study the effect of different establishment methods of rice in *Kharif* season on the succeeding green gram varieties in *rabi* season under conventional and zero/minimum tillage conditions to identify and recommend suitable green gram variety for conservation agriculture.

Among the growth parameters, the number of branches per plant recorded significant difference under different tillage practices (Table 1). The other parameters viz., plant height and dry matter accumulation did differ significantly at 60 days after emergence (DAE) when compared among different tillage practices. Though statistically non-significant, the zero tillage transplanted rice (TPR-ZT) recorded highest plant height and dry matter accumulation followed byconventional tillage (CT).The green gram varieties recorded significant differences in terms of plant height, dry matter accumulation and number of branches and followed the order: IPM 2-3> IPM 02-14> Landrace. Study on root development suggest that root length (cm), root volume (cm^3) and root density (cm^{-2}) did not vary significantly among the green gram varieties at 45 DAE (Table 2). However, the maximum number of nodules were recorded in IPM 2-3 which was at par with IPM 02-14. Landrace recorded significantly lower number of nodules. Among the tillage practices, DSR-ZT recorded significantly higher number of treatments compared to TPR-ZT and CT.

Table 1. Plant height (cm) and Dry matter accumulation (g/plant) at 15, 30, 45 and 60 DAE as influenced by treatments. The between the means of treatment is separated by least significant difference (LSD)at 5% level of significance

	15 DAE			30 DAE			45 DAE			60 DAE		
	Plant height (cm)	Dry matter accumulation (g/ plant)	Number of branches plant^{-1}	Plant height (cm)	Dry matter accumulation (g/ plant)	Number of branches plant^{-1}	Plant height (cm)	Dry matter accumulation (g/ plant)	Number of branches plant^{-1}	Plant height (cm)	Dry matter accumulation (g/ plant)	Number of branches plant^{-1}
Tillage practices (T)												
TPR-ZT	13.16 B	0.52B	-	16.14 B	1.24	2.81A B	36.99 B	10.14	4.22A B	45.81	12.27	5.00B
CT	14.17 A	0.59AB	-	18.30 A	1.31	3.53A	40.17 A	10.28	4.62A	44.89	11.72	5.88A
DSR-ZT	11.83 C	0.63A	-	15.60 B	1.35	2.40B	40.01 A	9.79	3.60B	44.87	11.37	4.95B
LSD(P≤0.05)	0.599	0.098	-	0.613	NS	0.870	1.882	NS	0.698	NS	NS	0.590
Mung bean varieties (M)												
IPM 2-3	13.40 B	0.67A	-	16.62 B	1.14B	2.66	39.77 A	10.24AB	4.13A	46.64 A	12.16A	5.62A
IPM 02-14	14.71 A	0.61A	-	17.52 A	1.57A	2.90	36.75 B	10.28A	4.00A B	43.89 B	11.89AB	5.28AB
Local Check	11.05 C	0.46B	-	15.90 C	1.20B	3.17	36.65 B	9.69B	3.94B C	45.04 B	11.31B	4.93B
LSD (P≤0.05)	0.758	0.083		0.656	0.268	NS	1.722	0.562	0.231	1.257	0.826	0.52
Interaction (P≤0.05)												
T*M	0.0002	0.0234	-	0.0001	0.5516	0.0424	0.0852	0.0273	0.0037	0.0379	0.0654	0.0008

Table 2. Root length (cm), root volume (cm^3), root density (cm^{-2}) and number of nodule count/ plant at 30 and 45 DAE as influenced by treatments. The difference between the means of treatment is separated by least significant difference (LSD) at 5% level of significance.

	30 DAE				45 DAE			
	Root length(cm)	Root volume (cm^3)	Root density (cm^{-2})	Nodule count/plant	Root length(cm)	Root volume (cm^3)	Root density (cm^{-2})	Nodule count/plant
Tillage practices (T)								
TPR-ZT	25.58B	0.101AB	301.09AB	17.33B	160.51B	0.47	336.85	25.44C
CT	34.49A	0.164A	222.64B	22.00A	164.67B	0.51	304.15	36.55B
DSR-ZT	29.75AB	0.078B	415.56A	15.11B	226.08A	0.66	355.19	42.11A
LSD (P≤0.05)	9.049	0.065	133.6	3.970	43.523	NS	NS	4.999

Mung bean varieties (M)								
IPM 2-3	27.85AB	0.103	281.81	19.22A	180.45	0.54	331.55	38.44A
IPM 02-14	26.86B	0.114	291.49	13.55B	189.04	0.53	344.31	36.33A
Local Check	35.10A	0.125	366.00	21.66A	181.77	0.58	320.32	29.33B
LSD (P≤0.05)	7.329	NS	NS	4.225	NS	NS	NS	2.32
Interaction (P≤0.05)								
T*M	0.0603	0.0140	0.5212	0.0044	0.0164	0.1357	0.7197	0.0001

Table 3. Yield and yield attributes of mung bean as influenced by treatments. The difference between the means of treatment is separated by least significant difference (LSD) at 5% level of significance.

	Number of pods plant^{-1}	Number of seeds plant^{-1}	100 seed weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
Tillage practices (T)						
TPR-ZT	31.37	12.00	3.42	775.78	2542.22	0.22AB
CT	35.76	12.12	3.43	834.94	2540.13	0.24A
DSR-ZT	30.57	12.24	3.37	746.76	2640.59	0.21B
LSD (P≤0.05)	NS	NS	NS	NS	NS	0.029
Mung bean varieties (M)						
IPM 2-3	34.53A	12.33A	3.45B	835.07B	2810.6A	0.22B
IPM 02-14	32.96A	12.30A	4.31A	974.22A	2734.4A	0.26A
Local Check	30.22B	11.93B	2.46C	548.18C	2178.0B	0.19C
LSD (P≤0.05)	2.626	0.204	0.084	62.964	280.17	0.0264
Interaction (P≤0.05)						
T*M	0.0052	0.0005	0.2851	0.0247	0.0277	0.9638

2.1.2 To Quantify the impact of resource conservation options on the physical, chemical and biological soil health

2.1.2.1 Soil Physical properties

CRIDA

Quantified impact of CA on soil health, input use efficiency, carbon sequestration and Greenhouse gas emissions

The soil physical (Soil BD, infiltration rate, hydraulic conductivity, penetration resistance aggregate stability, total porosity soil temperature, etc.), chemical (OC, POC, carbon fractions, N P K) biological properties (enzyme activities), soil, water and nutrient losses and GHG estimations were estimated in different systems periodically to study the impact of CA on soil health , GHG emissions and carbon sequestration rate.

1) Physical properties of soil

In Pigeonpea – castor cropping system the soil hydraulic conductivity (HC) was 8 and 6 % higher in zero tillage at sowing as compared to CT & RT but at harvest CT recorded 10 % higher HC then RT and ZT. Residues increased the HC by 20 and 25 % as compared to zero residues at both sowing and harvest. The soil bulk density in zero tillage decreased only up to 7.5 cm. But the bulk density increased in ZT after 7.5 cm.

In Finger millet + Pigeonpea system (8:2) the particle density, MWHC, porosity, pH, EC were not significantly influenced by tillage and residue treatments (Table 1). Interaction effect between different tillage and cover crop was found to be significant with particle density but non-significant with others. Tillage practices and nitrogen levels influenced the soil total porosity. A higher soil total porosity was observed under NT followed by RT and CT (Fig 10b). A 15.92 and 8.13% higher soil total porosity was observed under NT and RT as compared to the CT. In NT, 7.21% higher soil total porosity was observed as compared to the RT. The nitrogen levels i.e., N_{75}, N_{100} and N_{125}, improved the soil total porosity to a tune of 6.17, 10.08 and 12.09%, respectively as compared to the N_0 (Fig 1b).

Table 1: Soil physical parameters as influenced by conservation agriculture practices in finger millet+ pigeon pea intercropping (8:2)

Treatment	Bulk Density	Particle Density	MWHC	Porosity
	g/cc		(%)	
TILLAGE				
M_1 :Conventional tillage	1.35	3.09	29.79	52.38
M_2 : Reduced tillage	1.43	3.10	29.02	51.02
M_3 :Zero tillage	1.45	3.20	26.63	50.75
S. Em. ±	**0.03**	**0.06**	**0.95**	**0.77**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**
COVERCROPS				
C_1: Control	1.47	3.18	27.93	50.97
C_2: Field bean (HA-4)	1.39	3.10	29.10	51.57
C_3: Horse gram	1.38	3.11	28.40	51.61
S. Em. ±	**0.03**	**0.03**	**0.58**	**0.54**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**
INTERACTIONS				
M_1C_1	1.37	3.18	28.65	51.54
M_1C_2	1.39	3.22	29.26	52.65
M_1C_3	1.29	2.89	31.46	52.96
M_2C_1	1.48	3.00	28.21	50.71
M_2C_2	1.38	3.08	30.21	51.71
M_2C_3	1.44	3.21	28.62	50.66
M_3C_1	1.55	3.36	26.93	50.66
M_3C_2	1.41	3.01	27.84	50.37
M_3C_3	1.40	3.24	25.12	51.21
S. Em. ±	**0.05**	**0.06**	**1.01**	**0.93**
CD (p=0.05)	**NS**	**0.17**	**NS**	**NS**

In Maize-Pigeonpea system, the soil moisture content was influenced by the different tillage practices. NT and RT recorded 8.60 and 3.80% higher soil moisture as compared to CT respectively in 0-15 cm soil layer, during entire maize crop growing season. Whereas NT recorded 4.63% higher soil moisture as compared to the RT in 0-15 soil layer (Fig 1 a). In 15-30, 30-45 and 45-60 cm depth, NT and RT recorded 12.21 and 4.99; 13.69 and 5.36; and 16.03 and 4.90% higher soil moisture respectively as compared to the CT. NT recorded 6.87, 7.90 and 10.61% higher soil moisture over the RT in 15-30, 30-45 and 45-60 cm soil layer, respectively. In 0-30 cm and 30-60 cm soil layer, about 10.50 and 4.43; 14.85 and 5.13% higher soil moisture content was recorded in NT and RT as compared to the CT. NT recorded 5.82 and 9.25% higher soil moisture in 0-30 cm and 30-60 cm depth respectively as compared to the RT. In 0-60 cm soil layer 12.78 and 4.80% higher soil moisture was observed in NT and RT, respectively as compared to the CT, Similarly NT recorded the 7.62% higher soil moisture as compared to the RT in 0-60 cm soil layer during entire maize crop growing season (Fig 1b).

The soil moisture content in different soil layers was influenced by nitrogen application. N_{75}, N_{100} and N_{125}, registered 1.25, 2.45 and 3.38% lower soil moisture in 0-15 cm soil layer as compared to N_0 respectively (Fig 1c). At 15-30, 30-45 and 45-60, 1.24, 2.25 and 2.97%; 0.84, 1.57 and 2.25; 0.68, 1.23 and 1.50% lower soil moisture was observed in N_{75}, N_{100} and N_{125} respectively. In 0-30 cm and 30-60 cm soil layer, 1.25, 2.18 and 3.00% and 0.76, 1.40 and 1.88% lower soil moisture was observed in N_{75}, N_{100} and N_{125}, respectively as compared to 0 cm. Over all, in 0-60 cm soil layer 0.99, 1.85 and 2.48% lower soil moisture was observed in N_{75}, N_{100} and N_{125} (Fig 1d)

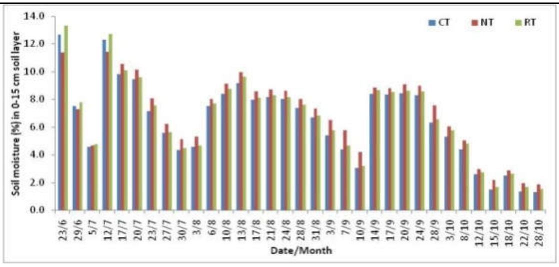


Fig 1 a. Effect of tillage practices on soil moisture (%) in 0-15 cm soil layer.

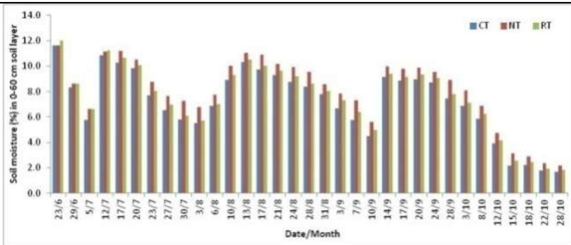


Fig 1 b. Effect of tillage practices on soil moisture (%) in 0-60 cm soil layer.

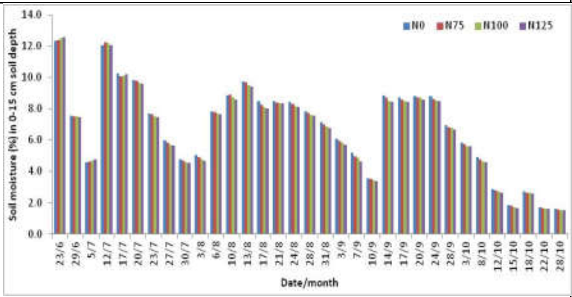


Fig 1 c. Effect of nitrogen levels on soil moisture (%) in 0-15 cm soil layer.

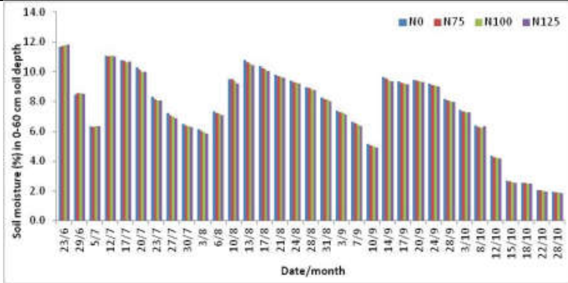


Fig 1 d. Effect of nitrogen levels on soil moisture (%) in 0-60 cm soil layer.

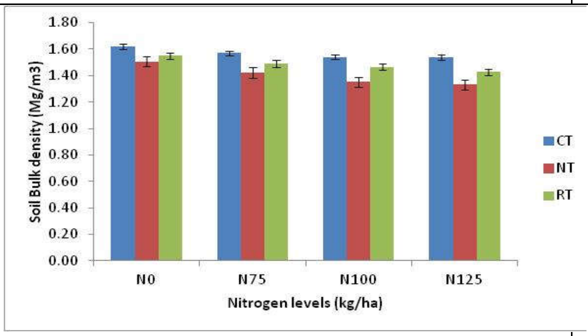


Fig 2a. Effect of tillage practices and nitrogen levels on soil bulk density in 0-15 cm soil layer.

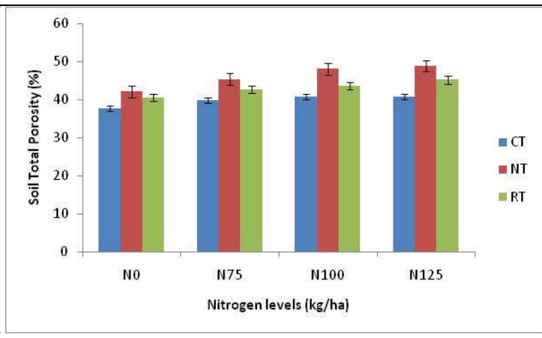


Fig 2b. Effect of tillage practices and nitrogen levels on soil total porosity in 0-15 cm soil layer.

Both tillage practices and nitrogen levels influenced the soil bulk density in 0-15 cm soil layer. About 10.5% and 5.4% lower bulk density was observed in NT and RT, respectively as compared to the CT (Fig 2a). In NT, about 5.43% lower bulk densities were observed as compared to the RT. The nitrogen levels i.e., N_{75}, N_{100} and N_{125} decreased the soil bulk density to a tune of 4.13, 6.74 and 8.09%, respectively as compared to the N_0 (Fig 2b).

IIFSR

Effect of CA practices on organic carbon and bulk density of soil: As indicated in table 09, 7.14 per cent higher organic carbon content was noted under CA practices as compared to initial value of organic carbon (0.42%) likewise reduction in bulk density to the tune of 3.84% was recorded under CA conditions as compared to initial value of bulk density (1.62 g/cc).

Table 2: Effect of CA practices on organic carbon and bulk density of soil

Cropping System	Bulk Density (g/cc)			OC (%)		
	CA	CP	Av.	CA	CP	Av.
Rice- wheat- green gram	1.55	1.56	1.56	0.44	0.42	0.43
Rice- wheat- sesbania	1.56	1.63	1.59	0.45	0.42	0.43
Maize (cob)- pea (veg)-wheat-cowpea (pod)	1.56	1.60	1.58	0.44	0.43	0.44
Sugarcane-ratoon- wheat	1.56	1.58	1.57	0.45	0.42	0.44
Average	**1.56**	**1.59**		**0.45**	**0.42**	

IARI

Soil Health

Considerable improvement was observed in soil physical properties (soil aggregation/aggregate associated C, N, P, MWD, water stable aggregates; reductions in bulk density , penetration resistance & compaction, Soil temperature and NDVI/Greenness). Soil chemical properties also showed improvement (SOC, soil N, P, K, micronutrients and S) alongwith improvement in biological properties (Soil microbial biomass, SMBC, DHA, FDA, Glomalin, acid/alkaline phosphatase).

Table 3. SOC and aggregate stability increase (%) in CA based systems compared to corresponding CT treatments

Cropping System	SOC increase (%)	Increase in Aggregate Stability (%)
Rice-wheat (with mung-bean)	20.2-22.4	33.8-37.6
Cotton-wheat	11.2-13.6	9.9-12.1
Pigeon pea –wheat	9.0-11.0	4.3-5.3
Maize –wheat	34.1-37.9	24.4-27.1

With continued CA practises, soil health of major cropping systems radically improved as observed in terms of increase in soil organic carbon (SOC). Maximum SOC increase of 34-38% was observed in maize-wheat cropping system followed by 20% SOC increase in triple zero till rice-wheat-mungbean system (Table 3). The CA based cotton-wheat and pigeonpea-wheat systems also showed comparable increase in SOC over the years. The maximum increase in aggregate stability of 33.8-37.6% was observed in triple ZT rice-wheat-mungbean system, followed by about 24.4-27.1% in CA based maize-wheat system.

i) Wheat based CA systems

After eight year of continuous CA based practices. it was observed that there was improvement in the **mean weight diameter (MWD)** of water stable aggregates compared to the CT system at 0-5 cm soil depth by 14.6, 31.8 and 14.7% in the cotton-wheat, maize-wheat and pigeon pea-wheat system, respectively (Table 4). Among the CA systems retention of crop residues could improve the MWD by 13.2, 32.8 and 13.9% in the cotton-wheat, maize-wheat and pigeon pea-wheat system, respectively. Across the cropping systems, Zero tillage flat bed with residue retention registered the highest MWD at 0-5 cm soil depth. The percentage of water stable aggregates (WSA) under CA increased by 3.4% compared to CT at 0-5 cm soil depth (Table 4). Among the CA systems, retention of residues could improve the WSA by 8.3% at 0-5 cm soil depth. There was decrease in the BD at 0-5 cm soil depth by 7.5, 0.4 and 0.8% under CA in the cotton-wheat, maize-wheat and pigeon pea-wheat system, respectively (Figure 3). In the CA system retention of residue further reduced the BD compared to residue removal in all the three cropping systems. The maximum water holding capacity (MWHC) of soil at 0-5 cm soil depth increased under CA by 9.9, 4.1 and 1.9% in the cotton-wheat, maize-wheat and pigeon pea-wheat system, respectively (Table 5). Retention of residues in CA system improved the MWHC of soil in all the three cropping systems.

Table 4. Mean weight diameter (mm) and water stable aggregates (%) under conservation and conventional agriculture practices at 0-5 cm soil depth after wheat 2018.

	Cotton-wheat		Pigeon pea-wheat		Maize-wheat		Mean	
	MWD (mm)	WSA (%)	MWD (mm)	WSA (%)	MWD (mm)	WSA (%)	MWD (mm)	WSA (%)
Zero tillage (ZT)	0.77	60.7	0.77	52.7	1.05	56.8	0.86	56.7
ZT + Residue	0.92	59.3	0.84	58.8	1.48	60.1	1.08	59.4
Broad bed (BB)	0.64	52.2	0.77	49.8	1.03	67.5	0.81	56.5
BB + Residue	0.71	58.5	0.91	53.4	1.12	66.5	0.91	59.4

Narrow bed (NB)	0.79	50.1	0.97	56.9	0.77	60.8	0.84	55.9
NB + Residue	0.85	58.8	1.11	65.5	1.19	61.5	1.05	61.9
Flat Bed	0.68	54.7	0.78	68.7	0.84	67.3	0.77	63.6
Mean	0.77	56.3	0.88	58.0	1.07	62.9	0.90	59.1

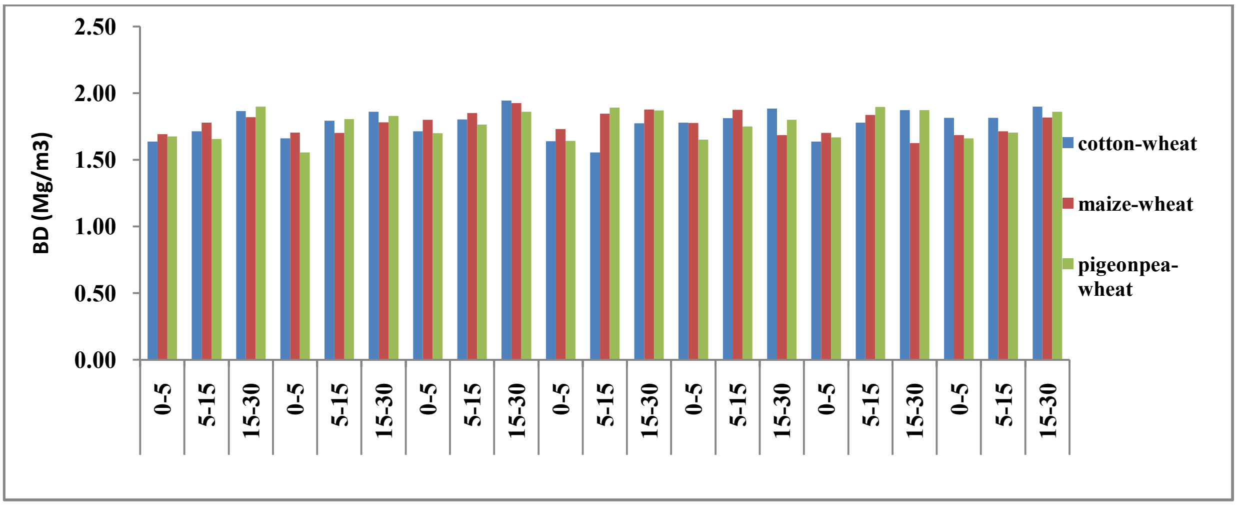


Fig. 3. Bulk density of soil as influenced by conventional and conservation agriculture practices in cotton-wheat, maize-wheat and pigeon pea-wheat system

Table 5 Maximum water holding capacity of soil under conservation and conventional agriculture practices at 0-5 cm soil depth after wheat 2018.

	Cotton-wheat	Pigeon pea-wheat	Maize-wheat	Mean
Zero tillage (ZT)	52.8	55.1	56.9	54.9
ZT + Residue	56.9	58.5	63.7	59.7
Broad bed (BB)	50.5	50.0	60.9	53.8
BB + Residue	62.2	53.6	59.4	58.4
Narrow bed (NB)	52.5	57.0	61.5	57.0
NB + Residue	55.4	59.1	59.7	58.1
Flat Bed	50.1	54.5	58.0	54.2
Mean	54.3	55.4	60.0	56.6

ii) Improvement in root growth under CA

The 7-year continuous field experimentation under CA in rice-wheat rotation revealed reduction in the sub-surface soil strength due to lowering in bulk density (Figure 4) and higher water content at this layer as evidenced by decrease in cone penetration resistance (Figure 5).

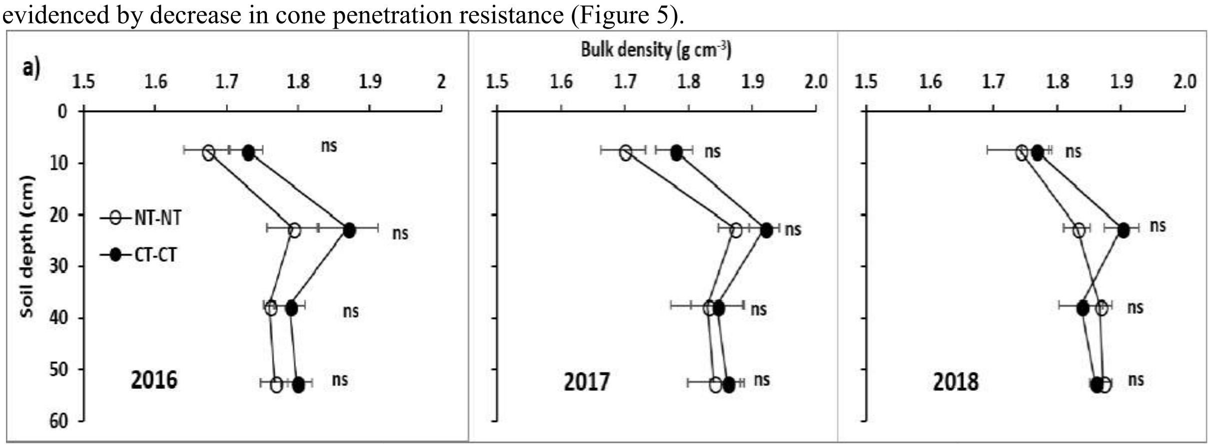


Fig. 4. Bulk density of soil under conventional *vis-à-vis* conservation agriculture practice in rice-wheat system

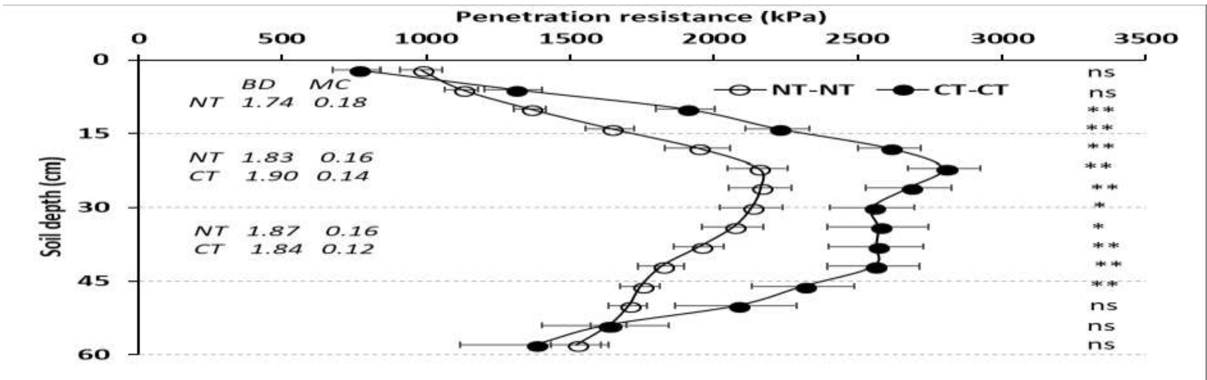


Fig. 5. Cone penetration resistance under conventional *vis-à-vis* conservation agriculture practice in rice-wheat system

Greater total porosity and relatively greater relative proportion of micro-pores ensured higher soil water retention in CA in the subsurface layer. The infiltration rate was higher and sorptivity was lower under CA than conventional tillage system (Figure 6).

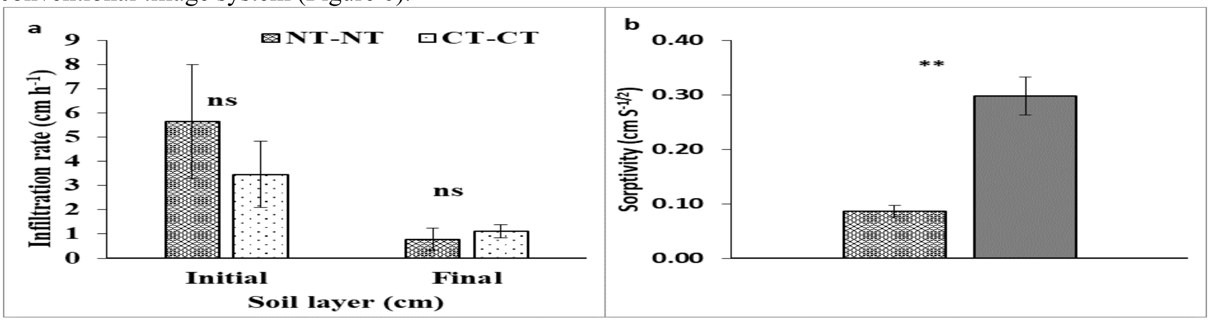


Fig. 6. Infiltration rate and sorptivity under conventional and conservation agriculture practices

Root growth significantly improved, and so the morphological parameters changed in favour of CA especially in subsurface, which was essentially a compact layer (>2.5 MPa cone index value) (Figure 12). HYDRUS 2D simulation firmly captured difference in evaporation, root water uptake and drainage out of root zone. Better crop growth and residue mulch in CA reduced the evaporation loss to a large extent. Root water uptake was 14-17% higher in CA than CT practice (Figures 8 a & b).

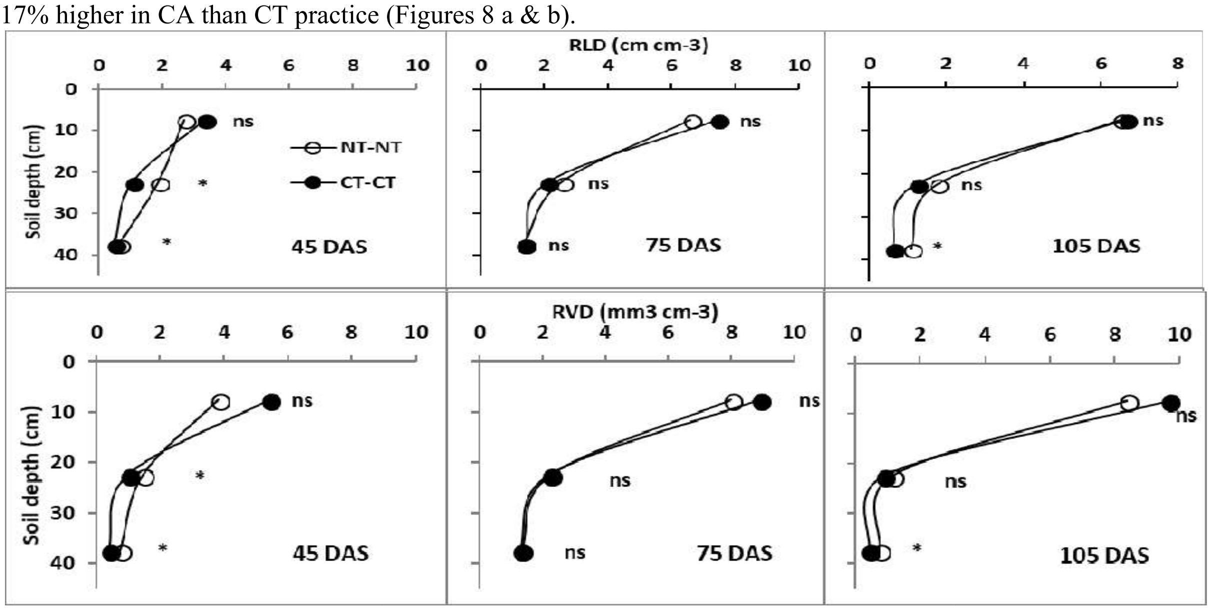


Fig. 7a&b. Root length density and root volume density of wheat under conventional and conservation agriculture practices in rice-wheat system

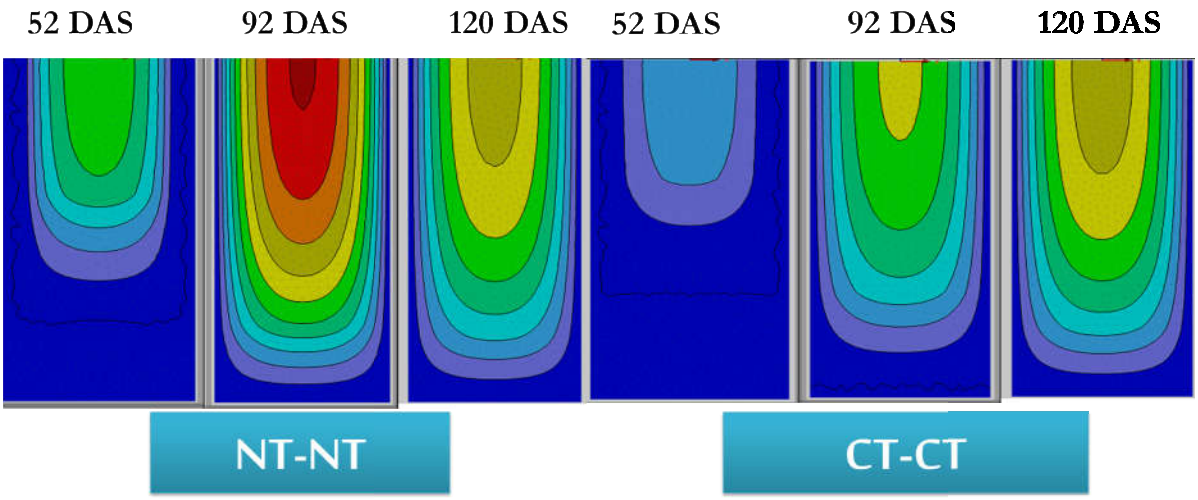


Fig. 8. Simulation of root water uptake by wheat under conservation (a) and conventional (b) agriculture practices in rice-wheat system using HYDRUS-2D model

In a similar study under maize-wheat-mungbean system, quantification of maize root systems indicated that CA-based practices promoted better root growth and proliferation compared to CT treatment (Table 6; Figure 9). Root length, mass and volume were significantly higher under the permanent broad-, flat- and narrow-beds with residue compared to CT. These CA-based practices greatly improved yield attributes such as cobs per plant, grains per cob, and test weight of maize and gave significantly higher cob yield compared to CT. The CA-based practices increased maize yields by 7.9-12.7% over CT. Among these, the permanent broad bed with residue (PBB+R) was most superior and gave highest grain yield of maize (7.1 t/ha).

Table 6. Root growth (up to 30 cm depth) and yield of maize under CA-based treatments

Treatment	Root length density (cm/cm^3)	Root mass density (mg/cm^3)	Root volume density (cm^3/cm^3)	Maize yield (t/ha)
CT (Conventional tillage)	0.95	3.66	0.006	6.30
ZT permanent narrow-bed with residue (PNB+R)	1.11	3.88	0.007	6.83
ZT permanent broad-bed with residue (PBB+R)	1.99	4.67	0.013	7.13
ZT flat-bed with residue (FB+R)	1.20	4.44	0.008	7.01
LSD (P=0.05)	0.15	0.62	0.0003	0.51

Fig. 9

iii) Meta analyis

Global data synthesis (meta-analysis) revealed an overall improvement in soil physical condition though conservation tillage practice. Change in soil bulk density due to conversion to CA system was not significant in shorter time period (Figure10). However,significantly higher mean weight diameter of soil aggregates, water retention at field capacity, and infiltration rate confirmed fundamental benefit from CA over the conventional tillage. The meta-analysis of global data set further revealed that soil organic C (SOC) content had a large difference in the surface, and significantly decreased down the profile, whereas SOC stock (0-60 cm) was marginally lower (1.1% only) in CA (Figure 11). It can be inferred from the meta-analysis that root length density of crops was significantly higher in the top 0-5 cm soil layer due to improved soil physical environment.

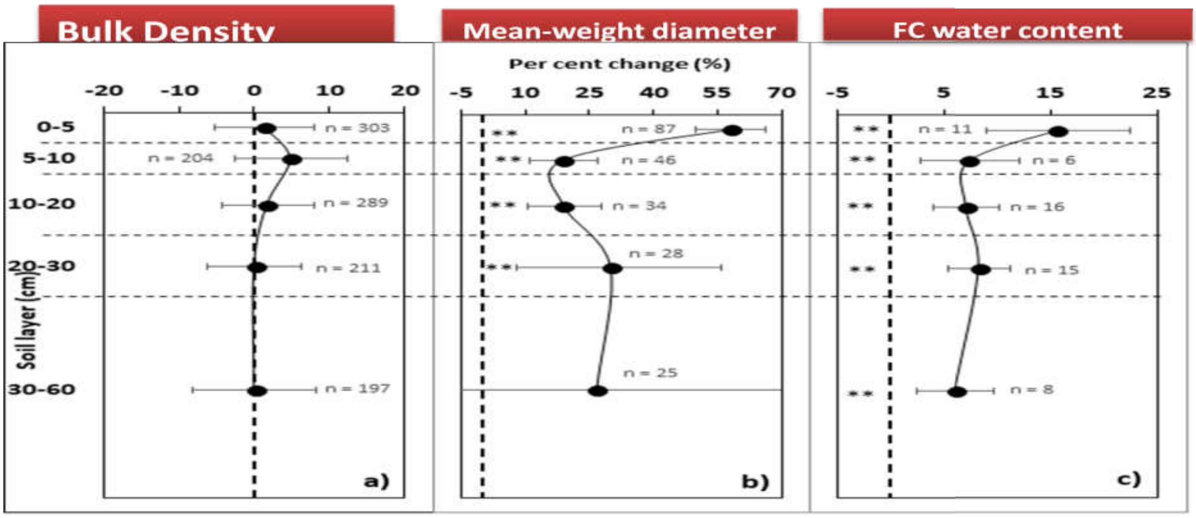


Fig. 10. Meta analysis of soil physical properties under conventional and conservation agriculture practices

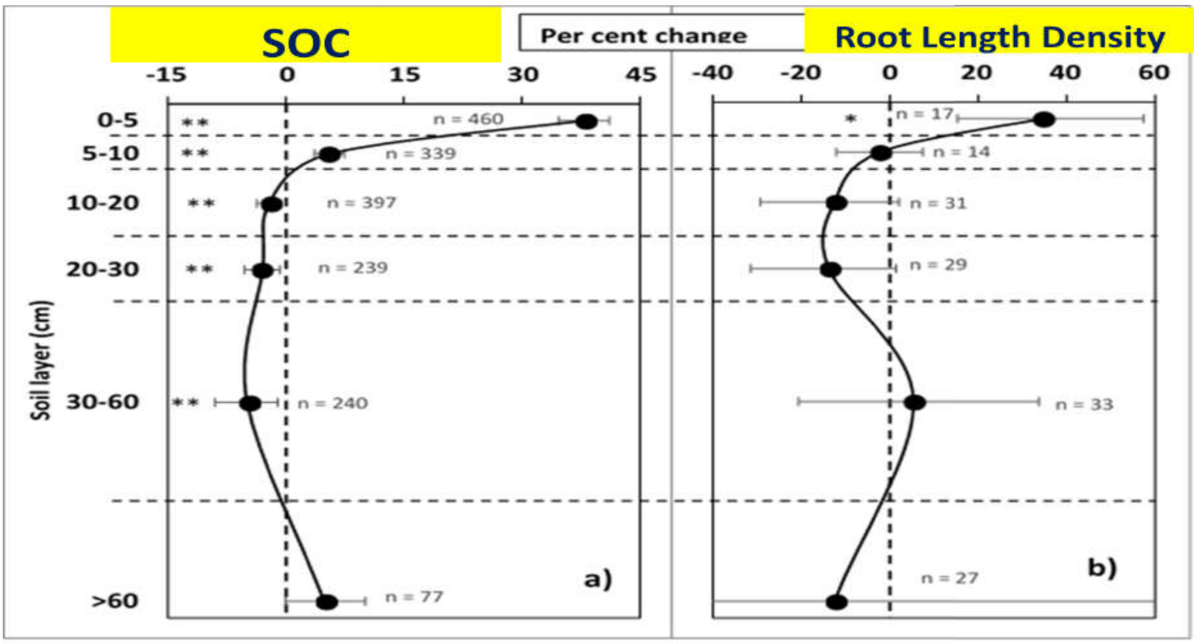


Fig. 11. Meta analysis of soil organic carbon and root growth under conventional and conservation agriculture practices

NIASM

Effect of trash, fertilizer-nitrogen and SORF techniques practices on soil properties:

Adoption of SORF techniques along with surface retention of chopped trash and influenced the soil properties significantly ($P \leq 0.05$) over conventional farmers' practices of trash burning and broadcast application of fertilizers. The significantly lower values of bulk density was recorded under surface retention of trash and SORF techniques (CT+SORF) as compared to trash burnt/ removed and control treatments (No-trash + No-N) in surface (0-15 cm) (Fig. 12). However, different practices of trash, fert-N and ratoon management did not influence the soil bulk density in sub-surface (15-30 cm) soil layer.

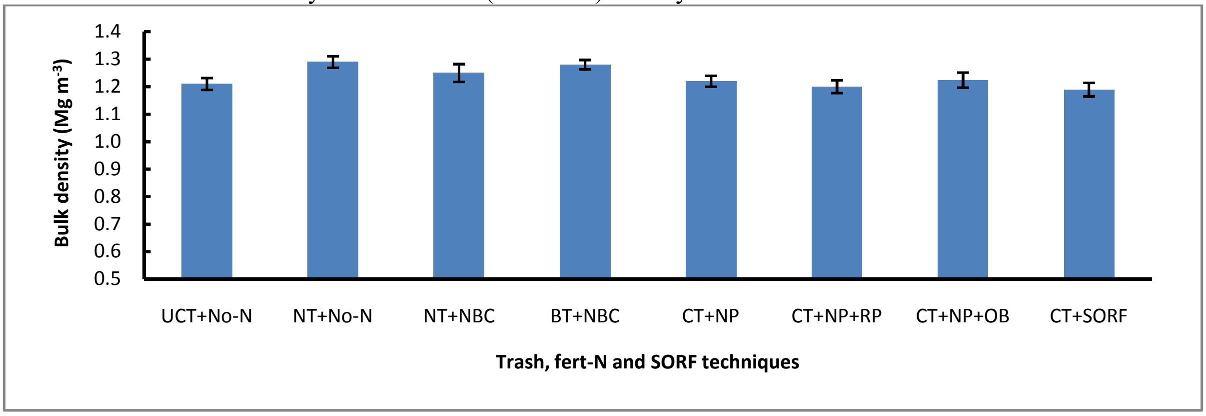


Fig. 12. Effect of trash, fert.-N and SORF techniques on bulk density in 0-15 cm soil layer.

Soil organic carbon content (SOC) in 0-15 cm soil layer build-up was noticed under the trash retained treatments. The maximum SOC content was recorded under CT+SORF treatment which was closely followed by other chopped trash + N placement treatments. Surface retention of chopped trash improved the SOC content by 6-17 % over un-chopped trash/trash removal or trash burnt treatments (Fig. 13). Surface retention of trash and other ratoon management practices did not influence the SOC content in 15-30 cm soil layer.

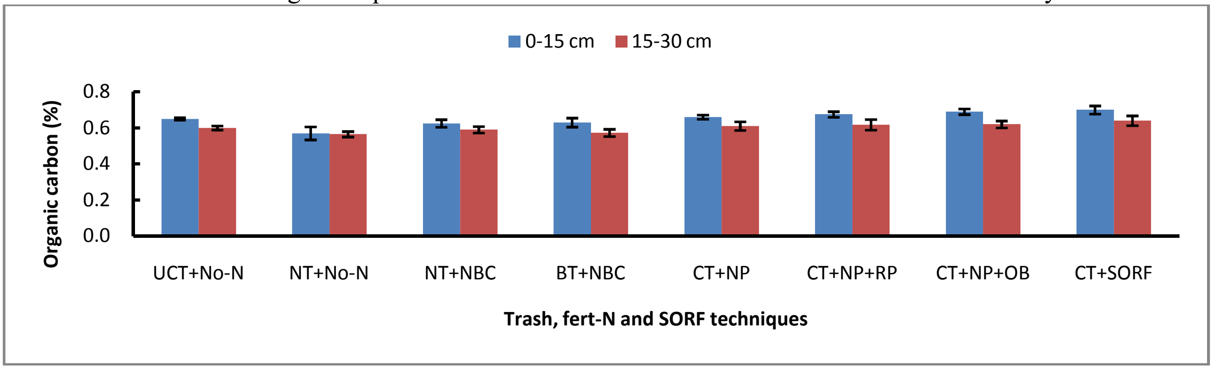


Fig. 13. Effect of trash, fert.-N and SORF techniques on organic carbon content in surface (0-15 cm) and subsurface (15-30) cm soil layers.

In current climate change scenario whole world is focusing on the technologies for decreasing greenhouse gas emission and environmental degradation. Agriculture is one the major contributor of greenhouse gas emission and mainly of carbon dioxide, nitrous oxide and methane. These emissions depend mainly on the management practices like tillage, fertilizer applications and irrigation etc. Sugarcane is one of the nutrient and water intensive crop of Maharashtra which is growing under various management practices. Conservation agriculture is one of the most adopted technology worldwide including Maharashtra to enhance the resource use efficiency and reduce the environmental degradation. On site crop residue burning is one of the common traditional practices following throughout India for residue management including Maharashtra. A research was conducted to develop a method to monitor the carbon dioxide (CO_2) flux/emission from Sugarcane field under crop residue burnt and residue retained conditions in Maharashtra.

For the sampling of soil carbon dioxide gas emission closed chamber method was used while for their quantification a titration based method is still in standardization stage. In closed chamber method a polypropylene chamber of dimension 30cm length, 30cm width and 40cm height was installed between rows of sugarcane for emitted gas collection. In 24 hour interval the emitted gas mixture was sampled in a syringe after homogenization with 12v DC motorized fan. The collected gas sample of 10ml volume was bubbled in 100ml 1N NaOH solution and allowed to absorb the present CO_2 in the gas mixture for the formation of sodium carbonate (Na_2CO_3). The unreacted NaOH content in the solution was quantified after titration against 0.01N hydrochloric acid in the presence of methyl orange indicator. Carbon dioxide content in the gas mixture was equivalent to the reacted sodium hydroxide or sodium carbonate formed in the solution. Variation in CO_2 flux from sugarcane field under trash burnt and trash retained condition was calculated per month is presented in graphical form in the fig 14.

Based on the collected data since Oct. 2018 the average carbon dioxide emission from sugarcane field was observed 0.43 ± 0.08 kg/ha/month. However, there is no significant difference in carbon emission from the sugarcane field under crop residue burnt and residue retained conditions was observed. In winter month soil CO_2 emission was reported minimum (0.34 ± 0.04 kg/ha/month) which is probably due to less atmospheric temperature and low soil microbial activity.

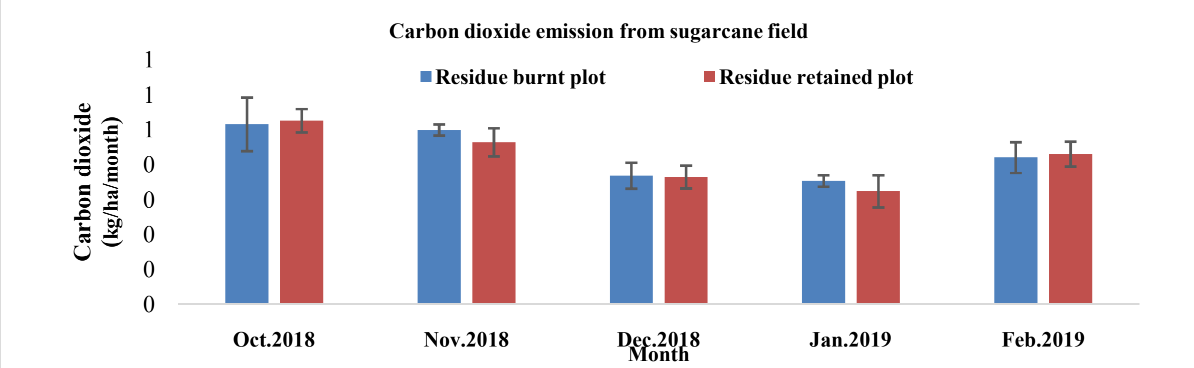


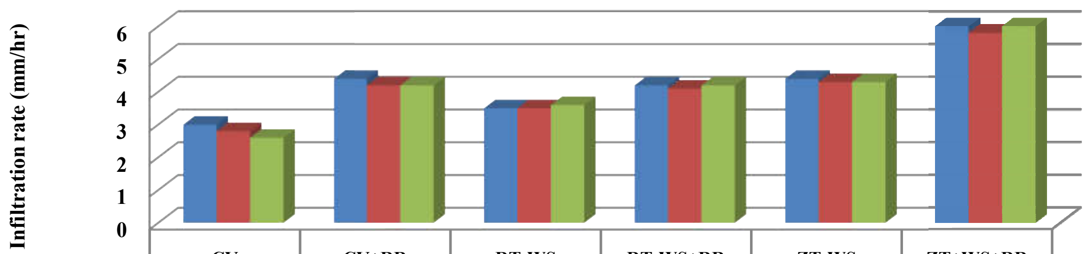
Fig. 14. Carbon dioxide emission from sugarcane field.

CSSRI

i. Infiltration rate-

a) Infiltration rate influenced by tillage and residue management practices was measured after wheat harvesting. Data in Fig. 15 shows that infiltration rate remains lower under conventional tillage method. Maximum infiltration rate was recorded in zero tillage, where crop residue added in the form of anchors.

b) Infiltration rate increased after incorporation of rice residue in conventional and reduced tillage (CV+R and ZT+R) but remains lower than anchored residue in zero tillage (ZT+R). It may be due to the fact that under zero tillage, roots of previous crop remain undisturbed and after decaying forms channels which is responsible for the downward movement of water. Also, the problem of water stagnation was not observed in zero tilled plots even after heavy downpour. **These above mentioned factors results in better growth, development and higher grain yield of wheat as compared to conventional tillage.**



	CV	CV+RR	RT-WS	RT-WS+RR	ZT-WS	ZT+WS+RR
2010	3	4.4	3.5	4.2	4.4	6
2013	2.8	4.2	3.5	4.1	4.3	5.8
2016	2.6	4.2	3.6	4.2	4.3	6

Fig. 15: Effects of tillage and crop residue on basic infiltration rate after wheat harvesting.

ii. Water stable aggregates-

a) Data given in Fig. 16 shows that water stable aggregates are influenced by crop residue and tillage management practices.

b) Soil aggregation is the function of soil organic carbon and microbes with clay content of soil.

c) Soil aggregation recorded in higher magnitudes where crop residue was added regularly in conventional (CV+R), reduced (RT+R) and zero tillage (ZT+R). In addition, higher crop yield was recorded where residue was added regularly.

d) Soil aggregation is associated with infiltration rate by improved infiltration and soil porosity. Optimum moisture and aeration was maintained which promotes plant growth and thereby higher productivity.

Effects of tillage and crop residue management on water stable aggregates(0-15cm)-2016-17

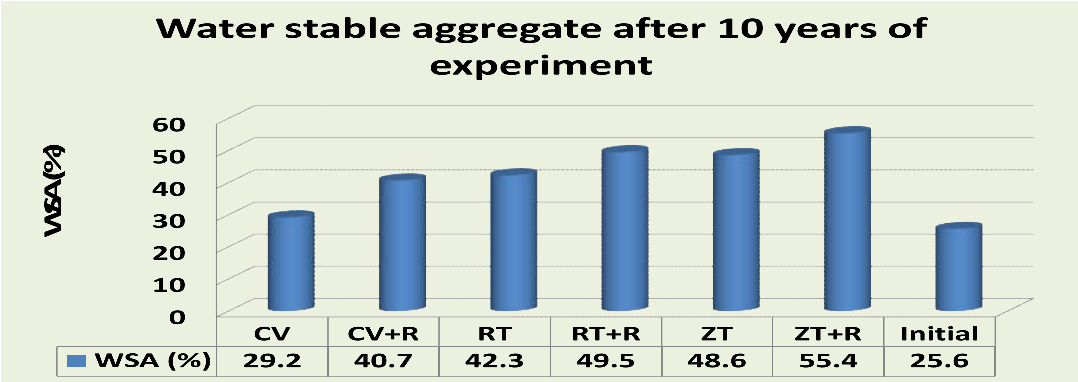


Fig 16: Effects of tillage and crop residue management on water stable aggregates (0-15 cm) during 2016-17

iii. Soil aggregation and associated carbon-

a) Data on per cent water stable aggregates (WSA) under residue and non-residue treatments behave in different ways (Fig. 17). Higher per cent water stable aggregates formation was reported in 0-15 cm soil layer where residue was added regularly than residue omission plots.

b) Soil aggregates of >0.5 mm size increased in residue incorporation/anchors treatments, where crop residue of rice and wheat was added regularly since last 9 years. It means rice and wheat residue has very good impact on soil physical condition that provides water and aeration to the root system regularly, which response favourable plant growth and ultimately higher grain yield.

Effects of tillage and crop residue management on soil aggregate and associated carbon

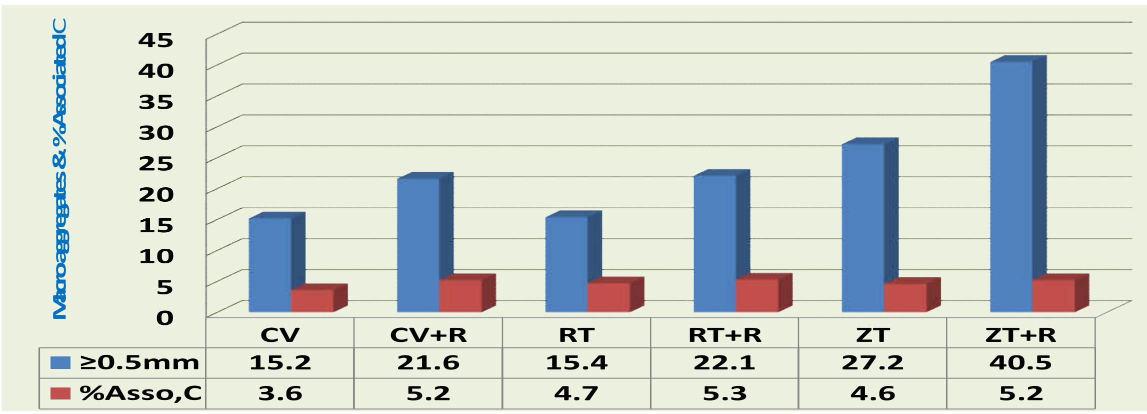


Fig 17: Effects of tillage and crop residue management on soil aggregates and associate carbon

iv. Water stable aggregates under different soil layers-

The results given in Fig. 18 revealed that:

a) Water stable aggregates (WSA) increased in 0-15 cm soil layer with the addition of crop residue and measured 17.1% higher than non-residue (NR) plots.

b) In 15-30 cm soil layer, aggregates in residue added plots increased by 2.59% than non-residue plots.

c) NR treatments increased WSA by 7.36 per cent in 15-30 cm than 0-15 cm soil layer.

d) Residue added plots recorded 7.15% lower WSA in 15-30 cm soil layer compared to 0-15 cm.

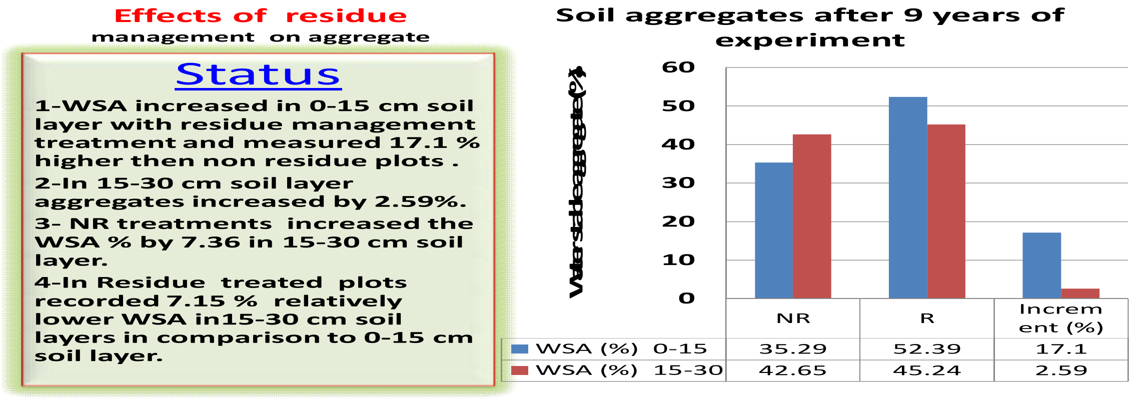


Figure 18: Effect of tillage and crop residue management on water stable soil aggregates in 0-15 and 15-30 cm soil layers

IISS

Impact of Conservation agricultural practices on soil health, Carbon Sequestration and Green House Gas Emissions in different production systems
Effect of different level of residue retention on soil properties

In order to study the effect of residue retention on soil properties under no till system in soybean-wheat cropping sequence, soil samples from 0-10 and 10-20 cm of soil depth was collected from research farm of ICAR-IISS, Bhopal. It was observed that five years of 90% of soybean and wheat residue retention had led to the improvement in soil organic carbon by 10% in comparison to no residue retention. However, the effect was not significant in 10-20 cm of soil depth. Regarding particulate organic carbon (POC), it was also significantly higher (62.5%) in 0-10 cm of soil depth as compared to no residue retention. Moreover, here also the effect was only pronounced in 0-10 cm of soil depth.Regarding, NO_3-N content at harvest in 0-10 cm of soil depth, it was 2.62 times higher in 0% residue retained plot in comparison to 90% of residue retained plot. The effect was also significant in 10-20 cm of soil depth. Here also, NO_3-N content was 1.74 times higher in 0% residue retained plot as compared to 90% of residue retained plot. Soil basal respiration was found to be 7.3% higher in 90% residue retained plot as compared to no residue retention. Similar trend was recorded in 10-20 cm of soil depth (Fig 19).

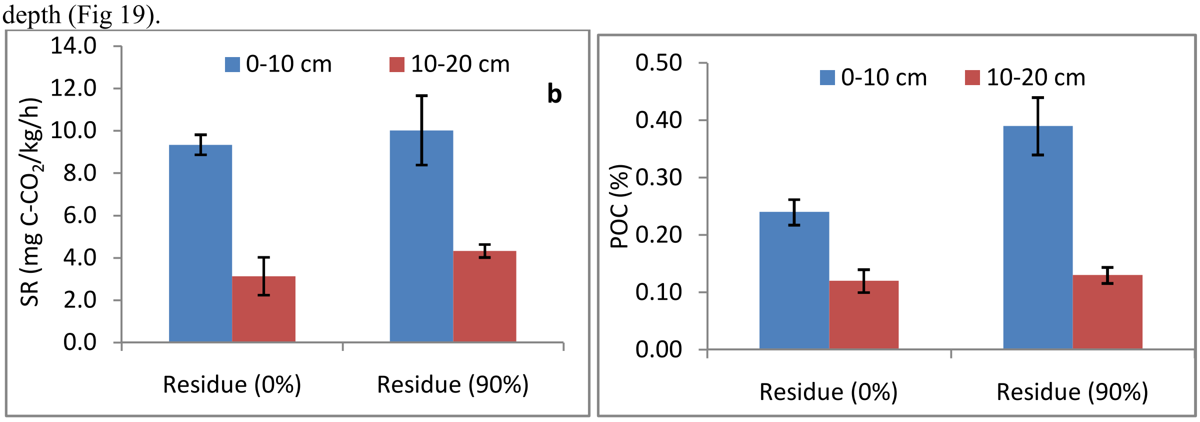


Fig 19. Effect of residue retention under no till system on a) % POC and b) basal soil respiration under soybean-wheat cropping system

Vesicular Arbuscular Mycorrhiza (VAM) colonization as affected by residue retention was studied during wheat growing season. It was observed the VAM colonization in wheat root was significantly higher in 90% of residue retained plot in comparison to no residue retained plot. It was recorded that in 90% of residue retained plot VAM colonization was 46% whereas it was only 26% in 0% of residue retained plot (Fig 20).

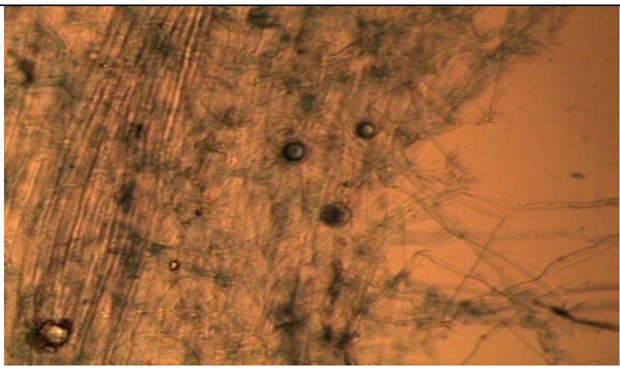
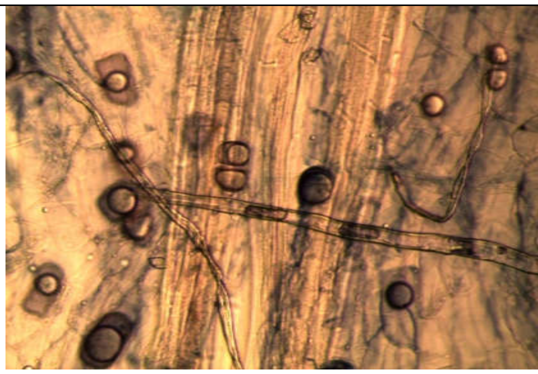
	
VAM colonization in 0% of residue retained plot (Wheat crop)	**VAM colonization in 90% of residue retained plot (wheat crop)**

Fig 20. Effect of residue retention on VAM colonization in no till system under soybean-wheat cropping system

The methane oxidation rate of soil under soybean-wheat and maize-wheat cropping system was also measured. It was observed that methane oxidation rate was significantly higher under 90% of residue retained treatment in comparison to no residue retained plot under both the cropping systems. Methane oxidation rate was almost 1.89 times higher in 90% of residue retained plot (Fig 20). Abundance of bacterial genes was also measured under soybean-wheat and maize-chickpea rotation under no till system. It was observed that the bacterial population was dominated by Eubacteria followed by Methanotrophs and Ammonia oxidizer under both the cropping systems. There was no significant difference in bacterial abundance due to retention of crop residues (Fig 21).

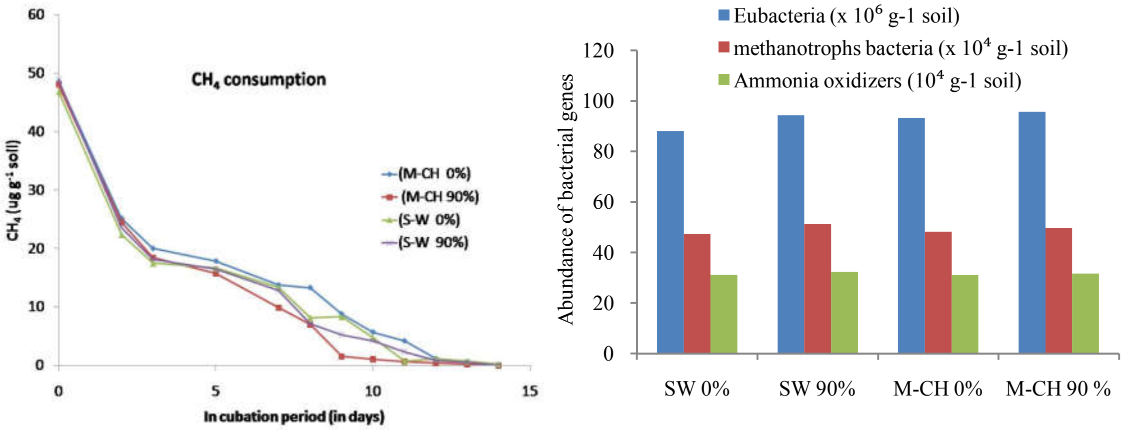


Fig 21. Effect of residue retention on methane oxidation and abundance of bacterial genes under no till system

During the reporting period, soil samples were also collected from the Institute ongoing conservation agriculture experiments which started in 2015. Samples were collected from 0-5, 5-15 and 15-30 cm soil depths. The samples were analyzed for pH, EC, organic C and available NPK. All together 96 soil samples were analyzed. Slight reduction in soil pH (0.15 units) was recorded under the no till system in comparison to CT plots (7.82). Among the different nutrient treatments, lowest pH was recorded in treatments where N was applied through STCR approach in 0-5 cm of soil depth (Table 7). No significant effect of crop residue retention (30 and 60 cm) on soil pH was noticed.

Table 7. Effect of conservation agriculture practices on soil pH

		Maize-Chickpea		**0-5 cm depth**		**Soybean-wheat**			
	N1	N2	N3	Mean		N1	N2	N3	Mean
NT30	7.69	7.67	7.66	**7.67**	NT30	7.82	7.63	7.73	**7.72**
NT60	7.83	7.86	7.56	**7.75**	NT60	7.76	7.80	7.87	**7.81**

RT30	7.85	7.67	7.53	**7.68**	RT30	7.86	7.78	7.90	**7.85**
RT60	7.84	7.81	7.73	**7.79**	RT60	7.78	7.83	7.74	**7.78**
CT	7.91	7.74	7.80	**7.82**	CT	7.75	7.71	7.74	**7.73**
Mean	**7.82**	**7.75**	**7.65**		Mean	**7.79**	**7.75**	**7.80**	
				5-15 cm					
NT30	7.96	7.95	7.95	7.95	NT30	8.17	7.98	8.10	8.08
NT60	8.00	7.97	7.92	7.96	NT60	8.09	8.15	8.20	8.15
RT30	7.99	7.94	7.98	7.97	RT30	8.20	8.16	8.07	8.15
RT60	7.98	7.97	7.96	7.97	RT60	8.15	8.20	8.06	8.14
CT	8.08	7.91	8.02	8.00	CT	8.15	8.15	8.14	8.15
Mean	**8.00**	**7.95**	**7.97**		**Mean**	**8.15**	**8.13**	**8.11**	
				15-30 cm					
NT30	7.96	7.95	7.95	**7.95**	NT30	8.17	7.98	8.10	**8.08**
NT60	8.00	7.97	7.92	**7.96**	NT60	8.09	8.15	8.20	**8.15**
RT30	7.99	7.94	7.98	**7.97**	RT30	8.20	8.16	8.07	**8.15**
RT60	7.98	7.97	7.96	**7.97**	RT60	8.15	8.20	8.06	**8.14**
CT	8.08	7.91	8.02	**8.00**	CT	8.15	8.15	8.14	**8.15**
Mean	**8.00**	**7.95**	**7.97**		Mean	**8.15**	**8.13**	**8.11**	

The reverse trend was recorded in case of soil EC. EC was found higher under NT and RT treatments as compared to CT treatments in 0-5 cm of soil depth. The highest EC value of 0.28 was recorded in treatments where N was applied through STCR approach. No significant change in soil OC was recorded between different treatments. However, maize-chickpea rotation had higher organic C in surface layer in comparison to soybean-wheat system. Soil OC content was deceased as the soil depth increased. No significant difference in labile C was recorded in 0-5 cm soil depth under different treatments. Cropping system could not influence labile carbon in 0-5 cm of soil depth. However, at 5-15 cm of soil depth, maize-chickpea rotation had 25-38% higher labile carbon content in comparison to soybean-wheat cropping system (Table 8). Nitrogen application did not influence the labile carbon content. Retention of residue resulted in buildup of labile carbon content. Under maize-chickpea rotation, 22-43% higher available N was recorded under NT and RT treatments in comparison to CT treatment. However, no significant difference in available N content was recorded under different treatments under soybean-wheat crop rotation.

Table 8. Effect of conservation agriculture practices on labile carbon content (mg/kg) of soil

		Maize-Chickpea		**0-5 cm depth**		**Soybean-wheat**			
	N1	N2	N3	Mean		N1	N2	N3	**Mean**
NT30	722.5	677.9	683.9	**694.8**	NT30	706	705	697	**702**
NT60	584.8	667.4	663.6	**638.6**	NT60	640	635	607	**627**
RT30	705.1	778.2	711.3	**731.5**	RT30	684	650	674	**669**
RT60	663.9	713.8	675.0	**684.2**	RT60	670	710	717	**699**
CT	678.3	697.5	677.0	**684.3**	CT	710	725	757	**731**

Mean	**671**	**707**	**682**		**Mean**	**682**	**685**	**690**	
				5-15 cm					
	N1	N2	N3	Mean		N1	N2	N3	**Mean**
NT30	666	647	643	**652**	NT30	461	469	484	**471.2**
NT60	607	587	653	**616**	NT60	458	476	460	**464.4**
RT30	606	600	648	**618**	RT30	439	466	467	**457.5**
RT60	605	601	608	**605**	RT60	460	434	460	**451.4**
CT	588	612	562	**587**	CT	482	479	440	**467.2**
Mean	**614**	**609**	**623**		**Mean**	**460**	**465**	**462**	
				15-30 cm					
	N1	N2	N3	Mean		N1	N2	N3	Mean
NT30	434	441	423	433	NT30	485	503	489	**492**
NT60	465	478	468	470	NT60	548	515	501	**521**
RT30	461	463	482	469	RT30	554	494	487	**512**
RT60	440	441	449	443	RT60	552	499	517	**523**
CT	397	468	502	456	CT	500	526	503	**510**
Mean	**440**	**458**	**465**		Mean	**528**	**508**	**499**	

In 0- 5 cm of soil depth, available P was higher to the tune of 22-46% under NT and RT in comparison to CT under maize-chickpea crop rotation. It was observed that maize-chickpea rotation had significantly higher available P content as compared to soybean-wheat cropping system. Available P was drastically reduced in 5-15 and 15-30 cm of soil depth (Table 9). Available K was higher by 12-21% under NT and RT treatments as compared to CT treatments in 0-5 cm of soil depth under maize-chickpea rotation. Maize-chickpea rotation contains 33% higher available K in comparison to soybean-wheat rotation. No significant difference in available K was recorded under different treatments under 5-15 and 15-30 cm of soil depth.

Table 9. Effect of conservation agriculture practices on soil available P (kg/ha)

		Maize-Chickpea		**0-5 cm depth**		**Soybean-wheat**			
	N1	**N2**	**N3**	**Mean**		**N1**	**N2**	**N3**	**Mean**
NT30	40.4	40.2	73.6	**51.4**	NT30	**33.0**	**46.0**	**37.3**	**38.8**
NT60	65.2	43.4	65.1	**57.9**	NT60	**39.1**	**42.7**	**50.0**	**43.9**
RT30	32.7	76.1	76.1	**61.6**	RT30	**25.8**	**48.4**	**32.4**	**35.5**
RT60	56.6	39.8	54.5	**50.3**	RT60	**46.2**	**16.8**	**46.0**	**36.3**
CT	29.6	28.5	68.2	**42.1**	CT	**36.6**	**50.8**	**45.0**	**44.1**
Mean	**44.9**	**45.6**	**67.5**		Mean	**36.1**	**40.9**	**42.1**	
				5-15 cm					
	N1	**N2**	**N3**	**Mean**		**N1**	**N2**	**N3**	**Mean**
NT30	11.34	8.3	18.6	**12.8**	NT30	7.3	12.4	10.0	**9.9**
NT60	13.5	10.3	20.1	**14.6**	NT60	14.1	14.2	12.9	**13.7**
RT30	12.4	17.7	14.8	**15.0**	RT30	11.2	12.9	18.1	**14.1**

RT60	19.7	12.4	18.5	**16.8**	RT60	10.1	7.7	16.2	**11.3**
CT	9.2	11.5	9.2	**10.0**	CT	13.0	13.8	14.7	**13.8**
Mean	**13.2**	**12.0**	**16.2**		Mean	**11.1**	**12.2**	**14.4**	
				15-30 cm					
	N1	N2	N3	Mean		N1	N2	N3	Mean
NT30	11.3	8.2	10.4	**10.0**	NT30	9.2	9.7	9.1	**9.3**
NT60	8.2	8.2	7.7	**8.0**	NT60	10.8	10.3	9.2	**10.1**
RT30	8.6	7.5	7.2	**7.8**	RT30	9.4	8.2	10.3	**9.3**
RT60	9.6	9.2	12.7	**10.5**	RT60	8.6	7.4	7.9	**7.9**
CT	8.7	9.2	10.4	**9.5**	CT	10.8	8.6	12.3	**10.5**
Mean	**9.3**	**8.5**	**9.7**		Mean	**9.7**	**8.8**	**9.7**	

Soil aggregation as influenced by different tillage and cropping system after 9 crop cycles

Soil aggregation often provides information on structural stability and physical condition of soil. Thus, soil aggregation is important process to physically protect organic carbon (C) thereby increasing C content in soil. In general trend, mean weight diameter (MWD) decreases with increase in soil depth under different tillage and cropping system. Tillage had significant effect on soil aggregation after 9 crop cycles (Fig. 1). But cropping system effect on MWD was not significant. The surface layer recorded higher MWD compared to subsurface layer (0-5 cm) and it decreased with depth. The mean MWD of surface layer for CT and NT was 1.60 and 1.80 mm, respectively. The interaction effect of tillage x cropping system x depth was not significant. Results indicated that conservation agriculture management practices had a positive effect on soil aggregation and aggregate stability.

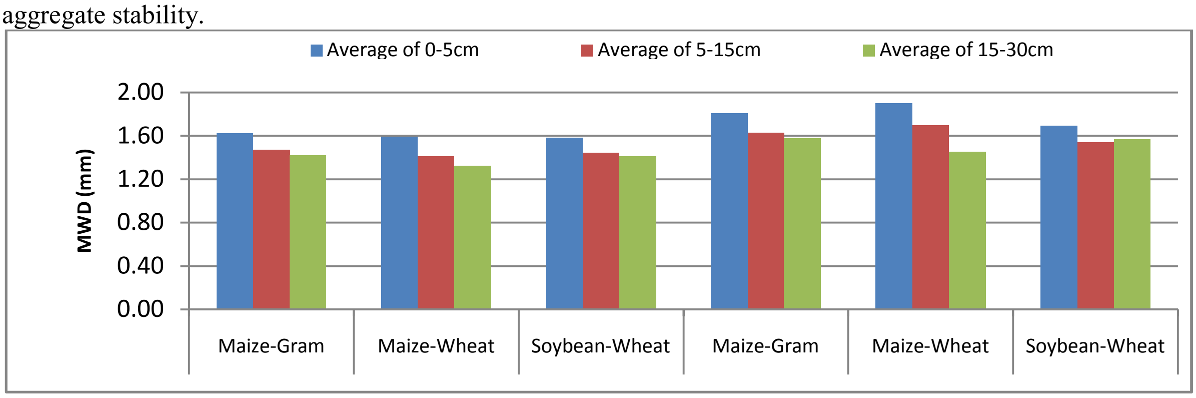


Fig. 1. Soil aggregation under different tillage and cropping system after 9 crop cycles

Water stable aggregates (WSA) under different tillage and cropping systems

Ability of aggregates to resist degradation is known as aggregate stability. Application of organic matter/crop residue into the soil improves the stability of aggregates. Changes in aggregate stability may serve as early indicators of recovery or degradation of soils. Aggregate stability is a credible indicator of organic matter content, biological activity, and nutrient cycling in soil. Generally, the particles in small aggregates (< 0.25 mm) are bound by older and more stable forms of organic matter. Microbial decomposition of fresh organic matter releases products (that are less stable) that bind small aggregates into large aggregates (> 2-5 mm). These large aggregates are more sensitive to management effects such as tillage system, cropping system and fertilizer/organic manure application.

Effect of different tillage and cropping system on water stable aggregate (WSA, %) at different soil depths were presented in Fig 10. The mean values for WSA across tillage systems showed that no-tillage with residue retention had relatively higher WSA (81.5%) than under CT (76.65) at surface layers and these values were decreased with increasing depth, irrespective of tillage and cropping system. Results indicated that tillage and cropping did not have significant effect on WSA. Higher percent of WSA was recorded at surface layer and decreased with depth (Fig 2).

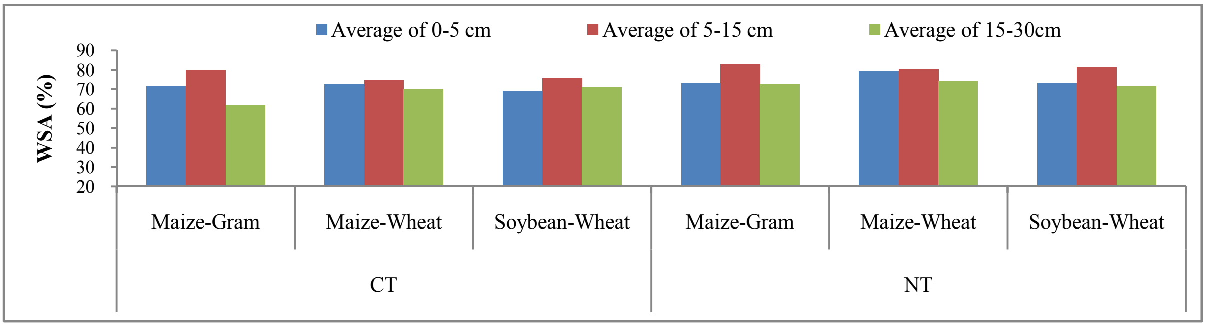


Fig 2. Water stable aggregates (%) under different tillage and cropping system

Long-term Impact of CA practices on Soil Organic Carbon (SOC) after 9 crop cycles

The mean data of SOC during the 9th years of experimentation is depicted in Fig. 3. In general, concentration of SOC was significantly decreased with increasing depth. The SOC content was significantly affected by different tillage systems and cropping system. The mean data of SOC concentration for CT and NT were varied from 0.69 to 0.83 percent and 0.46 to 0.57 per cent at surface layer (0-5 cm), and subsurface layer (5-15 cm), respectively. In general, surface layer (0-5 cm) recorded higher SOC compared to lower soil depths. Irrespective of soil depths, higher SOC was recorded under NT compared CT practices. The NT recorded significantly higher SOC (0.83%) than CT (0.69%) in surface depth (0-5) cm. Similarly, in the sub-surface layer (i.e. 5-15 cm) tillage systems had a significant effect SOC. It is inferred from the data that cropping system had significant effect on SOC content. Among the cropping systems evaluated, maize-gram and maize-wheat recorded significantly higher SOC (0.84%) followed by soybean-wheat (0.81%) under NT. Whereas, under CT maize-wheat recorded minimum SOC (0.65%) at 0-5 cm depth and SOC value decreased with increasing depth. It was evident from the data that the SOC content under NT is significantly higher than CT. Results indicated that interactive effect of tillage × cropping system × soil depth was not significant for SOC. The increased SOC in the surface soil was attributed to a combination of crop residue addition and relatively less soil disturbance by tillage operations under NT.

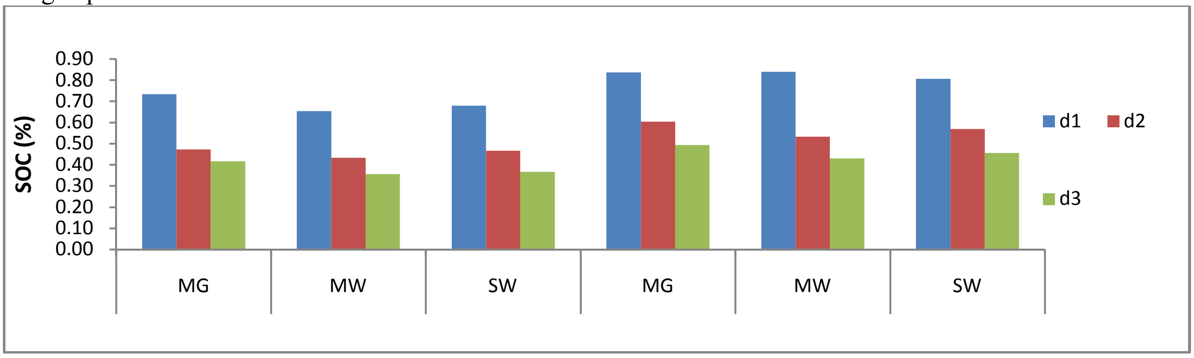


Fig 3. Effect of different tillage and cropping system on soil organic carbon (SOC) at different soil depths (MG-Maize-Gram; MW-Maize-Wheat; SW-Soybean-Wheat; d1-0-5cm, d2-5-15cm, d3-15-30cm)

Aggregate associated carbon under different tillage and cropping systems

Effect of different tillage and cropping system on aggregate associated C at different soil depths were presented in Fig 4. Perusal of data indicated that the aggregate-associated C content increased with aggregate size and it was in the following order of large macraggregate (LM) > small macroaggregate (SM) > silt+clay (S+C) > micro-aggregate (M) in the soil samples. Overall, LM had the highest aggregate C but small macro-aggregate and micro aggregate had almost on par aggregate C. However Silt +Clay had relatively higher aggregate C, regardless of tillage the lowest aggregate associated C across different tillage and cropping system. Tillage practices and cropping systems had significant effect on large macro aggregate associated-C. Similarly, tillage had a significant effect on small macro-aggregate. In contrast, cropping system had an significant effect on micro-aggregate C and Silt+Clay aggregate C. The interaction of cropping system × depth was significant for LM-C but was not having significant effect on the other aggregate classes. There was more LM aggregate C for NT (0.93 %), and CT (0.83) at 0-5 cm depth (Table 3) and aggregate C decreased with lower depth i.e. 5-15 cm and 15-30 cm. Similar trend was observed in SM aggregate C, M aggregate C and S+C aggregate C.

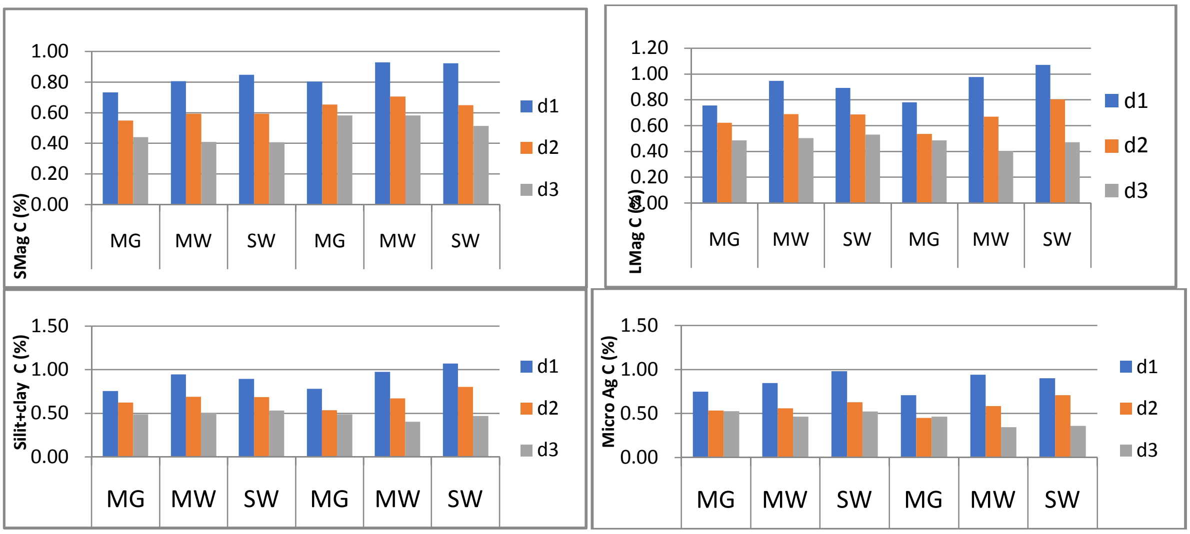


Fig 4. Effect of different tillage and cropping system on aggregate associated carbon at different soil depths A) large macro aggregate C, B) Small macro-aggregate C, C) Micro-aggregate C, D) Silt+Clay C

Impact of CA practices on Crop Yields

Grain yields of different crops were recorded and converted into soybean grain equivalent yield (SGEY) for comparing different cropping systems (Fig 5).Tillage had no significant effect on the soybean grain equivalent yield (SGEY), whereas cropping system had a greater effect on SGE yield. Among various cropping system studied, maize-wheat had significantly higher yield (7401 kg/ha) followed by soybean-wheat (6432 kg/ha) under NT. Similarly trend was observed under CT. SGEY indicated that maize-gram cropping system recorded higher average yield compared to other cropping system, regardless of tillage system.

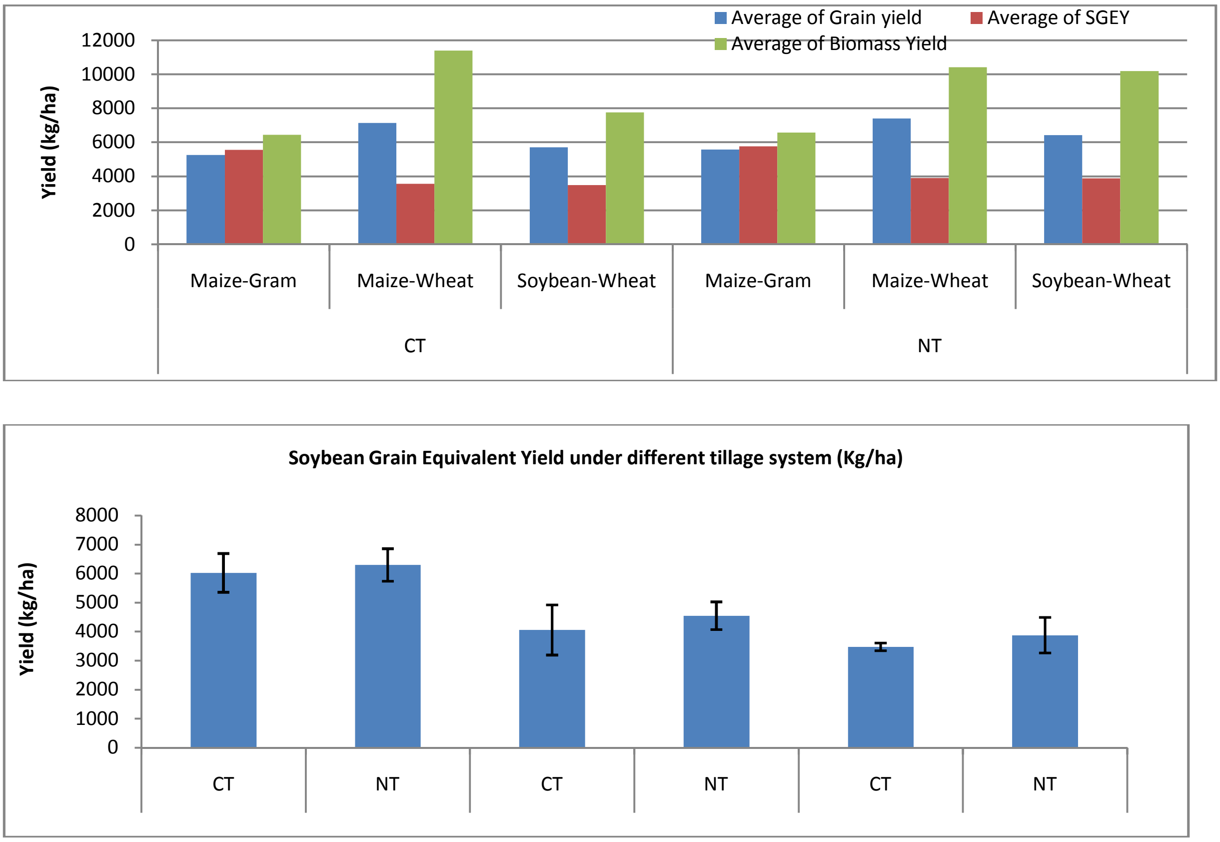


Fig. 5. Effect of different tillage and cropping system on A) Grain Yield and Biomass Yield B) soybean grain equivalent yield (kg/ha) [MSP/q in 2018-2019; soybean Rs 3399; maize Rs1700; wheat Rs 1840; gram Rs 4620]

2.1.2.2 Soil chemical propertie

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Soil pH was the highest in farmer's practice (4.98) followed by ZTTR-M (4.96). SOC content was maximum in ZTTR-M (0.60%) compared to farmer's practice (0.54%). Soil available-N content was significantly the highest (204.9 kg/ha) in farmer's practice over CA practices. Rice cultivars IR-64 and Lalat showed higher soil available-N of 171.9 and 165.6 kg/ha, respectively. Soil available-P content was slightly higher in ZTDSR-M. Sahabhagi dhan showed higher soil available-P content of 16.29kg/ha. Soil available-K was significantly the highest in ZTTR-M (100.3 kg/ha) over farmer's practice (52.2 kg/ha). Mulch imposed CA practices (ZTDSR-M and ZTTR-M) recorded higher available-K over their corresponding non-mulch (Table 1).

Table 1. Effect of CA practices on soil properties in the post harvest soils of rice in acid soils

Treatment	pH	Organic carbon (%)	Available-N (kg/ha)	Available-P (kg/ha)	Available-K (kg/ha)
Crop establishment methods					
Farmer practice	4.98	0.48	204.89	11.46	52.18
ZTDSR-M	4.49	0.60	141.02	17.17	82.41
ZTDSR-NM	4.52	0.54	147.77	17.44	67.95
ZTTR-M	4.96	0.60	148.15	13.73	100.30
ZTTR-NM	4.93	0.59	165.05	7.90	95.2
SEm (±)	0.050	0.029	4.82	2.31	5.94
LSD ($p \leq 0.05$)	0.144	0.084^{ns}	13.8	6.62^{ns}	17.0
Genotypes					
Naveen	4.66	0.62	147.16	11.27	81.74
Lalat	4.80	0.61	165.61	12.90	71.14
IR 64	4.77	0.50	171.95	13.71	78.8
Sahabhagi	4.87	0.52	160.68	16.29	86.75
SEm (±)	0.045	0.026	4.31	2.05	5.31
LSD ($p \leq 0.05$)	0.129	0.075	12.35	NS	NS

CRIDA

Organic carbon

In pigeonpea- castor system after 10 years ZT and RT recorded 16 and 13% higher organic carbon in 0-7.5 cm where as in deeper depths CT and ZT are on par with each other. The residue increased the carbon sequestration in all the tillage treatments.

In Maize-pigeonpea cropping system in situ moisture conservation system along with conservation agriculture practices increased the soil organic carbon. Permanent conservation furrow and permanent bed and furrow recorded higher OC as compared to conservation furrow.

After 6th year of the study in Sorghum-Blackgram system, soil organic carbon (SOC) was estimated at three soil depths 0 -7.5, 7.5-15 and 15-30 cm. Tillage levels did not significantly influence the organic carbon content at 0-7.5 cm soil depth. However, the SOC at this depth in minimum and conventional tillage was 4.68 and 4.53 g kg^{-1}. The higher level of residue retention (S2 : 60 cm cutting height) increased SOC (4.96 g kg^{-1}) (P = 0.05) followed by lower level of residue retention (S1 :30 cm cutting height) (4.59 g kg^{-1}) and control (S0 : No residue retention) (4.30 g kg^{-1}) . At 15 - 30 cm soil depth, tillage and residue application both significantly influenced the SOC status (Table 2).

Carbon pools were significantly influenced by conservation tillage practices and residue retention treatments. In this study, labile and microbial biomass carbon in the soil varied from 321.90 to 386.21 mg kg^{-1} and 127.98 to 190.03 mg kg^{-1} respectively across the treatment combinations (Fig 6). Despite, non significant influence, minimum tillage recorded relatively higher labile carbon and microbial biomass carbon contents (4.68 and 8.73% respectively) compared to conventional tillage. Among the residue levels, on an average, S1 and S2 residue retention treatments significantly increased (6.48% and 14.7%) the labile carbon content respectively compared to no residue retention. The increase in microbial biomass carbon under S1 and S2 residue retention treatments was significant over control and was to the extent of 15.24% and 36.98% respectively.

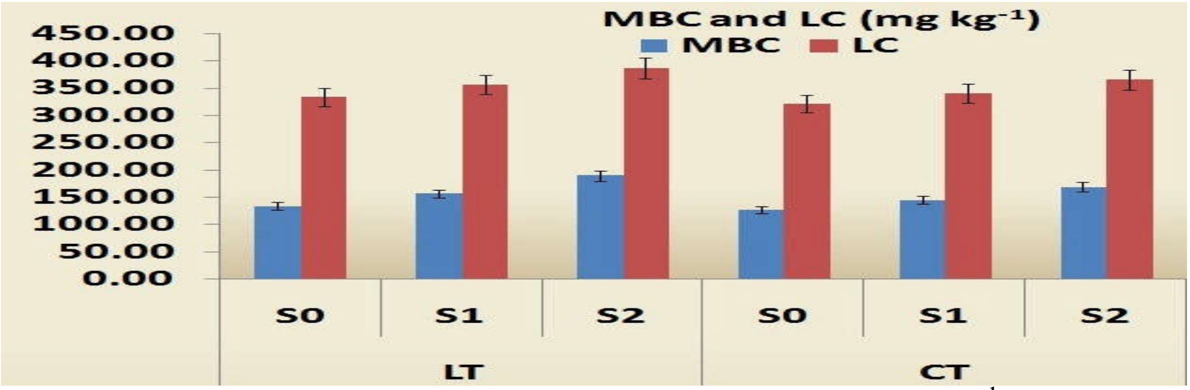


Fig 6. Effect of tillage and residue retention of previous crop (Sorghum) on MBC and LC (mg kg^{-1})

Table 2: Long term effect of conservation tillage and residue retention of previous crop on soil organic carbon SOC (g kg^{-1}) in three different depths 0-7.5, 7.5-15 and 15-30 cm.

Tillage	Residue	0 - 7.5 cm	7.5 - 15 cm	15 - 30 cm
Minimum tillage	S0: No residue application	4.3	4.1	3.5
	S1: Cutting at 35 cm height (1/3 rd height)	4.6	4.2	3.9
	S2: Cutting at 60 cm height	5.0	4.6	4.4
Conventional tillage	S0: No residue application	4.2	3.9	3.3
	S1: Cutting at 35 cm height (1/3 rd height)	4.5	4.1	3.6
	S2: Cutting at 60 cm height	4.8	4.4	4.0
CD (0.05)				
Tillage		NS	NS	0.26
Residues*		0.39	0.14	0.21
T X R		NS	NS	NS

p = 0.05

Earthworm castings

Soil earthworm castings as influenced by tillage and residue levels were assessed at two different dates i.e., at 60 DAS (14/08/18) and 80 DAS (12/09/18) in the black gram field. Despite non significant effect, minimum tillage recorded 34.4% and 5.63 % higher earthworm castings compared to conventional tillage on both the dates of recording. Residue retention treatments significantly influenced the earthworm castings. The S2 and S1 residue levels recorded 75.3% and 30.58% and 54.14% and 26.17% higher earthworm castings as compared to no residue retention at 60 and 80 DAS, respectively. (Fig 7)

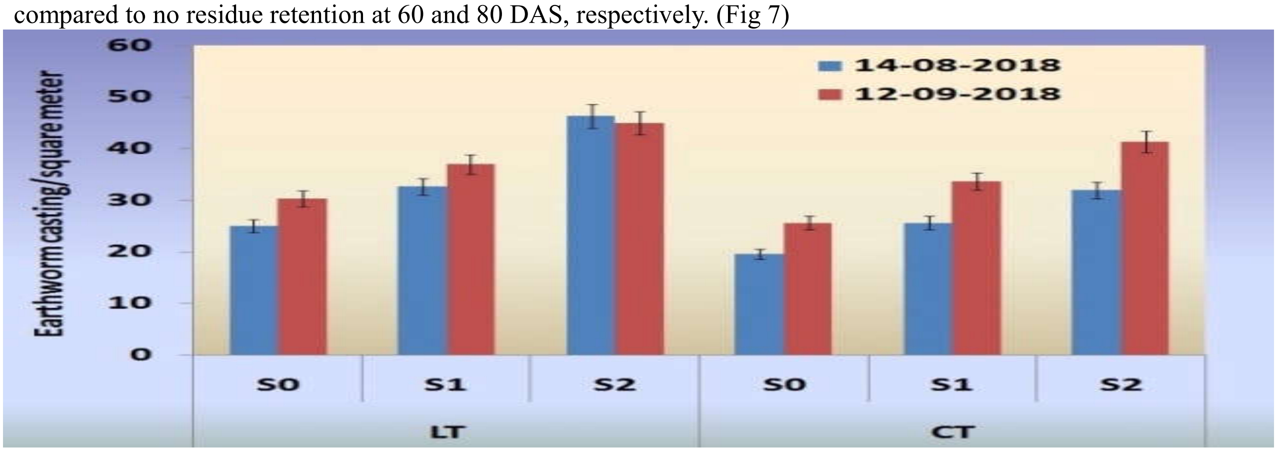


Fig 7. Long term effect of conservation tillage and residue retention of previous crop on earthworm castings (number per square meter) during 2018.

Carbon input to soil through retention of black gram crop residue during 2018

During the current year, the carbon input contribution through black gram crop residue retention under minimum tillage (122.64 kg C ha^{-1}) was higher compared to conventional tillage's (108.71 kg C ha^{-1}). When averaged over tillage, S2 (159.74 kg C ha^{-1}) residue level resulted in higher carbon contribution compared to S1 (71.61 kg C ha^{-1}) (Table 3).

Table 3: Carbon input through residue retention of Blackgram during the year 2018

Tillage	Residue	Black gram C input (kg ha^{-1})
Minimum tillage	S0: No residue	0
	S1: Cutting at 35 cm height (1/3 rd height)	72.43
	S2: Cutting at 60 cm height	172.85
Conventional tillage	S0: No residue	0
	S1: Cutting at 35 cm height (1/3 rd height)	70.79
	S2: Cutting at 60 cm height	146.63

In fingermillet+pigeonpea cropping system after 3 years tillage practices has not influenced the soil organic carbon but, the cover crops has increased soil organic carbon. Among the cover crops horse gram as cover crop recorded significantly higher organic carbon content (0.57 %) compared to control (0.48 %).

The organic carbon content in soil in soybean-chickpea system after 2 years was not significantly influenced by different treatments. However, numerically higher organic carbon content (0.570%) was recorded under reduced tillage (RT) – Pre sowing harrowing + Broad bed and furrow every year + Pre-emergence herbicide application + Crop residue mulch (T_3) followed by Conventional tillage (CT)- Pre sowing harrowing + One hoeing + One hand weeding + Crop residue mulch(T_1).The lowest organic carbon (0.548%)was recorded with permanent Broad bed and furrow + Pre-emergence herbicide application + crop residue mulch(T_5).

b) Available nutrients

In pigeonpea- castor system, ZT and RT recorded higher available nitrogen and phosphorus as compared to CT in 0-15 cm. whereas at 15-30 cm, CT recorded higher available nutrients. ZT and RT recorded higher available potassium as compared to CT in 0-7.5 cm whereas at lower depths CT recorded higher available potassium.

In maize-pigeonpea cropping system integration of in situ moisture conservation along with CA practices influenced the available nutrients. Permanent conservation furrow and permanent bed and furrow recorded higher available phosphorus and potassium as compared to conservation furrow. Total P is lower in permanent bed and furrow and conservation furrow as compared to conventional tillage the soil nutrient status was influenced by different tillage treatments. Permanent bed and furrow, Permanent conservation furrow recorded higher available nutrients up to 15 cm.

Table 4: Soil chemical parameters as influenced by conservation agriculture practices in finger millet+ pigeon pea intercropping (8:2)

Treatment	pH	EC (dS m^{-1})	OC (%)	Available (kg ha^{-1})		
				N	P_2O_5	K_2O
TILLAGE						
M_1 :Conventional tillage	5.19	0.06	0.50	216.89	132.94	144.79
M_2 : Reduced tillage	5.16	0.06	0.51	235.17	127.56	162.62
M_3 :Zero tillage	5.18	0.04	0.52	242.49	124.61	150.95
S. Em. ±	**0.12**	**0.13**	**0.02**	**9.93**	**3.77**	**12.64**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
COVERCROPS						
C_1: Control	5.13	0.05	0.48	201.22	124.37	132.87
C_2: Field bean (HA-4)	5.20	0.05	0.49	232.14	129.22	157.79
C_3: Horse gram	5.20	0.06	0.57	261.19	131.51	167.70
S. Em. ±	**0.08**	**0.004**	**0.02**	**12.91**	**2.72**	**10.12**
CD (p=0.05)	**NS**	**NS**	**0.06**	**39.77**	**NS**	**NS**
INTERACTIONS						
M_1C_1	5.22	0.05	0.46	161.27	130.29	116.20
M_1C_2	5.18	0.05	0.49	192.13	136.38	134.42
M_1C_3	5.16	0.08	0.54	297.28	132.16	183.73
M_2C_1	5.00	0.06	0.45	227.90	124.25	160.88
M_2C_2	5.10	0.07	0.45	246.58	122.53	198.29
M_2C_3	5.39	0.04	0.61	231.03	135.88	128.69
M_3C_1	5.18	0.04	0.51	214.50	118.57	121.53

M_3C_2	5.33	0.04	0.53	257.72	128.75	140.64
M_3C_3	5.05	0.05	0.55	255.25	126.50	190.68
S. Em. ±	**0.13**	**0.01**	**0.03**	**22.36**	**4.71**	**17.54**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**54.03**

Table 5: Available secondary and micro nutrients status in soil as influenced by conservation agriculture practices in finger millet+ pigeon pea intercropping

Treatment	Exch.(meq/ 100g)		Available (ppm)				
	Ca	Mg	S	Zn	Mn	Fe	Cu
TILLAGE							
M_1 :Conventional tillage	2.70	1.49	18.04	0.37	5.94	4.72	0.41
M_2 : Reduced tillage	2.58	1.47	19.56	0.35	6.01	4.88	0.38
M_3 :Zero tillage	2.50	1.62	20.17	0.36	5.92	4.49	0.40
S. Em. ±	0.15	0.14	0.83	0.03	5.94	0.20	0.07
CD (p=0.05)	NS	NS	NS	NS	NS	0.78	NS
COVER CROPS							
C_1: Control	2.44	1.44	16.73	0.32	5.74	4.52	0.39
C_2: Field bean (HA-4)	2.54	1.51	19.31	0.39	5.97	4.73	0.43
C_3: Horse gram	2.79	1.62	21.72	0.38	6.17	4.84	0.37
S. Em. ±	0.09	0.11	1.07	0.04	0.25	0.12	0.02
CD (p=0.05)	0.26	NS	3.31	NS	NS	NS	NS
INTERACTION							
M_1C_1	2.60	1.47	13.41	0.31	4.82	4.38	0.37
M_1C_2	2.57	1.47	15.98	0.41	6.17	4.72	0.46
M_1C_3	2.93	1.53	24.72	0.38	6.84	5.05	0.38
M_2C_1	2.67	1.57	18.95	0.30	6.35	4.83	0.37
M_2C_2	2.70	1.50	20.51	0.32	6.28	4.75	0.36
M_2C_3	2.37	1.33	19.21	0.43	5.40	5.07	0.41
M_3C_1	2.07	1.30	17.84	0.35	6.04	4.33	0.43
M_3C_2	2.37	1.57	21.43	0.43	5.45	4.73	0.47
M_3C_3	3.07	2.00	21.23	0.31	6.27	4.39	0.31
S. Em. ±	0.15	0.19	1.86	**0.08**	**0.44**	**0.21**	**0.04**
CD (p=0.05)	0.46	**NS**	**NS**	**NS**	**1.35**	**NS**	**NS**

In Fingermillet+ Pigeonpea system, the tillage practices have not significantly influenced the soil available nitrogen, phosphorus and potassium. The cover crops have increased the available nitrogen status as compared to no cover crop. Among the cover crops horsegram recorded significantly higher available nitrogen (261.19 kg ha^{-1}) compared to control (201.22 kg ha^{-1}) but was on par with field bean (232.14 kg ha^{-1}) whereas, the cover crops has not increased the available soil phosphorus and potassium. Interaction between tillage and cover crops was found to be non-significant but it was significant with respect to available potassium (Table 4).

The available secondary and micronutrients except calcium were not significantly influenced by different tillage practices, cover crops and also their interaction with each other (Table 5).Exchangeable Ca was not significantly influenced by tillage practices but was significantly influenced by cover crops and tillage and cover crop interaction. Among the cover crops horsegram recorded significantly higher exchangeable ca (2.79 meq/100g).

Among different tillage practices non-significant results were observed in soil biological parameters, acid phosphatase and alkaline phosphatise and urease enzyme activity with different tillage practices (Table 14). Significantly higher dehydrogenase activity (85.02 µg TPF/g per 24 hr) was recorded in zero tillage and urease activity significantly higher was recorded in reduce tillage (44 µg NH_4/ g soil/hr) (Table 6).

Table 6: Soil biological parameters as influenced by conservation agriculture practices in finger millet+ pigeonpea intercropping (8:2)

Treatment	Dehydrogenase (µg TPF/g per 24 hr)	Acid phosphatase µg PNP/g soil)	Alkaline phosphatase µg PNP/g soil)	Urease (µg NH_4/ g soil/hr)
TILLAGE				
M_1 :Conventional tillage	40.63	27.06	24.00	30.23
M_2 : Reduced tillage	84.80	29.16	27.66	44.22
M_3 :Zero tillage	85.02	24.85	22.57	22.93

S. Em. ±	**1.02**	**1.13**	**1.54**	**2.85**
CD (p=0.05)	**4.00**	**NS**	**NS**	**11.19**
COVER CROP				
C_1: Control	41.47	25.67	22.39	27.00
C_2: Field bean (HA-4)	79.13	25.83	24.00	32.44
C_3: Horse gram	89.85	29.57	27.85	37.93
S. Em. ±	**3.08**	**0.94**	**1.06**	**3.39**
CD (p=0.05)	**9.50**	**2.89**	**3.25**	**NS**
INTERACTIONS				
M_1C_1	26.53	26.50	21.67	23.33
M_1C_2	36.74	25.64	23.14	26.28
M_1C_3	58.63	29.04	27.20	41.07
M_2C_1	50.47	27.50	25.00	36.67
M_2C_2	101.88	28.30	27.80	48.93
M_2C_3	102.05	31.69	30.19	47.05
M_3C_1	47.42	23.01	20.51	21.01
M_3C_2	98.77	23.56	21.06	22.11
M_3C_3	108.86	27.99	26.16	25.65
S. Em. ±	**5.34**	**1.63**	**1.83**	**5.86**
CD (p=0.05)	**16.46**	**NS**	**NS**	**NS**

In Soybean -Chickpea cropping system the available nutrients (Nitrogen, phosphorus and potassium) in the soil was not significantly influenced by different treatments. However, numerically higher available nitrogen, phosphorus and potassium (180.25 kg ha^{-1}) was recorded under reduced tillage (RT) – Pre sowing harrowing + Broad bed and furrow every year + Pre-emergence herbicide application + Crop residue mulch (T_3) followed by Conventional tillage (CT)- Pre sowing harrowing + One hoeing + One hand weeding + Crop residue mulch(T_1). The lowest available nitrogen (178.10kg ha^{-1})was recorded with Permanent Broad bed and furrow + Pre-emergence herbicide application + crop residue mulch(T_5) (Table 7).

Table 7: Impact of different treatments on Organic carbon and available nutrients

Treatments	**Organic carbon (%)**	**Available Nutrients (kg ha^{-1})**		
		N	**P**	**K**
T_1	0.560	179.88	19.83	296.95
T_2	0.558	179.43	19.23	295.65
T_3	0.570	180.25	20.38	297.36
T_4	0.550	178.45	18.88	294.75
T_5	0.548	178.10	18.62	294.18
SE(m±)	0.008	1.034	0.417	0.63
CD (5%)	NS	NS	NS	NS

3) GHG emission

The CO_2, N_2O and CH_4 fluxes were measured using a vented insulated non steady state closed chamber technique.The data on GHG emissions in conservation agriculture revealed that CO_2, CH_4 and N_2O fluxes were influenced by tillage and anchored residue (residue levels 0, 30 60 cm). In pigeonpea- castor cropping system. The GHG emissions were influenced by tillage and residue levels. Zero tillage with 10 cm recorded lower GWP this year as compared to conventional and reduced tillage. Methane consumption was observed in all the tillage treatments. ZT recorded highest methane consumption as compared to RT and CT. Residue application influenced the methane emissions. Addition of crop residue has increased methane consumption. The GHG fluxes were correlated with soil moisture content and soil temperature.

4) Energy balance studies

In pearlmillet-pigeonpea cropping system the energy input and output were significantly influenced by tillage and nutrient management practices. ZT recorded higher energy use efficiency and this was followed by MT and CT. Among the nutrient management levels 125 % RDF recorded significantly higher output and input energy followed by 100% and 75% RDF. But higher energy use efficiency was observed in 75% RDF followed by 100% and 125% RDF.

The energy input and output in different treatments based on different operations and yield obtained in soybean-chickpea cropping system was estimated (Table 8). It was observed that the energy input (EI) is more in conventional tillage (CT) with crop residue mulch treatment (T_1) followed by conventional tillage (CT) without crop residue mulch treatment (T_2), Reduced tillage (T_3), Permanent BBF furrow after every 4 rows + crop residue mulch treatment (T_5) and Zero tillage + crop residue treatment (T_4). However, the energy output (EO) was highest in reduced tillage (T_3) followed by conventional tillage (CT) with crop residue mulch treatment (T_1), conventional tillage (CT) without crop residue mulch treatment (T_2), Zero tillage + crop residue treatment (T_4), Permanent BBF furrow after every 4 rows + crop residue mulch treatment (T_5). The energy use efficiency (6.69) and energy productivity (2.97) was highest in reduced tillage (T_3). The energy use efficiency was highest in T3 and this was followed by T4.

Table 8. Energy Balance as influenced by different treatments

Treatments	Energy Input (EI)	Energy output (EO)	Energy use efficiency (EUE)	Specific energy	Energy productivity
T_1	11230	66806	5.95	5.66	2.65
T_2	11136	63240	5.68	5.86	2.56
T_3	10575	70751	6.69	4.94	2.97
T_4	9697	60387	6.22	5.16	2.84
T_5	9713	58020	5.97	5.37	2.73

In fingermillet+pigeonpea cropping system at Bangalore input energy, output energy, net energy returns, energy use efficiency, energy productivity and specific energy were significantly influenced by the tillage as well as cover crops. Among different tillage practices, conventional tillage has recorded higher energy input, energy output, net energy returns, energy use efficiency, energy productivity and lower specific energy as compared to reduced tillage and zero tillage. Growing of horsegram as cover crop showed higher energy input, energy output and net energy returns followed by field bean compared to control (Table 9).

Table 9: Energy balance (kg ha^{-1}) in finger millet + pigeonpea (8:2) intercropping as influenced by tillage practices

Treatment	Input Energy	Output Energy	Net energy returns (MJ ha^{-1})	Energy use efficiency	Energy productivity (kg MJ^{-1})	Specific energy (MJ kg^{-1})
M_1C_1	6851	36905	30054	5.39	0.34	2.96
M_1C_2	7199	182264	175066	25.32	0.32	3.16
M_1C_3	7202	175942	168740	24.43	0.43	2.32
M_2C_1	6615	39634	33019	5.99	0.33	3.06
$M2C_2$	6853	177599	170746	25.92	0.29	3.47
M_2C_3	6879	167469	160591	24.35	0.41	2.45
M_3C_1	6332	29899	23567	4.72	0.22	4.57
M_3C_2	6680	156554	149874	23.43	0.30	3.29
M_3C_3	6684	137387	130702	20.55	0.30	3.36

In pigeonpea-castor cropping system the energy input and output were influenced by tillage and residue levels. Conventional tillage recorded higher energy input whereas reduced tillage recorded higher energy use efficiency and this was followed by zero tillage. Among the residue levels 10 cm recorded higher energy use efficiency as compared to o and 30 cm residues.

5) Soil water and nutrient losses

In pigeonpea- castor system, the soil water nutrient losses were monitored using gauging devices. In 2018-19, the conventional tillage recorded higher soil and nutrient losses, and this was closely followed by reduced tillage. Whereas water loss was higher in Zero tillage. ZT recorded 30 % lower soil and nutrient losses (NPK, OC) as compared to CT and RT, where as in 2017-18 ,the reduction in soil loss with zero tillage was 20 and 17 % over conventional tillage and reduced tillage. Reduction in soil loss was observed with addition of residues. 10 and 30 cm anchored residues recorded lower soil loss over 0 cm anchored residues.

In Pigeonpea – maize system, where the insitu moisture conservation treatments were integrated with conservation agriculture practices; lower soil and water loss were recorded in raised bed and conservation furrow under both CT and CA. The conservation furrow and raised bed reduced the water loss by 50 %. In CT with no residue, the runoff was 8 % of total rainfall, %. In CA furrow, the runoff was 4 % of total rainfall and in raised bed, the runoff was 1 % of total rainfall.

In Soyabean-Chickpea cropping system, the runoff and soil loss observed in different treatments is presented in Table 16. During the season total 6 runoff events occurred, out of which only two events were major. The highest total runoff of 41.6mm was observed in conventional tillage (CT) without crop residue mulch treatment (T_2) and lowest total runoff of 25.2mm was observed in Zero tillage + crop residue treatment (T_4) followed by permanent BBF furrow after every 4 rows + crop residue mulch treatment (T_5), Reduced tillage (T_3) and conventional tillage (CT) with crop residue mulch treatment (T_1) . Runoff in conventional tillage without crop residue mulch treatment (T_2) was 65.10% more than that of Zero tillage + crop residue treatment (T_4). Also the Zero tillage + crop residue treatment (T_4), permanent BBF furrow after every 4 rows + crop residue mulch treatment (T_5) and Reduced tillage (T_3) has less soil loss (0.8, 0.9 and 1.4tons ha^{-1}) as compared to conventional tillage without crop residue mulch (1.9tons ha^{-1}) and with crop residue mulch treatments (1.7tons ha^{-1}).

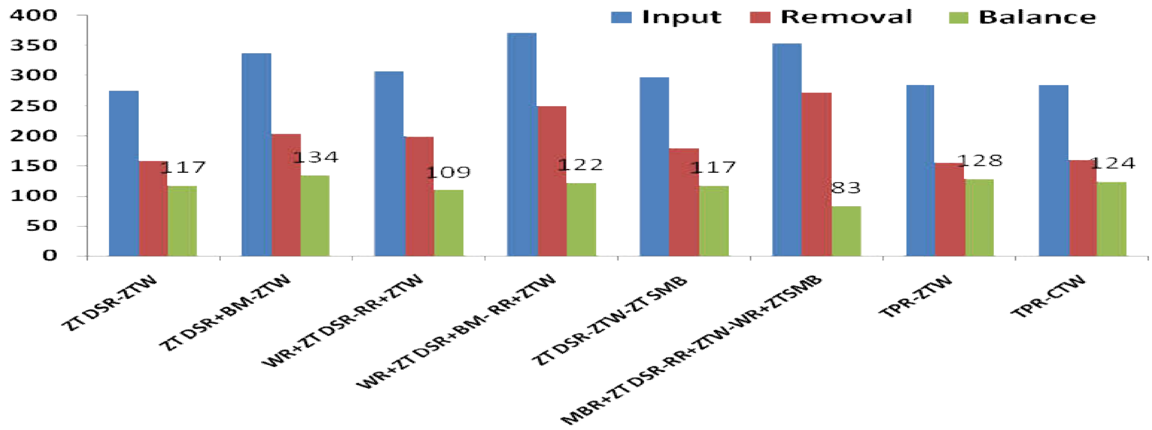
IARI

Nutrients balance (N, P, K) in CA based rice-wheat cropping system

(i) Nitrogen balance in rice-wheat system: The amount of total N taking into account using input (through fertilisers, residue, irrigation, rain and seed uptake) is maximum (371 kg/ha) in double ZT rice-wheat system with residue and brown manuring resulting in more input of nitrogen (Table 10). The triple ZT rice-wheat system with residue retention also showed high nitrogen at 354 kg/ha. This treatment also had higher removal , as a result of which the N balance was lowest (Figure 8).

Table 10. Input of nitrogen (kg/ha) under CA based rice-wheat system

Treatment	Fertilizer	Residue	Brown manuring	Irrigation	Rain	Seed	Total N
ZT DSR-ZTW	240	-	-	29.0	4.33	1.52	275
ZT DSR+BM-ZTW	240	-	63	29.0	4.33	1.52	338
WR+ZT DSR-RR+ZTW	240	34.6	-	27.7	4.33	1.52	308
WR+ZT DSR+BM- RR+ZTW	240	34.6	63	27.7	4.33	1.52	371
ZT DSR-ZTW-ZT SMB	258	-	-	33.0	4.33	2.10	297
MBR+ZT DSR-RR+ZTW-WR+ZTSMB	258	58.4	-	31.7	4.33	2.10	354
TPR-ZTW	240	-	-	38.3	4.33	1.58	284
TPR-CTW	240	-	-	38.3	4.33	1.58	284



(ii) Phosphorus balance in rice-wheat system: The highest amount of P input was observed to the tune of 81.2 kg/ha in triple ZT system with residue and the triple ZT system (without residue) at 74.1 kg/ha was comparable to it (Table 11). This was closely followed by double ZT system with residue and brown manuring at 68.9 kg/ha. It is clear that CA based practices of residue retention and zero tillage, aided by means like brown manuring enrich the soil by enhancing the phosphorus pool (Figure 9). All CA-based systems except ZTDSR-ZTW (without residue) had high P balance compared to TPR-ZTW/CTW.

Table 11. Input of phosphorus (kg/ha) under CA based rice-wheat system

Treatment	Fertilizer	Residue	Brown manuring	Irrigation	Rain	Seed	Total P
ZT DSR-ZTW	52.4	0		0.50	0.6	0.39	53.9
ZT DSR+BM-ZTW	52.4	0	10.8	0.50	0.6	0.39	64.7
WR+ZT DSR-RR+ZTW	52.4	4.25		0.48	0.6	0.39	58.1
WR+ZT DSR+BM- RR+ZTW	52.4	4.25	10.8	0.48	0.6	0.39	68.9
ZT DSR-ZTW-ZT SMB	72.5	0		0.57	0.6	0.45	74.1
MBR+ZTDSR-RR+ZTW-	72.5	7.13		0.55	0.6	0.45	81.2

WR+ZTSMB							
TPR-ZTW	52.4	0		0.66	0.6	0.39	54.1
TPR-CTW	52.4	0		0.66	0.6	0.69	54.4

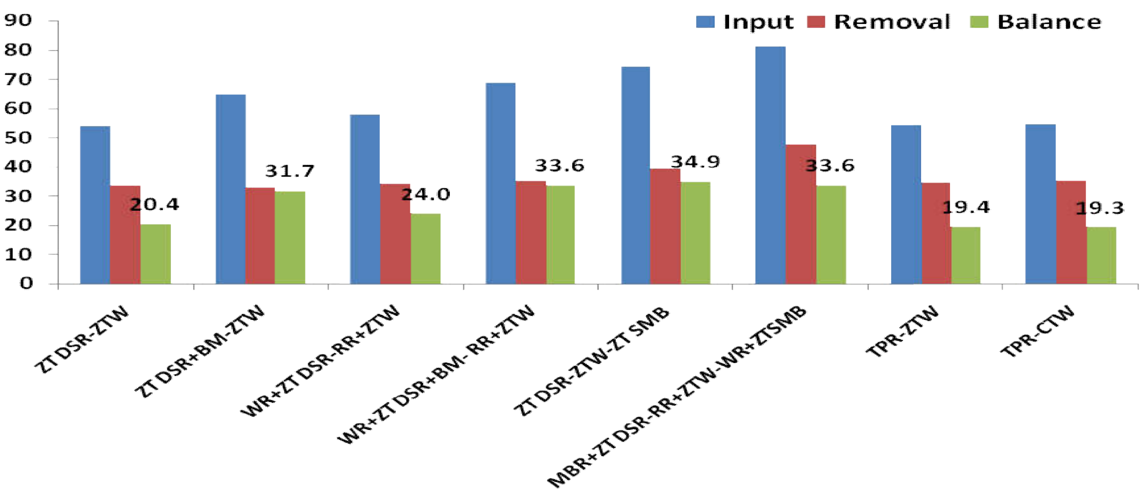
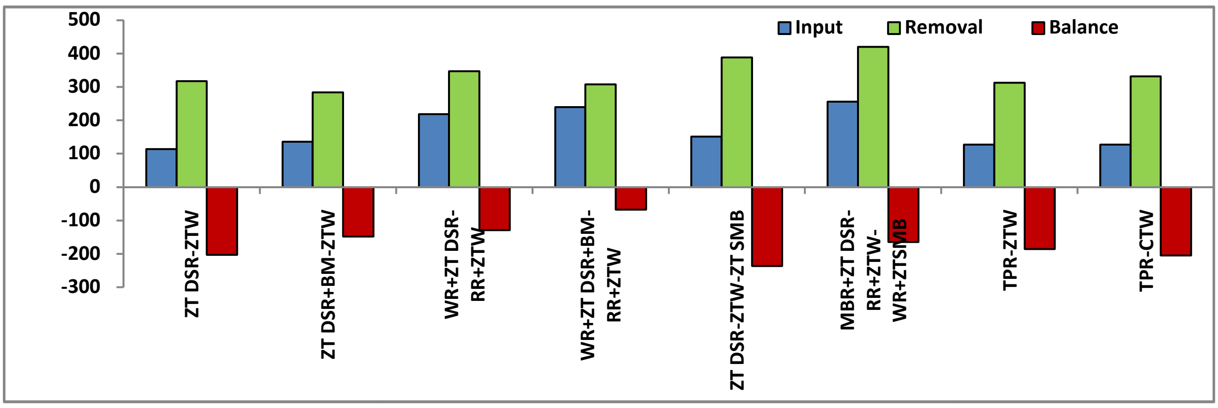


Fig. 9. Phosphorus balance (kg/ha) in rice-wheat system under CA

Potassium balance in rice-wheat system: The highest amount of K input was observed in triple ZT system with residue at 256 kg/ha followed by the double ZT system with residue and brown manuring (240 kg/ha) (Table 14). The lowest K input was observed in double zero till without residue and CT systems were comparable to it. Moreover, the balance tipped towards the negative side across all treatments, with less inputs but more removal. (Figure 10).

Table 12. Input of potassium (kg/ha) under CA based rice-wheat system

Treatment	Fertilizer	Residue	Brown manuring	Irrigation	Rain	Seed	Total K
ZT DSR-ZTW	66.7	0		40.9	5.97	0.45	114
ZT DSR+BM-ZTW	66.7	0	21.6	40.9	5.97	0.45	136
WR+ZT DSR-RR+ZTW	66.7	106		39.1	5.97	0.45	218
WR+ZT DSR+BM- RR+ZTW	66.7	106	21.6	39.1	5.97	0.45	240
ZT DSR-ZTW-ZT SMB	66.7			46.5	5.97	0.63	152
MBR+ZTDSR-RR+ZTW-WR+ZTSMB	66.7	138		44.6	5.97	0.63	256
TPR-ZTW	66.7	0		53.9	5.97	0.46	127
TPR-CTW	66.7	0		53.9	5.97	0.46	127



Carbon Sequestration in soil under conservation agriculture

i) Carbon Sequestration in wheat based system

There was decrease in the soil organic carbon concentration with the increase in soil depth indicating stratification of soil organic carbon (Figure11). The stratification ratio under CA was higher than that of CT (Table 13). Among the cropping systems, the stratification ratio was maximum for maize-wheat system (2.03) and minimum for pigeon pea-wheat system (1.71). Among the tillage methods, it was maximum for Zero tillage with residue retention (2.19) and minimum for conventional flat bed system (1.65). Among the CA systems, retention of residues could increase the stratification ratio by 35.7, 20.8 and 12.9% in cotton-wheat, maize-wheat and pigeon pea-wheat systems, respectively.

Among the cropping systems, soil organic carbon concentration was maximum in pigeonpea-wheat system (9.65 g/kg) and minimum in maize-wheat system (7.97 g/kg) at 0-5 cm soil depth (Figure 20) and among the tillage practices, maximum soil organic carbon concentration at 0-5 cm soil depth was recorded in broad-bed with residue treatment (10.44 g/kg) and minimum soil organic carbon was recorded in the conventional flat bed (6.81 g/kg) (Table 14). Among the CA practices, retention of crop residues significantly improved soil organic carbon concentration in all the three cropping system. Soil organic carbon stock at 0-30 cm soil depth was maximum in pigeon pea-wheat system (35.16 Mg/ha) and minimum in the maize-wheat system (28.47 Mg/ha). Among the tillage practices the soil organic carbon stock at 0-30 cm soil depth was maximum for Zero tillage with residue retention (33.15 Mg/ha) and minimum for conventional flat cultivation (26.88 Mg/ha). Among the CA systems, retention of residues improved soil organic carbon stock at 0-30 cm soil depth by 6.4, 3.3 and 12.1% in cotton-wheat, maize-wheat and pigeon pea-wheat system, respectively.

Carbon sequestration potential of conservation agriculture practices compared to conventional tillage was maximum for pigeon pea-wheat system (6.64 Mg/ha) and minimum for cotton-wheat system (3.46 Mg/ha) (Table 15). Among the conservation agriculture practices, the carbon sequestration potential was maximum for zero-tillage with residue retention (6.27 Mg/ha) and minimum for broad-bed and residue removal (3.06 Mg/ha).

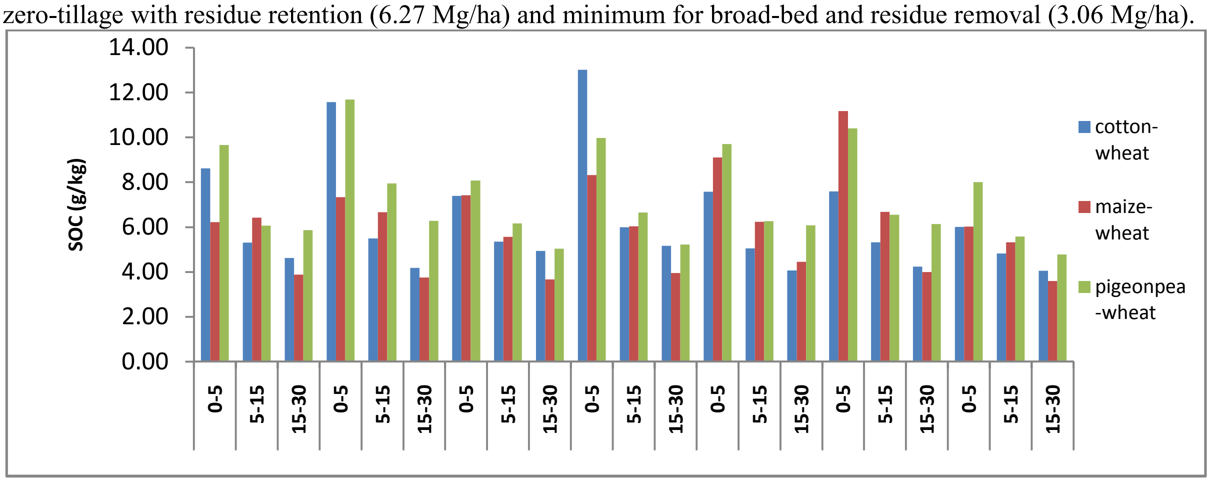


Fig. 11. Soil organic carbon as influenced by conventional and conservation agriculture practices in cotton-wheat, maize-wheat and pigeon pea-wheat system

Table 13. Soil organic carbon stratification ratio under conservation and conventional agriculture practices after wheat 2018

Treatments	Cotton-wheat	Pigeon pea-wheat	Maize-wheat	Mean
Zero tillage (ZT)	1.86	1.60	1.65	1.70
ZT + Residue	2.77	1.95	1.86	2.19
Broad bed (BB)	1.50	2.02	1.60	1.71
BB + Residue	2.52	2.10	1.91	2.18
Narrow bed (NB)	1.86	2.04	1.60	1.83
NB + Residue	1.79	2.80	1.70	2.09
Flat Bed	1.60	1.68	1.68	1.65
Mean	1.99	2.03	1.71	

Table 14. Soil organic carbon pool (Mg/ha) at 0-30 cm soil depth under conservation and conventional agriculture practices after wheat 2018

Treatments	Cotton-wheat	Pigeon pea-wheat	Maize-wheat	Mean
Zero tillage (ZT)	29.14	27.28	34.92	30.44
ZT + Residue	31.10	27.60	40.75	33.15
Broad bed (BB)	30.36	27.61	31.85	29.94

BB + Residue	33.71	29.52	35.39	32.88
Narrow bed (NB)	27.36	30.98	35.39	31.25
NB + Residue	27.60	31.57	38.36	32.51
Flat Bed	26.42	24.76	29.47	26.88
Mean	29.39	28.47	35.16	

Table 15. Carbon sequestration potential (Mg/ha) at 0-30 cm soil depth under conservation agriculture practices after wheat 2018

Treatments	Cotton-wheat	Pigeon pea-wheat	Maize-wheat	Mean
Zero tillage (ZT)	2.72	2.51	5.45	3.56
ZT + Residue	4.68	2.84	11.28	6.27
Broad bed (BB)	3.94	2.84	2.38	3.06
BB + Residue	7.30	4.75	5.92	5.99
Narrow bed (NB)	0.95	6.22	5.92	4.36
NB + Residue	1.19	6.81	8.89	5.63
Mean	2.72	2.51	5.45	

i) Carbon sequestration in rice-based systems

Estimated gross C input, carbon sequestration and temperature sensitivity of carbon decomposition: Sequestration of carbon (C) in arable soils has been considered as a potential mechanism to mitigate soil degradation. Hence, we appraised long-term (8 years) effect of different conservation agriculture (CA) practices on soil organic C (SOC) sequestration under a tropical rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system. Results revealed that annual estimated C input (~5.30 Mg C ha^{-1} $year^{-1}$) under mungbean residue (MBR) + direct seeded rice (DSR)-zero tilled wheat (ZTW) + rice residue (RR)-zero tilled mungbean (ZTMB) + wheat residue (WR) treated plots was ~186 and 189% higher than DSR-ZTW and puddle transplanted rice (TPR)-conventionally tilled wheat (CTW) treatments, respectively (Table 18). Plots under DSR + MBR-ZTW + RR-ZTMB + WR) had ~33 and 24% higher total SOC concentration in the 0-5 and 5-15 cm soil layers than TPR-CTW plots after eight years. That said DSR + MBR-ZTW + RR-ZTMB + WR plots had ~576 kg total SOC ha^{-1} $year^{-1}$ accumulation in the 0-30 cm soil layer. Thus, the MBR + DSR-ZTW + RR-ZTMB + WR treatment, has considerable potential to retain C in soil hence its adoption is recommended. The annual rate of change in total SOC was positively correlated ($P < 0.05$) with gross annual C inputs for all plots (Figure 12). Only ~9.6% of the estimated added C was retained in the 0–30 cm soil layer.

Table 16. Impacts of conservation agriculture on estimated annual gross carbon input under the rice-wheat system during eight years of experimentation.

Treatments	Estimated gross C input (Mg ha^{-1} $year^{-1}$)
DSR-ZTW	1.87e
WR + DSR-ZTW + RR	4.35a
DSR + BM-ZTW	3.05c
WR + DSR + BM-ZTW + RR	5.30a
DSR-ZTW-ZTMB	2.53d
MBR + DSR-ZTW + RR-ZTMB + WR	5.61a
TPR-ZTW	1.96e
TPR-CTW	1.94e

TPR-CTW: Puddle-transplanted rice-conventionally tilled wheat; DSR-ZTW: Direct-seeded rice (DSR) – zero-till wheat (ZTW); BM = Brown manuring; MBR = Mungbean (Green gram) residue; RR = Rice residue; ZTMB = Zero-tilled mungbean (green gram); WR = Wheat residue

Means followed by similar letters within the column are not significantly different at P <0.05 according to Tukey's HSD Test.

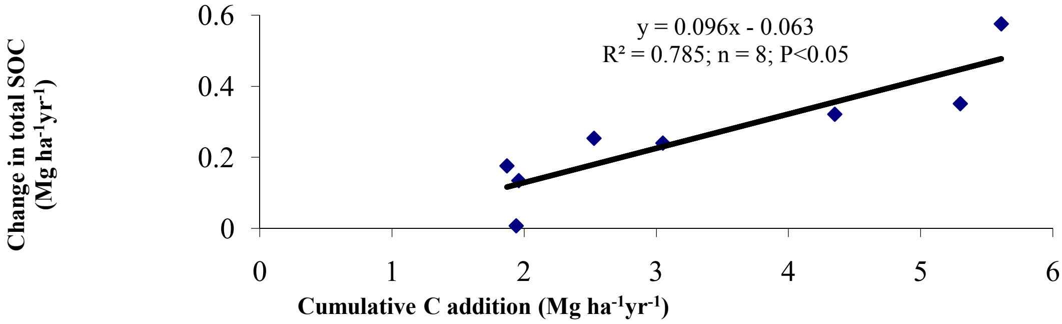


Fig. 12. Relationship between annual cumulative C input and change in total soil organic C (SOC) as affected by conservation agriculture under a rice-wheat cropping system in the Indo-Gangetic Plains.

Temperature sensitivity of carbon decomposition: Understanding temperature sensitivity of SOC decomposition (Q_{10}) of long-term CA plots is imperative to forecast soil C dynamics. Cumulative C mineralization (Ct) was the highest from DSR-ZTW-ZTMB plots at all temperatures (except 35 °C of the 15-30 cm soil layer) (Table 17). Ct values from MBR + DSR-ZTW + RR-ZTMB +WR plots were ~21, 19 and 10% lower than DSR-ZTW-ZTMB plots at 15, 25 and 35°C temperature in surface layer, respectively (Table 18). Soil organic C decay rates of TPR-CTW plots were ~51, 33 and 124% greater than MBR + DSR-ZTW + RR-ZTMB +WR at 15, 25 and 35°C temperature, respectively, in the 0-15 cm soil layer. Almost similar results were obtained for lower depths also. Interestingly, Q_{10} of SOC mineralization from MBR + DSR-ZTW + RR-ZTMB +WR was nearly 39 and 46% lower in the 0-15 cm layer and about 18 and 19% lower in the 15-30 cm soil layers than TPR-CTW and DSR-ZTW-ZTMB, respectively (Table 20). Plots under DSR-ZTW + RR and DSR + BM-ZTW had similar Q_{10} values despite the later having significantly higher decay rates, but lower Ct at all temperatures and for both soil layers. Hence, among all CA practices, the MBR + DSR-ZTW + RR-ZTMB +WR practice was the least temperature sensitive and should be adopted. The driving factors for enhanced SOC sequestration due to its long-term CA adoption lie in the thermodynamic changes occurring within soils during SOC decomposition reaction.

Table 17. Impact of eight years of conservation practices on cumulative SOC mineralization (Ct) and potentially mineralizable C (Co) in surface soil layer of an Inceptisol under a rice-wheat cropping system

Treatments	Ct			Co		
	15	25	35	15	25	35
	Temperature (°C)					
TPR-CTW	28.9c	41.5d	53.2c	33.2c	40.8c	51.8c
DSR-ZTW	33.2b	51.9b	57.8c	36.6b	53.9b	62.2b
WR + DSR-ZTW + RR	41.6a	54.9ab	61.5b	45.9a	60.1a	65.6b
DSR + BM-ZTW	33.1b	49.5bc	56.9c	37.9b	49.6b	61.4b
DSR-ZTW-ZTMB	41.4a	56.4a	65.9a	47.7a	57.7a	72.4a
MBR+ DSR-ZTW + RR-ZTMB +WR	32.5b	45.6c	59.2bc	33.9bc	51.6b	61.5b

Similar lower-case letters within a column defines non-significant differences according to Tukey's HSD (P<0.05).

Table 18. Impact of eight years of conservation practices on Q_{10} in surface and subsurface soil layers of an Inceptisol under a rice-wheat cropping system

	Q_{10}	
Treatments	0-15 cm	15-30 cm
TPR-CTW	1.84a	2.48a
DSR-ZTW	1.69b	2.34b
WR + DSR-ZTW + RR	1.59b	1.85c
DSR + BM-ZTW	1.52b	1.73cd
DSR-ZTW-ZTMB	1.37c	1.64d
MBR+ DSR-ZTW + RR-ZTMB +WR	1.12d	1.33e

Similar lower-case letters within a column defines non-significant differences according to Tukey's HSD (P<0.05).

CSSRI

(i) Soil organic carbon(SOC)-

Soil samples for determination of soil organic carbon were taken after harvesting of wheat crop (Table 19). Soil carbon content varied under different RCTs. Higher soil organic carbon (g/kg soil) was recorded in 0-15 cm soil layer compared to 15-30 cm and subsequent layers in all the treatments. SOC increased in those treatments/ technologies where crop residue was added regularly. In 0-15 cm soil layer, highest SOC (17.02 tha^{-1}) was in ZT+ Residue anchors followed by RT+R (16.58 tha^{-1}) and CV+R (16.13 tha^{-1}).

Table 19: Effect of resource conservation practices on organic carbon content after 10 years of experimentation

Treatments	OC (tha^{-1})				
	Depth				
	0-15 cm	15-30 cm	30-60 cm	60-90 cm	90-120 cm
T_1	12.11	6.83	4.50	3.49	2.37
T_2	16.13	10.30	4.84	3.76	2.42
T_3	12.32	7.39	4.52	3.63	2.49

T_4	16.58	11.65	5.13	5.13	2.51
T_5	12.51	7.45	4.77	3.70	2.53
T_6	17.02	9.86	5.33	4.01	2.49
SE(m)±	0.05	0.03	0.04	0.03	0.01
LSD (0.05)	0.12	0.07	0.08	0.07	0.02

(ii) Carbon sequestration potential (CSP)-

The perusal of data given in Table 20 shows that CSP varied with soil depth and decreased with increase in soil depth in all the treatments. Maximum CSP was recorded in 0-15 cm soil layer in all the treatments. Lowest CSP was recorded in conventional tillage where crop residues were not added. CSP was higher in those treatments where crop residue of both rice and wheat crop added (@ 1/3 of total crop residue) regularly since last 10 years. Among different tillage treatments, maximum CSP was recorded in zero tillage followed by reduced tillage and was lowest in conventional tillage. Similar trend was observed among the crop residue treatments. Residual effect of crop residue addition on crop productivity was observed & found that crop yield increased with increase in CSP in soil system. Simultaneously, atmospheric carbon assimilated in soil system shows encouraging role in improving soil health.

(iii) Soil carbon build up rate-

Soil carbon build up rate was calculated upto the depth of 120 cm. Data (Fig. 13) shows that carbon build up rate was greater in those treatments where crop residue was added regularly. Maximum carbon build up rate was reported in 0-15 cm soil layer and decreased gradually with increasing soil depth. Among residue added plots, highest carbon build up rate was reported in zero tillage (ZT+R) followed by reduced tillage (RT+R) and then conventional tillage (CV+R).

Table 20: Carbon sequestration potential (CSP (t/ha/year) study after 10 years of experiment under rice-wheat cropping system

RCTs	CSP (t/ha/year)					
	Depth (cm)					
	0–15 cm		15–30 cm	30–60 cm	60–90 cm	90–120 cm
CV	0.179	-	0.034	0.025	0.013	0.007
CV + R	0.582	225 %*	0.381	0.058	0.040	0.011
RT	0.202		0.090	0.027	0.027	0.018
RT + R	0.627	250 %	0.515	0.087	0.040	0.020
ZT	0.291		0.096	0.052	0.034	0.022
ZT + R	0.672	275%	0.336	0.108	0.065	0.018
SE(m)±	0.005		0.003	0.004	0.001	0.002
CD (p=0.05)	0.016		0.010	0.012	0.004	0.008
* Per cent increase in carbon sequestration potential in residue addition plots compared to without residue plots under same tillage practice						

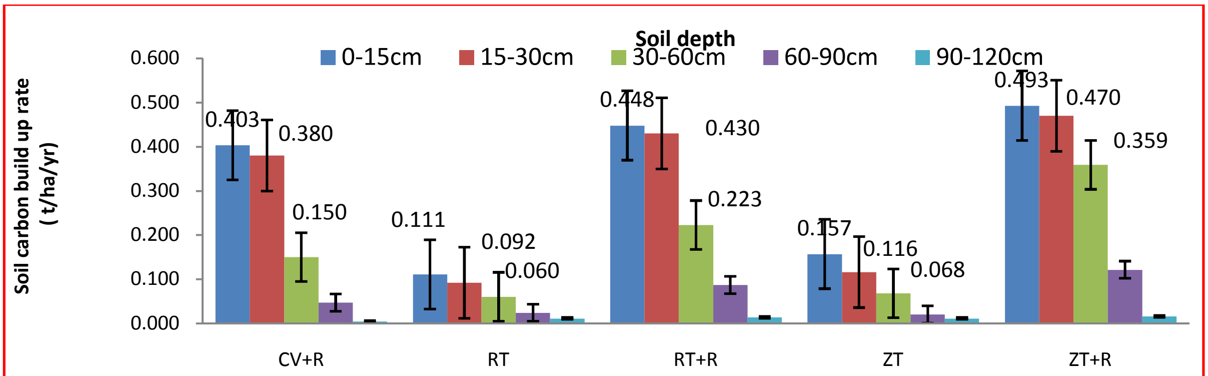


Fig. 13: Effects of crop residue with tillage on soil carbon build up rate (t/ha/yr) depth wise under different CA technologies

The carbon build up rate in 0-15 cm soil layer was closely followed by it in 15-30 cm layer and maximum root proliferation was also observed accordingly. So, roots take all minerals which released after decomposition of organic matter in soil system. Crop productivity of wheat crop reflected in the similar manner with higher grain as well as biological yield.

(iv) Carbon consumption-

Data given in Table 21 on carbon consumption was computed in the term of kg carbon equivalent per hectare (kg CE/ha) with the help of carbon coefficient associated with different cultural operations in rice–wheat cropping system. Maximum carbon consumption was through fertilizers followed by irrigation in form of electricity and similar pattern followed by different RCTs with variable magnitudes.

Table 21: Carbon consumption (kg CE/ha) in different operations in rice-wheat cropping system after 12 years of experimentation.

S. No.	Treatments	Fertilizers	Chemicals	Electricity	Diesel	Crop residue	Total CE input
T1	Conventional (CV)	418	14	392	122	0	946
T2	CV+RR/ CV+RR	418	14	391	122	2373	3318
T3	DSR-RT/RT	418	14	344	82	0	859
T4	DSR-RT+WR/RT+RR	418	14	358	82	2309	3182
T5	ZT/ZT	418	14	348	20	0	800
T6	ZT+WRR/ZT+RR	418	14	398	20	2168	3019
T7	DSR-RT/ ZT+RRM 100%-Drip	268	14	70	63	3494	3909
T8	DSR-RT/ZT+RRM 100%-Surf.	418	14	304	63	3894	4693
T9	DSR-RT/ZT+RRM 100 %-Sprl	268	14	143	63	3573	4061
T10	DSR+WR (33%)/ ZT+RRM 100% - Sprl	268	14	143	63	4583	5070
Average	-	**373**	**14.05**	**289**	**70**	**2239**	**2986**

Crop residue intervention contributed in a greater magnitudes increasing carbon emission rate/carbon consumption in those treatments where crop residue used either incorporated/anchors/ mulch. Among the treatments total carbon inputs was maximum in T_{10} (where 100% rice residue mulched in wheat crop and 1/3rd wheat straw added in rice crop under sprinkler irrigation system) followed by T_8 treatment (where 100% rice residue mulched in wheat crop under surface irrigation system.

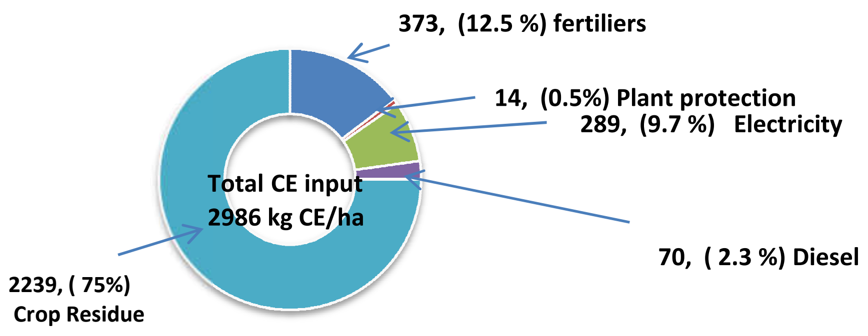


Fig 14: CE of different inputs in rice-wheat cropping system irrespective of different treatments.

v. Carbon Emission from different inputs-

Fig. 8 shows average carbon emission from different inputs from all the treatments. Total carbon emission through all inputs was 2968 kg CE/ha in rice-wheat cropping system (RWS). Among all the inputs, fertilizer contributed 373Kg CE/ha (12.5%), plant protection 14 kg CE/ha (0.5%), electricity contributed 289 kg CE/ha (9.7%) and diesel 70 kg CE/ha (2.3%). Crop residue intervention contributed maximum 2239 kg CE /ha (75%) in the rice-wheat cropping system with increasing system productivity.

vi. Soil Fertility Status: The data on soil fertility implies that

a) Available nitrogen increased from 0.8% to 28.4% where crop residue incorporated/ retention/mulched in 0-30 cm soil layer

b) Available P increased from 7.5% to 25% and K increased from 0.5% to 37.0% over conventional method of rice-wheat system

c) Similarly SOC increased up to 61% in crop residue added treatments over conventional method of rice-wheat cultivation

d) Higher soil microbial activity was recorded in the regularly residue added plots

e) Higher water stable aggregates recorded in residue added and zero tilled soil

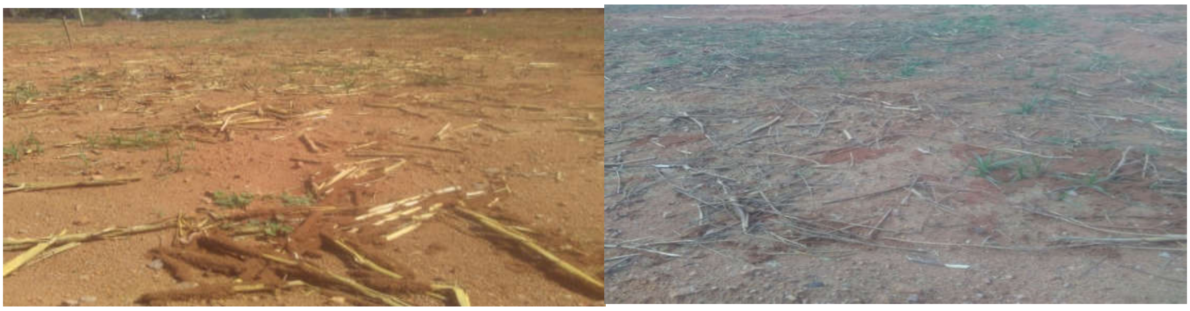
f) Higher total water stable aggregates were observed in crop residue added treatments

2.1.2.3 Soil biological properties

CRIDA

6) Termite Infestation

Termite Infestation on crop residue is a major problem in rainfed alfisols. We have observed that the intensity of termite infestation differed with the type of the crop residue. Higher termite infestation was observed in maize crop residue as compared to pigeonpea and castor (Plate 1).



Maize residues **Pigeonpea residues**

Cotton residues **Castor residues**

Plate 1: Infestation of termites on different crop residues

An experiment was conducted for the termite control at HRF with different crop residues (maize, pigeonpea, castor) with 3 treatments ie., control, choripyriphos and cowdung. Better termite control was observed in cowdung application and chloripyriphos spary (Plate 2).

Control **Chloripyriphos** **Application of cowdung**

Plate 2: Termite Control in Maize

IARI

Soil Biological Properties

Microbes are important regulators of the terrestrial nutrient (Carbon, Nitrogen etc .) budget through their influences on the mineralization, immobilization and emission of these nutrients in soil ecosystems.

a)The order of fungal PLFA biomarkers (18:1w9c, 18:2w6, 9c) found in different treatments were TPR-CTW> TPR- ZTW > ZTDSR+Mung residue-ZTW+Rice Residue-Moong> ZTDSR- ZTW >ZTDSR-ZTW+ Rice Residue> ZTDSR+BM -ZTW- > ZTDSR-ZTW +Mung (Table 21).

b) The order of Arbuscular Mycorrhizal PLFA biomarkers:

ZTDSR+Mung Residue-ZTW+RICE> TPR- ZTW> ZTDSR- ZTW (Brown Manuring)> ZTDSR-ZTW+ Rice Residue> ZTDSR-ZTW +Mung Residue -Mung> TPR- CTW >ZTDSR+BM -ZTW-Mung

c)ZTDSR+Mung Residue-ZTW+Rice treatment favoured the maximum abundance of the AM fungi as indicated by the PLFA biomarkers (16:1ω5c). This treatment with minimum soil disturbance that favours the hyphal network of the AM fungal hyphae coupled with the favourable C:N value provides an optimum condition for the proliferation of the fungal hyphae and spore production. AM Fungi are established microbial system providing many ecosystem services (Carbon sequestration and N cycling) as well as assist in nutrient acquisition by the above ground crop. This treatment appears to help conserve more energy and resources as compared to others.

d) Methanogens were more abundant in the Transplanted rice (TPR)- ZTW than TPR-CTW. Methanogens accounts for the losses of C from the soil and contributes to the GHG emissions. TPR - ZTW provide the anaerobic conditions (low redox) micro environments that favours their abundance.

e)The order of abundance of gram positive (Branched chain PLFA) bacteria was: ZTDSR- ZTW > ZTDSR+BM -ZTW-Mung>TPR- ZTW.

f) ZTDSR- ZTW followed by ZTDSR+BM -ZTW-Mung and TPR- ZTW recorded the highest abundance of the gram positive bacterial populations indicating that recalcitrant carbon concentrations are higher. Addition of brown manuring, rice residue, mung residue and a combination of rice residue, moong residue in the ZTDSR- ZTW system were at par w.r.t the gram positive microbial PLFA signature molecules.

Table 1. Biological parameters in CA-based rice-wheat system (0-15 cm)

Treatment	Straight	Branched	Cyclo	MUFA	PUFA	DMA	18:1w9c	18:2w6,9c	10-methyl	16:1w5c	Hydroxy
ZTDSR- ZTW	19.62	44.63		5.41	9.81	5.16	8.00	3.82	3.55		
ZTDSR + BM (brown manuring) - ZTW	36.34	6.35	0.36	4.01	37.04	4.35	4.15	2.05	2.14	3.21	_
WR (wheat residue) + ZTDSR - ZTW + RR (rice residue)	33.29	5.96	0.37	4.16	39.35	5.38	3.31	1.91	3.71	2.56	_
WR+ZTDSR+ BM – ZTW +RR	13.22	24.52	--	3.98	51.97	0.90	1.69	0.97	2.30	0.45	-
ZTDSR - ZTW –ZT SMB (summer mungbean)	43.74	7.94	--	2.65	40.42	0.62	1.59	0.72	0.99	1.32	-
ZTDSR + MBR (mungbean residue) –ZTW + RR – ZT	30.71	5.46	_	6.98	34.58	5.24	5.52	3.47	_	6.99	1.06
TPR- ZTW	21.40	12.36	0.26	7.53	34.28	4.47	7.57	4.43	3.10	4.21	0.39
TPR-CTW	15.51	6.86	0.11		56.97	5.25	5.41	7.89	2.90	1.11	-

14.4 Greenhouse gas emissions rice-based and wheat-based systems

The emissions of methane and nitrous oxide were quantified in rice-wheat and three alternate cropping systems to rice-wheat system, such as maize-wheat, pigeon pea-wheat and cotton-wheat systems to quantify their global warming potential (GWP). The GWP of rice-wheat system ranged from 890 kg CO_2 equ./ha in zero-till (ZT) direct-seeded rice followed by ZT wheat to 1045 kg CO_2 equ./ha in ZT direct-seeded rice with wheat residue followed by ZT wheat with rice residue retention. The conventional transplanted puddled rice followed by conventional till (CT) wheat had higher GWP of 1580 kg CO_2 equ./ha. The GWP of three alternate systems maize-wheat, pigeon pea-wheat and cotton-wheat was quantified in CT, and ZT flat and broad beds with and without residue (Table 2). Highest GWP was recorded in cotton-wheat system followed by maize-wheat and pigeon pea-wheat systems. The lowest emissions in pigeon pea-wheat system was due to lower nitrous oxide emissions.

Table 2. Global warming potential of wheat-based alternate cropping systems (kg CO_2 equ./ha)

Treatments	Global warming potential (kg CO_2 equ./ha)		
	Maize- wheat	Pigeon pea-wheat	Cotton- wheat
CT	732	438	812
ZT	795	454	866
ZT+R	877	538	924
BB	729	427	828
BB+R	838	514	902
LSD (p=0.05)	47.5	35.2	52.8

IISS

Long-term conservation tillage effect on soil biological properties

The deteriorating soil health coupled with production fatigue poses a great threat to Indian agriculture. A long term (10 years) resource conservation experiment was evaluated for changes in soil biological properties under rice-wheat cropping system. Soil samples were collected from ongoing long-term experiment on resource conservation technology conducted at CSSRI, Karnal. All together 10 treatment combinations comprising of conventional, reduced and no tillage were evaluated with and without residue for changes in measured microbial biomass carbon, soil respiration and metabolic quotient in 0-5 and 5-15 cm of soil depths. Also easily extractable glomalin related soil protein was estimated under the different treatments. In general, it was observed that Fluorescein activity (mg/kg/h) was higher in 0-5 cm of soil depth as compared to 5-15 cm of soil depth. However, in treatments of T1 and T2 (conventional tillage) FDA content was almost similar in both the soil depths. It was observed that adoption of CA practices (DSR in rice and reduced/no tillage in wheat) resulted in buildup of FDA activity in 0-5 cm of soil depth. Amongst the different RCTs, DSR with wheat residue incorporation in reduced tillage with sprinkler irrigation followed by wheat in Zero tillage with rice residue retention and sprinkler irrigation maintained highest FDA activity in soil (Figure 1).

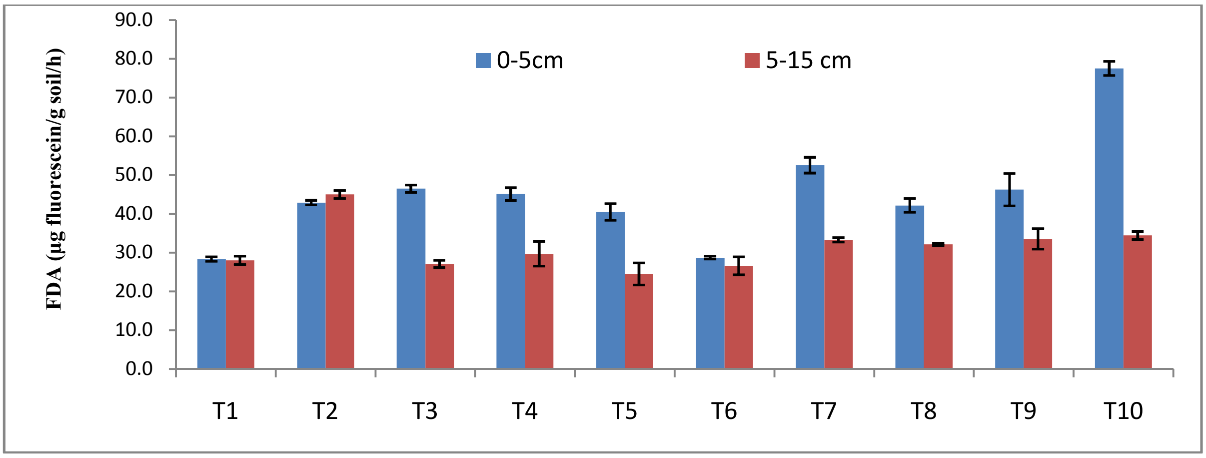


Fig. 1. Effect of different RCT treatments on FDA activity (Total microbial activity) in soil

Measurement of β-glucosidase activity in soil gives an idea about the carbon cycling process in soil. β-glucosidase activity followed the similar trend as of FDA activity in 0-5 cm of soil depth (Figure 2). Here also DSR with wheat residue incorporation in reduced tillage with sprinkler irrigation followed by wheat in Zero tillage with rice residue retention and sprinkler irrigation maintained highest β-glucosidase activity in soil (Figure 28). Highest concentration of microbial biomass carbon was recorded (256 mg/kg) was recorded in 0-5 cm of soil depth in treatments of zero tilled rice (direct seeded) with wheat residue incorporation and zero tilled wheat plots which retained of 1/3rd residue of the previous crop. The lowest concentration of 72.4 mg/kg of MBC was recorded in plots of directed seeded rice followed by wheat in reduced tillage with previous crop residue incorporation.

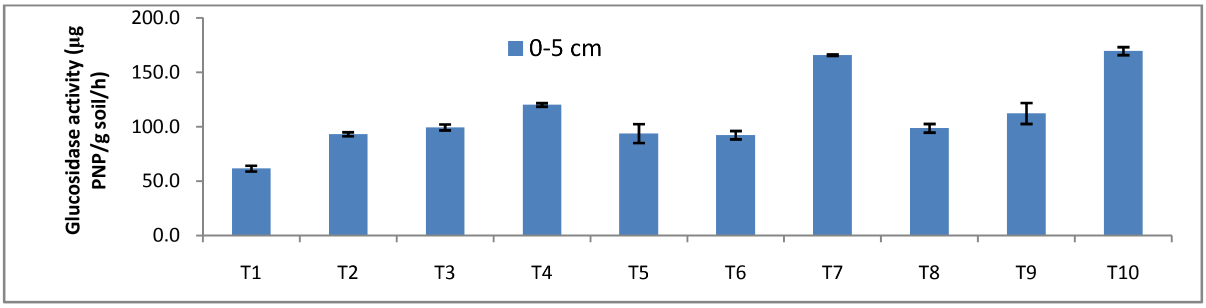


Fig. 2. Effect of different RCT treatments on β-glucosidase activity (Total microbial activity) in soil

Easily extractable glomalin related soil protein was found maximum in plot of direct seeded rice followed by wheat in reduced tillage. This treatment was found to be at par with the treatment of direct seeded rice with wheat residue in reduced tillage followed by zero tilled wheat with entire rice residue retention (Figure 3).

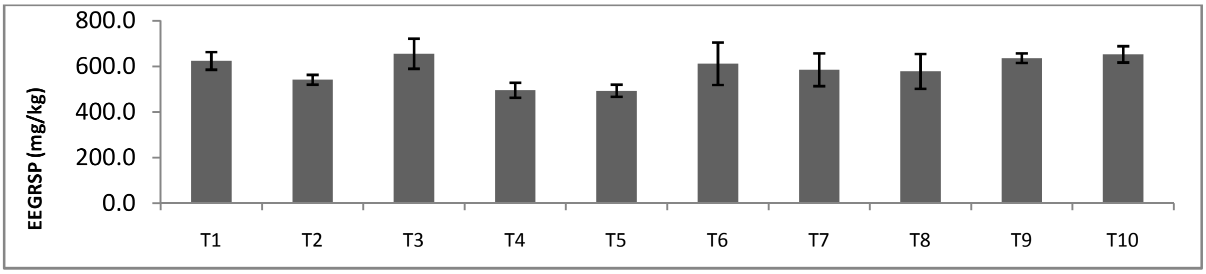


Fig. 3. Effect of different resource conservation technologies on easily extractable glomalin related soil protein (EEGRSP) (mg/kg) content for the surface 0-0.05 m soil layer

3.1.1 Adapt and mainstream available best bet location specific CA practices for enhanced productivity and profitability in rainfed and irrigated eco-system

Adaptation/ development and validation of location specific CA machinery for different cropping systems.(CIAE)

Activity-1

Adaptation/development of zero till planter with herbicide applicator as an attachment.

Objective:

1. Adaptation of pre-emergence herbicide applicator as an attachment to zero till planter.
2. Performance assessment of adopted machineries/technologies for resource saving along with energy and carbon foot print.

Progress:

ICAR- CIAE developed tractor operated pre-emergence herbicide strip applicator with spraying attachment was evaluated in IISS farm and in farmers field for no tillage planting and application of herbicide in the field. Inverted "T" type furrow openers were mounted on the frame of machine for planting of seeds under no tillage condition. Independent seed boxes (6 Nos) having incline plate having grooves has been used to precise metering of seed rate (Fig.1).

The developed machine is suitable for herbicide application and simultaneously planting of wide spaced crops like maize, soybean, pigeon pea etc. The specifications of developed machine are given in Table 1. Based on the suggestions of farmers and scientists of IISS, the planter has been modified for its larger tank capacity of 200 l in place of 80 l so that, it can contain the chemical for one acre area. Numbers of tines were increase from 6 to 8 for increasing the field capacity of the machine. Primary evaluation of this modified planter for stability and spraying performance was carried out in Institute field(fig.-2).

Table.1. Specifications of zero till planter cum herbicide applicator before and after modification

Sl. No.	Specification	Exiting Planter	Modified Planter
1.	Power requirement	35 hp tractor	35 hp tractor
2.	Types of furrow openers and nos. of rows	Inverted "T " type; 6 Nos.	Inverted "T " type; 8 Nos.
3.	Row adjustment	250 – 750 mm	250 – 750 mm
4.	Seed metering	Inclined plate having grooves on its periphery	Inclined plate having grooves on its periphery
5.	Spray pump type	Single action piston pump	Single action piston pump
6.	Nozzle type and Nos.	Flat fan nozzle, (60550) - 6	Flat fan nozzle, (60550) - 8
7.	Spray tank capacity	80 l	200 l
8.	Field capacity of m/c	0.4 ha/h	0.53 ha/h
9.	Cost of operation	Rs. 1350/ha	Rs. 1050/ha
10	Suitable crops	Maize, soybean, pigeon pea, sorghum, cotton, groundnut	Maize, soybean, pigeon pea, sorghum, cotton, groundnut

Field capacity of machine was increased from 0.4 ha/h to 0.53 ha/h and cost of operation decreasedfrom Rs 1350/ha to Rs 1050/ha.The energy saving and reduced carbon foot print/ ha were due to reduction of fuel consumption and reduction in quantity of herbicide sprayed (40-50%). The machine has resulted saving of soybean and pigeon pea seeds as compared to convention herbicide application and sowing of crop using seed cum fertilizer drill. It was due to placement of seeds at required spacing and depth by the developed zero till planter cum herbicide applicator,

Activity-2

Adaptation/development of slit till drill.

Objective:

1. Adaptation of slit till drill
2. Performance assessment of adopted machineries/technologies for resource saving along with energy and carbon foot print.

Progress:

Institute developed slit till drill was tested and based on the feedback following modification were made

1. Proper size and location of press wheel for proper pressing and cutting of straw
2. Selection of appropriate spring for proper compaction
3. Use of different material for cutting of straw
4. Ground wheel size and location (rear to side) was changed for reduction of slippage
5. Adoption of inverted T type furrow openers.

After above modifications, slit till drill was used for sowing of pigeon pea at IISS on 2 & 4, July, 2018 as shown in figure.

Fig, 3 Sowing of pigeon pea at IISS on 2 & 4, July, 2018

The machine was also used to sown the crop directly into the uncultivated field just after the harvesting of previous crop by eliminating the tillage operations. The machine was tested in fieldat IISS Bhopal for direct sowing of gram (27 Nov. 2018) after harvesting of mustard. The crop was sown in dry condition and first irrigation was given after 10 days of sowing.

Fig. 4. Sowing of gram on 27 Nov.2018 and germination data were recorded on 26 Dec. 2018

Based on the feedback and observation, continuous modification were made in the machine.***Indian Institute of Soil Science requested to CIAE for providing one unit of this machine for research purpose***

Activity-3

Characterization and improvement of wear resistance of soil working components of conservation machinery

Objectives

1. To study the wear characteristic of straw-soil cutting components of selected CA Machinery.
2. To evaluate wear resistance of developed components of CA machinery in field.

Progress:

The fast wearing components of agricultural machinery requires frequent replacement in general and conservation agriculture machinery in particular, in CA, sowing or planting machinery is operated in untilled or dry condition. The components of these machines require a good combination of mechanical as well as tribological properties. Keeping it in mind the need of preparation of data base of material properties of critical soil engaging components of conservation agricultural machinerysuch as furrow opener, rotary disc of zero till drills, cutter blades used in stubble saver and residue mulcher and blade of rotovator,were selected to study. Commercialtest reports of 1371 fast wearing components were collected from different testing institutes to know the material and their treatment. Study reveals that only 39.20 and 32.53% tested components are confirming BIS standards in case of chemical composition and hardness. Data further reveals that manufacturers of Rotavator blade (60%), Chaff cutter blade (57%) Rotary tiller (43%), Disc of harrow (34%) are doing heat-treatment. Manufacturers are using low carbon steel (25.00%), medium carbon steel (33.00%), high carbon steel (38.50%) and tool steel (3.50%). Testing centers are not concern with actual chemical composition of the components, they are just following the guidelines of DOAC. Even some manufacturers are using alloy steels and doing proper heat-treatment as indicated from the testing of some rotavator blades listed in table-2

Table-2 Chemical composition and hardness of the rotavator blade

S. No.	Manufacturers	No of samples	C	Mn	Cr/B	Si	S	Hardness (Hv)/HRc
1.	M/S MaschioGaspardo India Pvt. Ltd., Pune,	7	0.73-0.87	0.57-0.59	0.85-0.94	0.22-0.27	0.022-0.025	314-456 32.2-46.1
2.	M/s Mahindra & Mahindra Limited, Mohali	6	0.71-0.77	0.58-0.69	0.68-0.76	0.11-0.14	0.011-0.017	420-448 42.7-45.3
3.	M/s Mahindra & Mahindra Limited, Mohali (Swaraj Division)	6	0.68-0.75	0.61-0.66	0.72-0.77	0.13-0.23	0.014-0.018	322-465 33.3-46.9
4.	M/s Tirth Agro Technology Pvt(Shaktiman)	1	0.62	0.65	1.08	0.36	0.021	463 46.7
5.	Italian rotavator blade	1	0.32	0.76	1.2/0.0035	0.10	0.15	458 46.1
6.	M/s Machino Agriculture Implement, Karnal,	1	0.73	0.52	0.78	0.23	0.024	388 39.8

Based on the test four steels were selected for the wear study.It is evident from fig.-5 that the wear rate reduced initially with increase in the sliding distance at a faster rate and finally attained a steady state value. The wear rate of tool steel (D2) is minimum followed by high carbon alloy steel (EN-31), medium carbon alloy steel (M4) and medium carbon steel (EN-8). This reduction in wear rate of alloy steels is due to formation of hard carbides during heat-treatment of steels. In laboratory condition low stress abrasive relative wear loss of tool steel, high carbon alloy steel, medium carbon alloy steel and medium carbon steel was 0.25, 0.36, 0.61 and 1.00 respectively (fig.-6).The relative wear loss of developed component in rotary soil bin was 0.42. 0.51, 0.65 and 1.00 respectively.

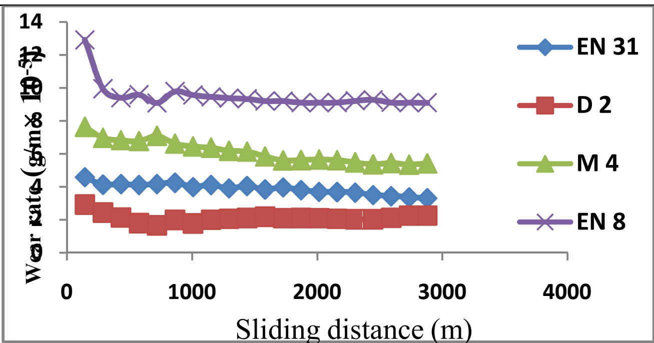


Fig. 5

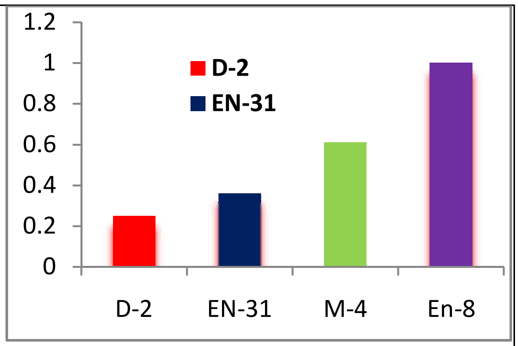


Fig. 6

<u>**Activity-4**</u>

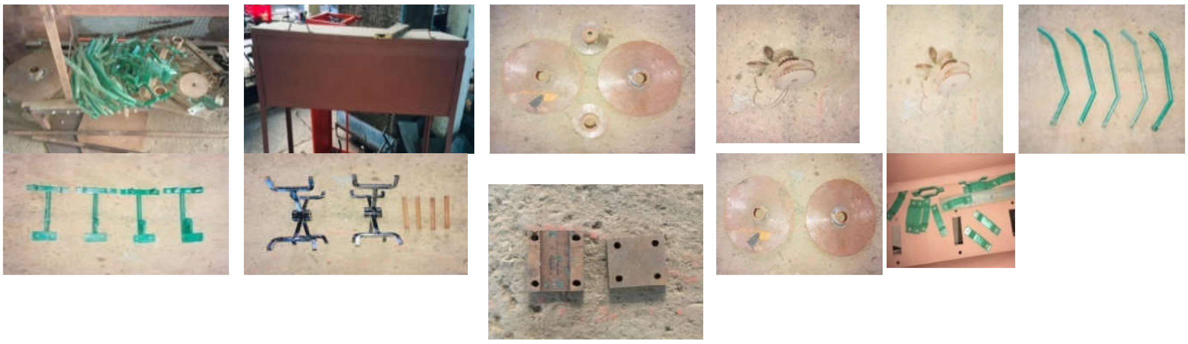
Fabrication of rotary disc

Objectives

1. To fabricate rotary disc seed cum fertilizer drill

Progress

Fabrication of two units ofrotary disc seed cum fertilizer drill is in progress. All the components of the machine has been fabricated. The purchase of rotavator gear box is in progress. Various fabricated components such as discs, chain, flange etc.Rotary disc seed cum fertilizer drill are shown in figure -7.



<u>Activity-5</u>

Development of solar sprayer and weeder.

Objectives

1. To fabricate solar sprayer and weeder

Progress:

Development of Solar sprayer

Solar Triple Nozzle Knapsack Sprayer developed to apply herbicides/Pesticides/ micro-nutrients to crop, spraying operation is done mostly by manual sprayers where the labour has make efforts for pumping using lever rod mounted at the bottom of tank. This solar triple nozzle Knapsack sprayer reduces drudgery and make the spraying operation more effective (Fig. 8).It is light in weight, easy to carry on the back of the operator, capable to develop high pressure without human effort and requires only 33% man hours.

The specifications of solar sprayer are given below.

Tank capacity	Number of nozzles	Solar panel capacity	Battery capacity	DC pump capacity	Field capacity
10-14 L	3	20 Wp	12V, 7Ah	5 l/min	0.3 ha/h 0.11 ha/h for manual knapsack sprayer

Development of Solar Weed Cutter

Solar Weed Cutter is a very light weight weeder. It consists of handle, frame, wheels, solar panel, battery, cutting blade and depth control wheel and having arrangement for height adjustment as per operater's convenience (Fig. 9). The weight of this weeder is about 5 kg. This is used for weeding in between rows. Main specifications and performance data are listed below.

Machine specification

Dimensions in mm L× W × H	Weight, Kg.	Solar panel, watt	Battery	D.C. motor
1680× 570 360	08	20	12V× 7Ah	12 W, 05 Ah

Solar weed cutter is useful for Weed plant cutting and weeding operations in soybean and maize crop fields

Adapting and mainstreaming available best bet location Specific conservation agriculture practices (CRIDA)

Experiments were conducted in different cropping systems (Table 1) on both KVK farm as well as farmers fields to demonstrate the advantage of reducing tillage practices and residue retention.

1. Cowpea-Finger millet (ML-365) cropping system

Experiments were conducted in Horsegram- fingermillet and Cowpea- fingermillet system on vertisols at KVK Tumkuru.on vertisols at KVK Tumkuru.

Traditional systems	Fallow finger millets system
Proposed cropping sequence	**Cowpea-Finger millet (ML-365)/ Horse gram-Finger millet (ML-365)**
T1-Farmers Practice	Sowing of Finger millet in August (Two ploughing + One harrowing)
T2-Minimum Tillage	Sowing of Cow pea/ Horsegram in June (One pre sowing passing tractor drawn cultivator followed by harrowing. Cow pea/ Horsegram) and Sowing of Finger millet with seed drill in August.
T3-No tillage	No till for both the crops.

Results: Ragi ML-365

1. **Farmer: Vishveshwariah, D.Nagenahalli, Koratagere, Taluk, Tumakuru District**.

Treatments	**Plant Height (cm)**	**No. of fingers / Plant**	**Fodder Yield (kg/ha)**			**Seed Yield (kg/ha)**		
			Cowpea	Horsegram	Mean	Cowpea	Horsegram	Mean
T1	94	11	3725	3640	3683	2650	2520	2585
T2	83	10	3450	3410	3430	2550	2405	2478
T3	74	9	3010	3160	3085	2300	2310	2305

2. **Farmer: Ranganath, D.Nagenahalli, Koratagere, Taluk, Tumakuru District.**

Treatments	**Plant Height (cm)**	**No. of fingers / Plant**	**Fodder Yield (kg/ha)**			**Seed Yield (kg/ha)**		
			Cowpea	Horsegram	Mean	Cowpea	Horsegram	Mean
T1	87	10	3615	3545	3580	2450	2500	2475
T2	84	10	3235	3125	3180	2350	2450	2400
T3	77	9	2950	2705	2827	2250	2300	2275

3.**Farmer: KVK, Hirehalli, Tumakuru Taluk, Tumakuru District.**

Treatments	**Plant Height (cm)**	**No. of fingers / Plant**	**Fodder Yield (kg/ha)**			**Seed Yield (kg/ha)**		
			Cowpea	Horsegram	Mean	Cowpea	Horsegram	Mean
T1	98	11	3840	3706	3773	2700	2650	2675
T2	87	10	3570	3345	3457	2630	2485	2557
T3	82	10	3350	3100	3225	2480	2210	2345

In farmers field of D.Nagenahalli, Tumakuru District and field of KVK there was significant difference in plant height, fodder yield and seed yield of Ragi ML-365 in all three treatments (Table 1). The cover crops viz. horsegram and cowpea failed due to dryspells in July and August 2017

Ragi Ml-365

3. Rice-Field pea cropping System

In the trials conducted on Paddy-pea system at Sonitpur, two methods of paddy cultivation -pea sowing were tested. The results of the study revealed that DSR paddy matured 10 days earlier to transplanted paddy in both KVK Farm and farmer's field. Yield and yield attributes (table 2) were higher in transplanted paddy as compared to DSR in both farmers' fields and KVK farm, this higher yields in transplanted paddy is may be due to lower weed competition in transplanted paddy but the benefit: cost ratio was higher in DSR than transplanted rice due to lower cost of cultivation in DSR than transplanted rice (table 3).

Direct seeded paddy at farmers field

Transplanted paddy at farmers field

Table 1: Yield and yield attributes of *Sali* paddy (var.TTB 404) under DSR and transplanted methods of cultivation.

	KVK farm		Farmer field	
Parameters	DSR with drum seeder	Transplanted	DSR with drum seeder	Transplanted
Plant height (cm)	125.3	128.1	121.5	123.2
No. of effective tiller/plant	5.4	6.1	4.7	5.5
Panicle length (cm)	23.1	22.6	21.1	21.8
Grains/panicle	141.4	158.5	132.9	161.2
Duration (Days)	133	145	131	148
Yield (q/ha)	41.09	53.0	38.75	46.3
Cost of cultivation (Rs/ha)	23700.00	30900.00		
Gross Return (Rs/ha)	47,904.00	61800.00		
Net Return (Rs/ha)	24,204.00	30900.00		
B : C	2.02	2.00		

Table 2: Yield and yield attributes of Field Pea (var.Prakash) under zero tillage and relay methods of cultivation. (Location; KVK, Farm, farmer's field)

	KVK, Farm		**Farmers field**	
Parameters	**Zero tillage pea**	**Relay pea**	**Zero tillage pea**	**Relay pea**
No. of Branches	3.6	2.9	3.4	2.7
Nos. of pod/branch	7.5	5.3	7.0	5.4
Nos. of seed/pod	6.5	6.0	5.7	6.2
1000 seed Weight	155 g	150.2	151 g	149.5
Yield (q/ha)	8..75	5.5	7.90	5.3

Table 3: Cost of cultivation of *Field pea* (var. Prakash) under Zero tillage and relay methods of cultivation.

Parameters	**Zero tillage pea**	**Relay pea**
Gross Cost (Rs/ha)	14500.00	12900.00
Gross Return (Rs/ha)	41625.00	29000.00
Net Return (Rs/ha)	27125.00	16100.00
B : C (Gross return/gross cost)	2.53	2.33

The yield and yield attributes of zero tillage pea were higher in KVK, farm and farmers field condition than conventional relay pea after transplanted paddy. This may be due to better and early establishment of pea under zero tillage condition.

IARI

Field Demonstrations
At IARI Research Farms

A comparision between CT and CA system (with and without residue) was made under rice-wheat-mungbean and maize-wheat-mungbean systems in different locations with varying soil textural classes at IARI for grain yield, gross returns and net returns (Table 4). Different soil conditions like clayey-loam and sandy-loam exisiting in farms influenced the yield of mungbean crop. In all the cases, the CA-based ZT with residue gave higher yield of mungbean, gross and net returns, which led to more favourable values of net B:C. The CA-based systems were not only yield efficient but also were economically sustainable. The ZT+R resulted in 7-16.5% higher mungbean yield and Rs 6200 -13100 higher net returns compared to CT or ZT without residue treatment (Table 4).

Table 4. Mungbean yield and economics across soils and cropping systems at IARI

Treatments and systems	Mungbean grain yield (t/ha)	Gross returns ('000 Rs./ha)	Net returns ('000 Rs./ha)	Net B:C
MB-14B (Clayey-loam soil) (rice-wheat-mungbean)				
ZT+R	1.12 (+12%)	78.1	48.7 (+8.3)	1.66
ZT-R	1.00	69.8	40.4	1.37
Mid-A5 (Sandy loam soil) (maize-wheat-mungbean)				
ZT+R	0.91 (+7%)	63.5	34.1 (+6.2)	1.16
Conventional	0.85	59.3	27.9	0.89
Mid-BA (Sandy loam soil) (maize-wheat-mungbean)				
ZT+R	1.13 (+16.5%)	78.8	49.4 (+13.1)	1.68
Conventional	0.97	67.7	36.3	1.16

(a) With residue **(b) Without residue**

Fig 22. Mungbean crop under triple ZT rice-wheat-mungbean system (a, with residue; b, without residue)

On-Farm trial:

2.1.4 Capacity building and knowledge management for accelerated adoption of conservation agriculture machinery

CIAE

Various activities related to capacity building and knowledge management for accelerated adoption of conservation agriculture machinery were organized as depicted in figure 10.

Field day :A field day was organized on conservation agriculture on 01/03/2019. A total of (95) farmers from various villages [Islam Nagar (05), RondiaBarasia road (25), Hatiyakheda (11), Naihedi (01), Sayadsemera (02), Dharmera (02), KarondKhurd (30), Bhairopura (14), Khamkheda (03), Pipliya (01) and Palasi (01)], of Bhopal district participated in the field day.The participants were briefed on updates of C A technologies and covered cultivation. They were given hands on training including demonstrations of improved conservation agricultural machineries such as laser land leveler, happy seeder, pre-immergence herbicide applicator with inclined plate planter, zero till drill and strip till, pipe less drainage system, hand operated dibblers and other agricultural machineries.

Demonstration of CA machinery : Demonstrated CA machinery in Kisanmelaorganised at institute campus during foundation day ceremony held on 16 February, 2019 and on other similar events.

Trainings and Demonstration : Conservation agricultural machinery like laser leveler, no till drill, happy seeder, rotary disc bed farmer cum seeder, stubble saver (rotary chopper cum spreader), rotary slit till drill were demonstrated at the Institute to the 604 farmers of Madhya Pradesh (231),Chhatishgarh (28), Maharashtra (97), Orisha (75), Gujrat (102), Bihar (58) and Uttar Pradesg (13) during various training programmes..

Fig. 1

DWR

On-farm research and demonstration of weed management technologies in rice-wheat/chickpea-greengram and blackgram-wheat-greengram system under conservation agriculture (Patan Locality)

Wheat (*Rabi,* 2017-18)

Five On-farm research trials cum demonstrations on weed management were undertaken at locations *viz*. Podi, Khera, Ramkhiriya and Boria villages of Patan locality in wheat crop under conservation agriculture during *Rabi* 2017-18. Good germination and establishment of wheat crop had occurred under conservation agriculture. The major weed flora observed was *Phalaris minor, Avena ludoviciana, Lathyrus aphaca, Vicia sativa, Medicago polymorpha* and *Chenopodium album*. Application of recommended fertilizer dose (RFD) (120:60:40 N, P_2O_5, K_2O kg/ha) along with herbicide (clodinofop+metsulfuron 60+4 g/ha as post-em) under conservation agriculture at 30 DAS resulted in the lowest weed density and biomass and higher grain yield (4.88 t/ha), higher net income (Rs. 80240/ha) with higher B:C ratio of 5.62 compared to farmer"s practice (conventional tillage + high seed rate+ unbalanced fertilizer without proper weed management) (**Table 1**).

Table 1: **Weed management and productivity of wheat under conservation agriculture in OFR at Patan locality during *Rabi* 2017-18 (average of 5 farmers)**

S. No.	Treatments	Weed density (no./m^2)	Weed dry weight (g/m^2)	WCE (%)	Grain yield (t/ha)	Gross return (Rs./ha)	Net profit (Rs./ha)	B:C ratio
1	CA+ RFD + WM	17.2	12.54	80	4.88	97600	80240	5.62
2	Farmers Practice	100	63.16	-	4.03	80600	53990	3.00

RFD: Recommended fertilizer dose

Chickpea (Rabi 2017-18)

Two OFR cum demonstrations were conducted on weed management in chickpea under conservation agriculture in Boria and Khera villages of Patan locality during *Rabi* 2017-18. The major weed flora observed was *Phalaris minor, Avena ludoviciana, Chenopodium album* and *Lathyrus aphaca*. Weed density and dry weight in chickpea grown with recommended fertilizer (20:60:40 N, P_2O_5, K_2O kg/ha) and herbicide (pendimethalin 750 g/ha as pre-em) under CA was lower than farmers practice (**Table 2**). The seed yield of chickpea was 2.16 t/ha in CA practice with improved weed management technique. The higher B:C ratio of 5.60 was recorded with the same treatment, whereas the B:C ratio was only 2.93 in farmers practice.

Table 2. Weed management and productivity of chickpea under conservation agriculture in OFR at Patan locality during *Rabi* 2017-18 (average of 2 farmers)

S. No.	Treatments	Weed density (no./m^2)	Weed dry weight (g/m^2)	WCE (%)	Seed yield (t/ha)	Gross return (Rs./ha)	Net profit (Rs./ha)	B:C ratio
1	CA+ RFD + WM	28.00	23.75	58	2.16	99792	84992	5.60
2	Farmers practice	70.50	56.40	-	1.32	60984	40164	2.93

RFD: Recommended fertilizer dose

Greengram (Summer 2018)

On-farm research (OFR) trials were undertaken on greengram under conservation agriculture during summer season of 2018 at six farmer‟s fields in the villages Khera, Ramkhiriya and Boria of Patan locality. Result revealed that RFD (20:60:40 N, P_2O_5, K_2O kg/ha) + CA + imazethapyr 100 g/ha as post-em was effective and gave broad spectrum weed control and a seed yield of 1.26 t/ha, as compared to 0.9 t/ha under FP (CT + 1 hand weeding); and provided an additional net return of Rs.25112/ha with higher B:C ratio over farmers practice. Beside this, use of Happy Seeder saved time and favoured early sowing which helped to utilize residual soil moisture, and saved field preparation cost (**Table 3**).

Table 3. Weed management and productivity of greengram under conservation agriculture in OFR at Patan locality during summer 2018 (average of 6 farmers)

S. No.	Treatments	Weed density (no./m^2)	Weed dry weight (g/m^2)	WCE (%)	Seed yield (t/ha)	Gross return (Rs./ha)	Net profit (Rs./ha)	B:C ratio
1	CA+ RFD + WM	33.17	33.83	41	1.26	80942	63092	4.53
2	Farmers practice	56.17	57.07	-	0.90	62775	37980	2.53

RFD: Recommended fertilizer dose

Rice (DSR) (*Kharif*, 2018)

On-farm research (OFR) trials were undertaken on weed management in direct-seeded rice during *Kharif* season of 2018 at 2 farmers‟ fields in the village Podi and Ponia of Patan locality. Weed management through herbicides with recommended fertilizer dose (RFD) was compared with the farmer‟s practice. The major weed flora observed was *Echinochloa colona, Dinebra retroflexa, Cyperus iria, Phyllanthus niruri,* and *Physallis minima*. Application of recommended fertilizer dose (RFD) (120:60:40 N, P_2O_5, K_2O kg/ha) along with the application of herbicide (bispyribac-Na 25 g/ha as post-em) was more effective (weed dry weight 53.8 g/m^2; grain yield 4.05 t/ha; B: C 3.31) over farmer‟s practice (high seed rate+ unbalanced fertilizer without proper weed management) (weed dry weight, 82.1 g/m^2; grain yield 3.39 t/ha; B:C 1.86) (**Table 4**).

Table 4. Weed management and productivity of DSR rice in OFR at Patan locality during *Kharif* 2018 (average of 2 farmers)

S. No.	Treatments	Weed density (no./m²)	Weed dry weight (g/m²)	WCE (%)	Grain yield (t/ha)	Gross return (Rs./ha)	Net profit (Rs./ha)	B:C ratio
1	CA+ RFD + WM	46.5	53.8	35	4.05	70788	49428	3.31
2	Farmers practice	68.0	82.1	-	3.39	59238	27378	1.86

Rice (*Kharif* 2018) (Transplanted)

On-farm research (OFR) trials were undertaken on weed management in direct-seeded rice during *Kharif* season of 2018 at 4 farmers‟ fields in the village Ramkhiriya and Khera of Patan locality. Weed management through herbicides with recommended fertilizer dose (RFD) was compared with the farmer‟s practice. The major weed flora observed was *Echinochloa colona, Dinebra retroflexa, Phyllanthus* spp., *Caesulia auxillaris, Alternanthera sessilis* and *Cyperus iria*. Application of recommended fertilizer dose (RFD) (120:60:40 N, P_2O_5, K_2O kg/ha) along with the application of herbicide (bispyribac-Na 25 g/ha as post-em) was more effective (weed dry weight 30.2 g/m^2; grain yield 4.88 t/ha; B: C 2.72) over farmer‟s practice (high seed rate+ unbalanced fertilizer without proper weed management) (weed dry weight, 53.9 g/m^2; grain yield, 4.02 t/ha; B:C 2.06) (**Table 5**)

Table 5. Weed management and productivity of transplanted rice in OFR at Patan locality during *Kharif*2018 (average of 4 farmers)

S. No.	Treatments	Weed density (no./m²)	Weed dry weight (g/m²)	WCE (%)	Grain yield (t/ha)	Gross return (Rs./ha)	Net profit (Rs./ha)	B:C ratio
1	CA+ RFD + WM	25.0	30.2	44	4.88	85365	54005	2.72
2	Farmers practice	45.5	53.9	-	4.02	70403	36293	2.06

RFD: Recommended fertilizer dose

On-farm research and demonstration of weed management technologies in rice-wheat-greengram and maize-chickpea-greengram system under conservation agriculture (Bargi locality)

On-farm research (OFR) trials cum demonstration on weed management in rice-wheat-greengram and maize-chickpea-greengram under conservation agriculture (CA) were carried out to transfer and evaluate the improved weed management technologies at farmers‟ field. At Bargi locality, OFR trials were conducted at five villages, *viz.* Silua, Sagda, Rosara, Pindrai, Barha and Pipariya Charghat during *Rabi* 2017-18, summer 2018 and *Kharif* 2018 in rice, maize, wheat, chickpea and greengram under rice-wheat-greengram and maize-chickpea-greengram cropping systems. Improved weed management in crops grown under Conservation Agriculture (CA) with recommended fertilizer dose (RFD) and weed management were compared with conventional practice done by the farmers. The sowing of crops under CA practice was done using Happy Seeder machine without removal of previous crop residues.

Wheat (*Rabi*, 2017-18)

The major weed flora observed were *Medicago polymorpha, Vicia sativa, Phalaris minor, Convolvulus arvensis, Lathyrus aphaca, Chenopodium album* and *Sonchus oleraceus*. Application of recommended fertilizer dose (120:60:40 N, P_2O_5, K_2O kg/ha) along with herbicide (clodinafop + metsulfuron 60+4 g/ha at 25 DAS) under CA resulted in the lowest weed density and dry biomass accumulation (**Table 6**). This treatment also produced higher plant height, number of spike/m row and spike length. As compared to farmers practice (conventional tillage, higher seed rate and without proper weed management), the improved weed management techniques in CA produced 33% of higher wheat grain yield (4.40 t/ha), net return (Rs. 60199) and B:C ratio (3.91).

Table 6. Weed management and productivity ofwheat in OFR at Bargi locality during *Rabi,* 2017-18

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	Tillers (no./m^2)	Plant height (cm)	Panicle length (cm)	Grain yield (t/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
CA with RFD and herbicide	17.3	3.4	21.8	78.5	17.2	4.40	80874	60199	3.91
Farmers practice	81.0	18.5	28.1	74.5	11.9	3.30	60635	30260	2.00
CA with RFD and without herbicide	236.3	50.9	15.7	77.8	14.6	2.73	50153	31103	2.63

Values are the average of four farmers; CA: Conservation agriculture; RFD: Recommended fertilizer dose; Herbicide: clodinafop + metsulfuron 60+4 g/ha at 25 DAS

Chickpea (*Rabi,* 2017-18)

The major weed flora observed were *Vicia sativa, Lathyrus aphaca, Avena fatua, Euphorbia heterophylla, Parthenium hysterophorus* and *Sonchus oleraceus*. Weed density and dry weight in chickpea grown with recommended fertilizer (30:60 N, P_2O_5 kg/ha) and herbicide (pendimethalin 750 g/ha at 2 DAS) under CA was 40 and 73%, respectively, lower than farmers practice. The maximum plant density was observed with farmers practice, whereas, number of pods/plant and branches/plant was higher in plots, which received recommended fertilizer and

improved weed management practice under CA. The seed yield of chickpea was 1.53 t/ha in CA practice with improved weed management technique. The higher B:C ratio 3.19 was recorded with the same treatment, whereas the B:C ratio was only 1.43 in farmer‟s practice.

Greengram (Summer, 2018)

During summer, 2018, OFR trials on greengram under CA were conducted with three treatments, *viz*. (i) CA with RFD and herbicide (imazethapyr 100 g/ha at 20 DAS) (ii) farmers‟ practice (iii) CA with RFD and without herbicide. The major weed flora observed were *Dinebra retroflexa, Euphorbia heterophylla, Eleusine indica, Brachiaria reptens, Parthenium hysterophorus* and *Phyllanthus maderaspatensis*. As compared to farmers‟ practice, application of recommended fertilizer dose (30:60 N, P_2O_5 kg/ha) along with herbicide under CA resulted in 80 and 84% lower weed density and dry biomass accumulation, respectively (**Table 7**) than farmers‟ practice. Same treatment produced the maximum plant height and number of pods per plant in greengram. Improved weed management technique in CA produced higher greengram seed yield (0.82 t/ha) and B:C ratio (2.77) compared to farmers practice, Values are the average of two farmers; CA: Conservation agriculture; RFD: Recommended fertilizer doseHerbicide: imazethapyr 100 g/ha at 20 DAS

Table 7. Weed management and productivity of greengram in OFR at Bargi locality during summer, 2018

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	Plant height (cm)	No. of branches/plant	No. of pods/plant	Seed yield (t/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
CA with RFD and herbicide	12.4	3.6	47.0	4.56	21.78	0.82	56963	36363	2.77

Farmers practice	63.0	22.8	36.6	3.22	9.22	0.66	45907	10407	1.29
CA with RFD and without herbicide	127.3	33.7	33.0	2.78	7.89	0.48	33713	14463	1.75

Rice (*Kharif,* 2018)

On-farm research trials were undertaken on weed management in direct-seeded rice under CA. The major weed flora observed was *Echinochloa colona*, *Commelina communis*, *Cyperus iria* and *Alternanthera sessilis*. The recommended weed management and fertilizer dose practice were compared with farmers practice. As compared to farmers practice, application of recommended fertilizer dose (120:60:40 N, P_2O_5, K_2O kg/ha) along with herbicide (bispyribac-Na 25 g/ha at 20 DAS) effectively reduced the weed density and dry weight by 53 and 62%, respectively.This treatment also produced higher number of tillers (59.3/m^2), panicle length (23.1 cm) and number of grains per panicle (143). The grain yield (4.28 t/ha) and net return (Rs. 54508 /ha) was also higher in CA with RFD and herbicide in comparison to farmers" practice.

Maize (*Kharif,* 2018)

The major weed flora observed was *Commelina communis*, *Echinochloa colona*, *Alternanthera sessilis*, *Mullogo pentaphylla*, *Convolvulus arvensis* etc. Weed density and dry weight in maize grown with recommended fertilizer (120:60:40 N, P_2O_5, K_2O kg/ha) and herbicide (atrazine 750 g/ha *fb* tembotrione 120 g/ha at 30 DAS) under CA was 35 and 14%, respectively lower than farmers practice (**Table 8**). The maximum plant height and number of cobs/m^2 were recorded from the plots received recommended fertilizer and advanced weed management practice under CA. The grain yield of maize was 6.04 t/ha in CA practice with improved weed management technique. As compared to the farmer practice, the higher net return (Rs. 78843) and B:C (4.31) ratio were recorded with the same treatment.

Table 8. Weed management and productivity of maize in OFR at Bargi locality during *Kharif,* 2018

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	No. of plants / m^2	Plant height (cm)	No. of cobs /m^2	Grain yield (t/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
CA with RFD and herbicide	19.5	12.5	15.7	169	17.4	6.04	102643	78843	4.31
Farmers practice	30.2	14.6	15.7	149	15.5	5.25	89329	54329	2.55
CA with RFD and without	124.3	76.3	9.5	124	10.3	3.50	59525	40725	3.17

Values are the average of two farmers; CA: Conservation agriculture; RFD: Recommended fertilizer dose; Herbicide: atrazine at 750 g/ha as PRE *fb* tembotrione 120 g/ha at 30 DAS

Herbicide residues under conservation agriculture experiments

Soil and plant samples were collected at harvest in *Rabi* 2017-18 and *Kharif* 2018 for determination of terminal residues. Presence of herbicide residues in soil, and plant samples were determined by standardized UFLC methods using a PDA detector. The UFLC methods makes use of Phenomenex C-18 (ODS) column (3.5 µm particle size, 5×3.5 mm i.d.) and acetonitrile: H_3PO_4 0.01% (70:30 v/v) as mobile phase at a flow rate of 0.35 ml/min. 10 µl of the aliquot of standards and samples was injected by using micro syringe.

In rice-maize/mustard/pea-greengram cropping system, pendimethalin residues in mustard seed were found below detection limit (0.01 µg/g) in pendimethalin 678 g/ha (W_2) and pendimethalin 678 g/ha *fb* HW (W_3). In mustard straw, 0.021 to 0.074 µg/g residues were detected in pendimethalin 678 g/ha (W_2) and pendimethalin 678 g/ha *fb* HW (W_3).

In maize, pendimethalin residues in maize grain were found below detection limit (0.01ug/g) in atrazine + pendimethalin (500+500 g/ha; W_2) and atrazine + pendimethalin (500+500 g/ha) *fb* HW (W_3), whereas, in maize straw pendimethalin residues were found to be 0.022 to 0.044 µg/g in atrazine + pendimethalin (500+500 g/ha; W_2) and atrazine + pendimethalin (500+500 g/ha) *fb* HW (W_3).

In *rabi*, mesosulfuron and iodosulfuron residues were found to be below 0.01ug/g in soil, wheat grain and straw at harvest (**Table 9**). Metsulfuron, sulfosulfuron and clodinafop-propargyl and residues were found to be below instrument detection limit (0.01 and 0.001 µg/g) in soil, wheat grain and straw at harvest.

Table 9. Residue of mesosulfuron + iodosulfuron in soil, grain and straw of wheat under conservation agriculture

Treatment	Residues (µg/g)		
	Soil	Wheat grain	Wheat straw
Mesosulfuron + iodosulfuron (CT)	<0.01	<0.01	<0.01
Mesosulfuron + iodosulfuron (ZT)	<0.01	<0.01	<0.01
Mesosulfuron + iodosulfuron (ZT)	<0.01	<0.01	<0.01
Mesosulfuron + iodosulfuron (ZT+R)	<0.01	<0.01	<0.01
Mesosulfuron + iodosulfuron (ZT+R)	<0.01	<0.01	<0.01
Mesosulfuron + iodosulfuron (ZT)	<0.01	<0.01	<0.01

In rice-wheat-greengram cropping system, in *kharif* 2018, bispyribac –sodium and penoxsulam residues were found below 0.001 µg/g.

In soybean-wheat-greengram cropping system, metribuzin residues in soybean were found to be 0.031 to 0.234 µg/g in metribuzin 500 g/ha *fb* HW. Pendimethalin residues in soybean grain were found to be 0.046 to 0.0524 µg/g in pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha.

In maize-wheat-greengram cropping system, tembotrione residues were found < 0.01 in maize grain at harvest. An amount of 0.0824 to 0.115 µg/g atrazine residues were found in maize grains.

In maize-mustard-greengram cropping system, topramezone residues were found 0.0181 to 0.0405 µg/g in the maize grain in atrazine+topramezone (500+25.3 g/ha) and atrazine+topramezone (500+25.3 g/ha) *fb* HW.

Report of Workshop-cum-Meeting on 'Weed management in Conservation Agriculture' under CRP on CA project

ICAR-Directorate of Weed Research, Jabalpur organized 2 days Workshop-cum-Meeting on „Weed management in Conservation Agriculture" under CRP on CA project during 11-12 September, 2018.

Dr. S.K. Chaudhari, ADG (Soil & Water Management), NRM division, New Delhi, in his inaugural address, appreciated the works done by Directorate in the form of on-farm research and demonstration of conservation agriculture in nearby districts of Jabalpur for promotion of the technology. He informed that Madhya Pradesh has greater scope for the conservation agriculture which may be helpful to save the resources and environment in future. He appealed participants to interact more and more to have fruitful results and recommendations at the end of the workshop.

Dr. A.K. Patra, ICAR-Indian Institute of Soil Science, Bhopal stressed upon the need of weed management in conservation agriculture and hoped that this workshop will help in finding the solution of the problems related to weed management in conservation agriculture.

Dr. A.K. Biswas, LCPC, CRP on CA, ICAR-IISS, Bhopal briefed about the objectives of the workshop-cum-meeting and urged that this workshop should be more interactive for finding the weed management options in different cropping systems under CA.

Dr. P.K. Singh, Director, ICAR-Directorate of Weed Research, Jabalpur informed the participants about the work carried out by Directorate in nearby districts of the Jabalpur and in 16 states through centres of AICRP-WM located at different State Agricultural Universities.

During the inaugural session, 3 publications of the Directorate were also released by the dignitaries. This workshop was attended by PIs/scientists of 10 different ICAR institutes located in 8 states who are working on CRP on Conservation Agriculture project along with scientists of the Directorate. Besides the technical sessions, field visit to the farm of the Directorate and farmers field where crops are being raised under CA, were also organized for the participants. The programme was coordinated by Dr. V.K. Choudhary, Senior Scientist and Principal Investigator, CRP on Conservation Agriculture at ICAR-DWR, Jabalpur (MP).

IIWBR

Demonstrations at farmers field:

Three CAwheat demonstrations were conducted in two villages (Badarpur and Taraori) in rice-wheat system. Wheat cultivar HD 2987 and HD 3086 were sown using a seed rate of 125 kg/ha using the Turbo Happy Seeder. The mean wheat yield was similar in CA (65.8 q/ha) and CT (65.0 q/ha) system.

Wheat seeded in sugarcane ratoon crop with full trash using Rotary Disc Drill

Under "MeraGaonMera Gaurav" scheme in Village Badarpur, two field were selected for seeding of wheat in ratoon crop of Sugarcane. The growing of wheat or other crops like green gram will be additional crops for the farmers and will enhance the profitability of the farmers as well as the wheat production. Moreover, this will promote the conservation agriculture with better environmental health by reducing the pollution with no straw/trash burning.

The two late sown varieties WR 544 and DBW 90 were sown using a seed rate of 150 kg/ha on 28th Jauary 2019. The new version of RDD was used for seeding in full trash of sugarcane. Whereas for Turbo Happy Seeder seeding was done in absence of residue.

The wheat yield obtained was 27.73 (DBW 90) and 26.33 (WR 544) q/ha when sown using RDD. Whereas with THS sown DBW 90 yielded 21.77 q/ha. Therefore an additional crop of wheat can be taken in sugarcane ratoon using RDD.

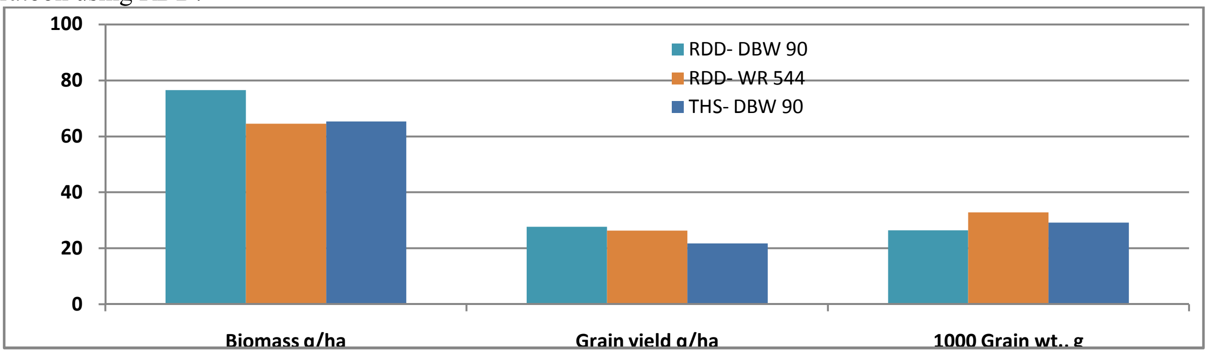


Fig. Wheat seeded in sugarcane ratoon using Rotary Disc Drill

Impro

During ... straight powered discs with New version with notched and serrated powered disc (SoilRazor CT Disc) with better residue cutting effect. These discs had been imported by Beri Udyog Ltd, Karnal. This was tested for seeding in full rice residue and full sugarcane trash and found significant improvement in its efficiency. Further work is going on for its depth control and precision drilling mechanism.

Photo : New version with notched and serrated powered disc (SoilRazor CT Disc) with better residue cutting effect.

Photo: Rolling type Double disc on the back of RDD for guiding seed and fertilizer in the slit made by powered disc

IIFSR

Activities under SCSP programme:

Under this programme village Kanoda, Daurala (Meerut, UP) have been selected which consists 90% population of Schedule caste group. Crops (mainly sugarcane, rice, wheat, sorghum &barseem), animal component (buffalo & cow) and earning though wages as laborers are the major source of income in the community. One hundred farmers have been selected in March, 2019underthis programme. Presently for the upliftment of the community sorghum (kanpuri white) seed for fodder, fertera (insecticide) for controlling insects in sugarcane and rice crop, animal feed supplement for higher milk production and small tools (pitthidarati, sickle, &balkati) for facilitating the farmers for enhancing their efficiency in day to day operations have been provided.

IARI

At Farmers' Fields

The success of the CA based rice-wheat system was validated on farmers' fields in three districts of the north-western Indo-Gangetic plain *viz.* Bareilly, Karnal and Gurgaon (Table 10). The fields of eighteen farmers (six from each district) were planted with direct-seeded rice, transplanted rice, zero-till wheat and conventional-till wheat and compared for their respective crop yields and net returns. In all the districts, zero till wheat exhibited much higher yield than conventional tilled wheat while DSR yield was closely comparable to TPR yield. The DSR-ZTW system performed at par in terms of yield with TPR-CTW and even showed higher yield in Karnal district. With respect to net returns, zero tilled wheat gave approximately 20% higher net returns as compared to conventional system. The DSR-ZTW also performed better than TPR-CTW and gave about 14-15% higher net returns (Fig.2).These successful field demonstrations not only proved the superiority of CA based systems in terms of yield but also established its importance as a highly sustainable and an economically viable alternative to conventional agriculture systems.

Table 10: Crop yield (t/ha) and net returns (Rs./ha) in farmer's fields in three districts under study

District	Rice yield t/ha (WEY)		Wheat yield t/ ha		System productivity (t/ha)	
	DSR	TPR	ZTW	CTW	DSR-ZTW	TPR-CTW
Bareilly (6 farmers)	3.91 (3.72)	4.63 (4.40)	5.24	4.7	8.96	9.10
Karnal (6 farmers)	4.0 (3.80)	4.75 (4.52)	5.43	4.88	9.43	9.40
Gurgaon (6 farmers)	4.06 (3.92)	4.9 (4.73)	5.7	5.15	9.62	9.88
Rice-wheat system net returns (Rs/ha)						
District	DSR	TPR	ZTW	CTW	DSR-ZTW	TPR-CTW
Bareilly (6 farmers)	42315	42849	92432	75937	134747	118786
Karnal (6 farmers)	44608	45973	96418	79576	141026	125549
Gurgaon (6 farmers	45670	48628	101373	84530	147043	133158

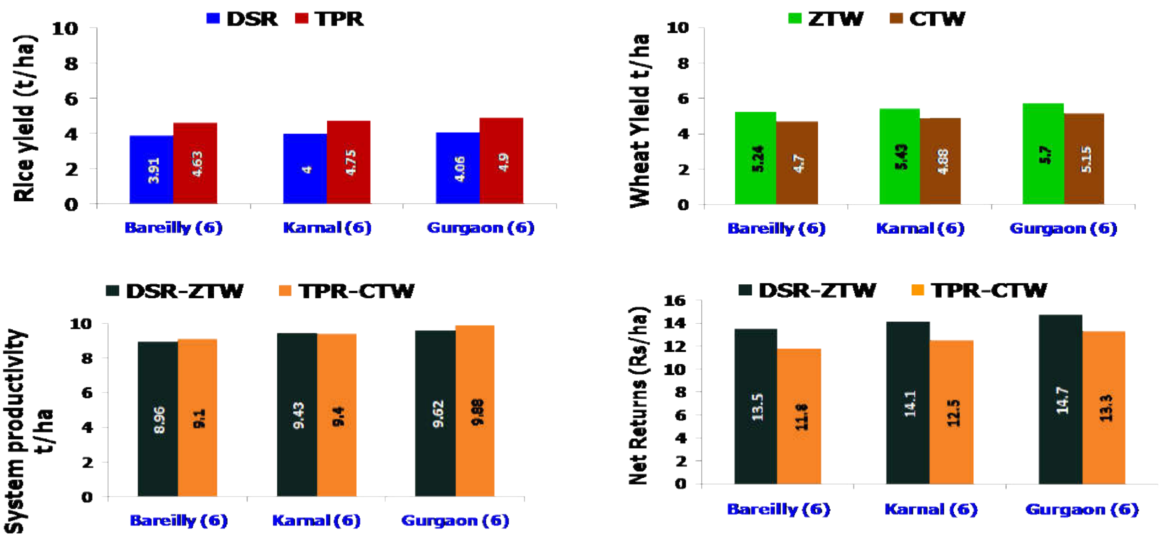


Fig 2: Crop yield, system productivity and net returns in farmers' field (CA v/s CT)

CSSRI

Demonstration of best between conservation technologies, developed at CSSRI, Karnal in rice–wheat cropping system

The Agri- CRP project- CRP on Conservation Agriculture in farmers' participatory mode during June 2015 has been started. The promising conservation technologies developed at CSSRI, Karnal under rice-wheat cropping system has been demonstrated at farmer's field at four sites. Technical programme of rice–wheat cropping system demonstrated at farmer's field is given below in Table 11&12.

A total of 4 demonstrations at four different locations representing diverse environment with different soil and water quality as described Table 16 under rice-wheat cropping sequence were carried out in farmers' participatory mode in collaboration with respective district KVKs to evaluate, validate and refine (if required) the technological interventions.

The details are as under-

The following technical programme is totally under investigation at farmers' fields in 4 villages under different CA techniques, were taken as per the technical programme (Table 11) under testing different tillage, residue and water management, especially micro irrigation methods.

Table 11: Cropping system, soil type, water quality and area under different offsite experiment on farmers' fields.

Cropping system	Soil type	Water quality	No. of demonst.	Area (ha)	Location
Rice-wheat	Sodic/saline	Saline/Sodic/ Fresh	4	1.6	Karnal, Kaithal, Panipat
Total			**4**	**1.6**	

Table 12: Technical programme of best conservation technologies at farmers fields for demonstration from 2018-2019

Rice-Wheat Cropping System		
S. No	**Symbol**	**Treatments**
T_1	CV	Conventional –Prevailing farmers practices-(rice-TPR and wheat with rotavator)
T_2	CV+ RR	TPR with wheat residue incorporation (1/3 part)-ZT wheat with rice residue mulch/anchored
T_3	DSR-ZT wheat	Direct seeded rice -ZT wheat with rice residue mulch/anchored under surface irrigation method
T_4	DSR-ZT wheat	Direct seeded rice -ZT wheat with rice residue mulch/anchored with sprinkler irrigation method

Whereas, CV+RR = conventional tillage in both rice and wheat crops with wheat and rice crop residue;
DSR-ZT wheat=Direct seeded rice followed by zero tilled wheat
CV=Conventional practices of rice-wheat crop
RR=rice residue

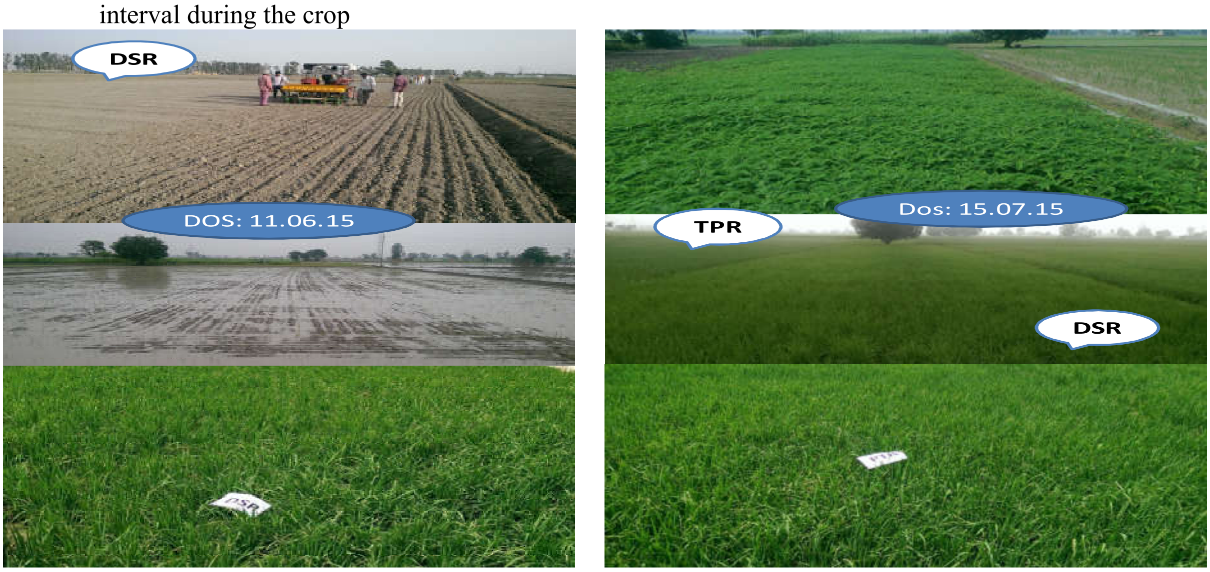
Experimental area= One acre (4000 m^2).
Package and practice- Recommended package and practice followed (150:60-N:P) for both rice and wheat crops
Variety: Rice- Basmati CSR 30 and wheat –KRL 210
Farmers practice- Rice harrow 2 times, tiller= 2 times, leveling= 2 times, laser leveling= one time/year and puddling with harrow
Residue management- Crops cutting was done 15-20 cm from soil surface
ZT= Zero tillage

Farmers not interested to grow and maintain dhaincha in plots under saline and RSC water. They reported that dhaincha required frequent irrigation during summer, which further deteriorated soil condition (soil physical condition). Therefore this treatment has been changed as direct seeded rice -ZT wheat with rice residue mulch/anchored under surface irrigation method.

Results-

(i) **Rice Crop-** The details of different CA technologies at farmers' fields are presented accordingly.

- Rice variety basmati CSR 30 was grown in direct seeded (DSR) and transplanted (TPR) conditions
- DSR with 50% tillage with CSR 30 basmati rice experiment was laid out along with the farmer practice (TPR) for the demonstration
- The recommended dose of nitrogen (90 kg ha^{-1}), phosphorus (60 kg ha^{-1}), potash (40 kg ha^{-1}) and Zinc (24 kg zinc sulphate ha^{-1}) were applied
- Irrigation was applied in DSR after 4/5 days interval under surface method at the depth of 6.0 cm.
- Irrigation was scheduled when soil surface dry with small cracking, irrigation was made at 4/5 days interval during the crop



Field view of DSR and TPR during *kharif* season at farmers' fields

(a) Crop yield under different RCTs from fields demonstration during rice 2018-

- The grain yield of Basmati CSR 30 vary with soil and water quality (Table 13)
- The averaged data on grain yield from four different locations shows that green manuring with dhaincha gave statistically similar grain yield in puddle transplanted rice.
- However, this technique is feasible only where irrigation water is not a problem.
- Under constraint of irrigation water, mini-sprinkler in DSR is best suited, with grain yield at par with conventional TPR practice.
- The grain yield under various technologies was higher in village Shambhli (Karnal) than all other locations.
- The lowest grain yield under all technologies was in village Kaith (Panipat). The reason for poor yield in this location was problematic soil and water. However, at this location TPR with green manuring performed better compared to other DSR treatments.
- The grain yield of rice under DSR was at par with puddle transplanted rice.

- DSR with dhaincha as green manure produced highest grain yield at all the locations except at village Shambhali where conventional practice gave maximum yield.
- Grain yield in DSR with sprinkler irrigation was lower than conventional practice, while it is higher than DSR under surface irrigation
- Among four locations, highest grain yield of DSR in sprinkler irrigation (3.40 tha^{-1}) was at village Shambhali and lowest at village Kaith (2.32 tha^{-1}).
- In DSR, with the omission of puddling, there is saving of irrigation water, labour, diesel, electricity and time. These resources can be used to cover additional area under DSR.
- Salt tolerant variety (CSR 30 basmati) performed well under higher RSC water with yield up to 3.51 tha^{-1} in TPR technique.

Table 13: Productive potential of rice under different crop establishment techniques during *kharif* 2018 at farmers' field

	TPR	TPR (GM)	DSR	DSR+Sprl	Mean	CD
Shambhali	3.21	3.32	3.19	3.40	3.36	0.23
Geong	3.12	3.42	3.20	3.30	3.26	0.31
Bahupur	3.34	3.46	3.20	3.40	3.35	0.29
Kaith	2.90	2.70	2.22	2.32	2.56	0.28
Mean	3.24	3.23	2.95	3.11	3.16	0.25

(b) Economic analysis of different RCT's in rice during kharif 2018 at farmers' field-

- **Shambhali village:** Data on economic analysis of rice during *kharif* 2018 clearly shows that all CA technologies are economically better (Table 14). Highest B:C ratio (2.22) was calculated in direct seeded rice under surface irrigation system closely followed by direct seeded rice under sprinkler irrigation alone (1.95). CA technologies are economically feasible and have economical potential.

- **Geong village:** Economic analysis of rice under different technologies at village Geong during *kharif* 2018 shows that different RCT's performed better than farmers' practice (Table 15). The net income and B:C ratio under different RCT's were higher than conventional transplanted rice (farmers practice). Highest net income (Rs.844400.0 ha^{-1}) was obtained under transplanted rice with dhaincha as green manure followed by direct seeded rice under surface irrigation (Rs.83954.0 ha^{-1}). However, highest B: C (2.23) was in DSR under surface irrigation followed by DSR in sprinkler system (1.87). Lower cost of cultivation was recorded in DSR with surface irrigation, was responsible for their higher B:C ratio.

Table 14: Economic analysis of rice crop under different CA techniques

Economic analysis of rice crop cultivated at village Shambhali					
RCTs	**Grain yield, tha^{-1}**	**Cost of cultivation (Rs ha^{-1})**	**Gross income (Rs ha^{-1})**	**Net income (Rs ha^{-1})**	**B:C**
TPR (CV)	3.21	44560	121980	77420	1.74
TPR+DGM	3.32	45560	126160	80600	1.77
DSR-surface irrg.	3.19	37646	121220	83574	2.22
DSR-SPRL	3.40	43725	129200	85475	1.95
SE(m) ±	0.13	-	-	-	-
CD at 0.05	0.23	-	-	-	-
Note- Market rate of basmati CSR 30 for the year 2018, Rs. 3800/q. Rice straw income not included. Cost of cultivation includes-operational cost. srf=surface irrigation, SPRL=sprinkler irrigation system.					

Table 15: Economic analysis of rice crop under different CA techniques.

Economic analysis of rice crop cultivated at Geong village					
RCTs	**Grain yield, t/ha**	**Cost of cultivation (Rs ha^{-1})**	**Gross income (Rs ha^{-1})**	**Net income (Rs ha^{-1})**	**B:C**
TPR (CV)-srf	**3.12**	**44560**	**118560**	**74000.0**	**1.66**
TPR+DGM-srf	**3.42**	**45560**	**129960**	**84400.0**	**1.85**
DSR-surf.	**3.20**	**37646**	**121600**	**83954.0**	**2.23**
DSR-SPRL	**3.30**	**43725**	**125400**	**81675.0**	**1.87**
SE(m)±	**0.11**	**-**	**-**	**-**	**-**
CD at 0.05	**0.31**	**-**	**-**	**-**	**-**
Note- Market rate basmati CSR 30 for the year 2018, Rs. 3800/q. Rice straw income not included. Cost of cultivation includes-operational cost. srf = surface irrigation, SPRL=sprinkler irrigation system.					

➢ **Bahupur village:** Perusal of data in Table 16 on economic analysis of rice crop under different RCT's revealed that B:C varied from 1.85 to 2.23, and highest was recorded under direct seeded rice under surface irrigation (2.23) closely followed by direct seeded rice under sprinkler irrigation (1.95). Highest net income was computed under transplanted rice with dhaincha green manuring (Rs.85920 ha^{-1}) followed by direct seeded rice under sprinkler irrigation system (Rs.85475 ha^{-1}). Sprinkler irrigation method in rice crop is feasible under DSR with saving of natural resources.

Table 16: Economic analysis of rice crop under different CA techniques at Bahupur in Panipat district

Economic analysis of rice crop cultivated at Bahupur village					
RCTs	**Grain yield, t/ha**	**Cost of cultivation (Rs ha^{-1})**	**Gross income (Rs ha^{-1})**	**Net income (Rs ha^{-1})**	**B:C**
TPR (CV)	**3.34**	**44560**	**126920**	**82360**	**1.85**
TPR+DGM	**3.46**	**45560**	**131480**	**85920**	**1.89**
DSR-surface irrg.	**3.20**	**37646**	**121600**	**83954**	**2.23**
DSR-SPRL	**3.40**	**43725**	**129200**	**85475**	**1.95**
SE(m)±	**0.10**	-	-	-	-
CD at 0.05	**0.29**	-	-	-	-
Note- Market rate basmati CSR 30 for the year 2018, Rs. 3800/q. Rice straw income not included. Cost of cultivation includes-operational cost. srf =surface irrigation, SPRL=sprinkler irrigation system.					

➢ **Kaith village**- Data given in Table 17 shows rice crop performance and economic analysis at village Kaith. There grain yield under different treatments was comparatively lower compared to other sites. The main reason behind this was poor quality of irrigation water and soil. At this site, transplanted rice with dhaincha as green manure performed better with highest grain yield (2.90 t ha^{-1}), net returns (Rs. 65640 ha^{-1}) and B:C (1.47) than other CA technology.

Table 17: Economic analysis of rice crop under different CA techniques at Kaith village

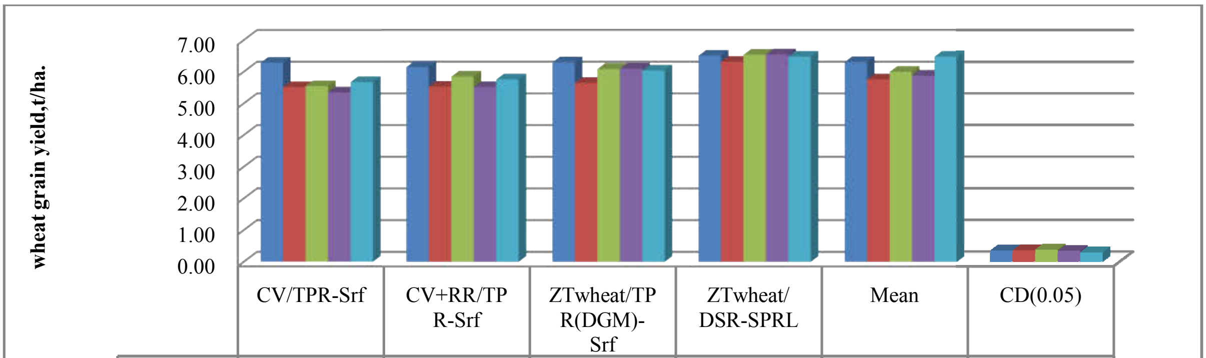
Economic analysis of rice crop cultivated at Kaith village					
RCTs	**Grain yield, tha^{-1}**	**Cost of cultivation (Rs ha^{-1})**	**Gross income (Rs ha^{-1})**	**Net income (Rs ha^{-1})**	**B:C**
TPR (CV)	**2.70**	45560	**102600**	**57040**	**1.25**
TPR+DGM	**2.90**	44560	**110200**	**65640**	**1.47**
DSR-surface irrg.	**2.22**	37646	**84360**	**46714**	**1.24**
DSR-SPRL	**2.32**	43725	**88160**	**44435**	**1.02**
SE(m)±	**0.12**	-	-	-	-
CD at0.05	**0.28**	-	-	-	-
Note- Market rate basmati CSR 30 for the year 2018, Rs. 3800/q. Rice straw income not included. Cost of cultivation includes-operational cost. Srf=surface irrigation, SPRL=sprinkler irrigation system.					

Wheat Crop:

The details of different CA technologies at farmers' fields are presented accordingly.

Wheat during *rabi* 2018-19: Wheat cultivar KRL 210 was sown at four sites in rice-wheat cropping system on one acre land adopting four techniques, i.e., farmers practice, wheat in conventional tillage with rice residue, zero tillage wheat after green manuring of sesbania (residual effect of DGM), wheat in zero tillage with rice residue under sprinkler irrigation system. The recommended package and practices were followed. Nitrogen 150 kg ha^{-1}, phosphorus 60 kg ha^{-1} and potash 40 kg ha^{-1} and Zinc (24 kg ha^{-1} zinc sulphate) were applied. Water was applied through surface irrigation method in all techniques except in zero tilled wheat with rice residue under sprinkler irrigation system.

The residual effect of sesbania green manuring was observed in wheat under zero tillage with rice residue, in terms of higher grain yield at all four locations (Table 198 & Fig.3). The highest averaged grain yield of four locations (5.94 tha^{-1}) was reported in this treatment which is 12% higher than farmers practice. Second best technique was zero tilled wheat in sprinkler irrigation in terms of grain yield of wheat. All improved practices gave higher grain yield than conventional farmers practice.



	CV/TPR-Srf	CV+RR/TPR-Srf	ZTwheat/TPR(DGM)-Srf	ZTwheat/DSR-SPRL	Mean	CD(0.05)
Shambhali	6.29	6.15	6.30	6.51	6.31	0.35
Geong	5.52	5.53	5.65	6.32	5.76	0.36
Bahupur	5.55	5.85	6.09	6.54	6.00	0.38
Kaith	5.35	5.52	6.10	6.55	5.88	0.34

Figure 3: Wheat grain yield at different villages under different improved conservation practices during *rabi* 2018-19 (CV=Conventional wheat sowing**;** CV+RR= conventional wheat with rice residue; ZR-TPR (DGM) Wheat = Zero tilled wheat in sequence with transplanted rice with dhaincha green manuring ; ZT wheat-DSR= Zero tillage wheat in sequence with DSR (direct seeded rice)

High light of CA demonstration experiments

"Out of the four locations, in Shambhali village highest grain yield was obtained mainly due to application of good quality irrigation water. Rice residue and green manuring using dhaincha improved grain yield even under saline and alkali environment as evident from yield data of Kaith village. At this location, grain yield of wheat was 5.8% and 11.3%, higher under rice residue incorporated and green manure plots, respectively compared to conventional practices. Crop residue improved the wheat grain yield as it maintained soil hydro-thermal regime in favour of plant growth and production".

(a) Wheat crop economic analysis of the demonstration sites-

Kaith village- Economic analysis of wheat crop at Kaith village is given in Table 18 shows that wheat grain yield under different treatments was comparatively lower in comparison to other sites. The main possible reason may be poor quality of irrigation water and soil. The residual effects of crop residue management increased wheat grain yield by 6.55 tha^{-1} under ZTW/DSR cropping sequence under sprinkler irrigation system which was maximum with 2.58 B:C ratio. 2nd higher grain yield of wheat was recorded (6.09 tha^{-1}), net income (Rs.85478 ha^{-1}) and B:C ratio (2.99) in ZTW crop establishment techniques than other CA technologies. Lowest cost of cultivation was observed in ZTW wheat cultivation method.

Table 18: Economic analysis of wheat crop under different CA techniques.

Wheat Crop Economic analysis demo at Kaith village-2018-19					
RCTs	Grain yield, tha^{-1}	Cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	B:C
CVW/TPR (CV)-srf	5.35	36578	100440	63862	1.75
CVW+RR/DSR(DH)-srf	5.52	36578	103568	66990	1.83
ZTW/DSR-srf	6.09	28578	114056	85478	2.99
ZTW/DSR-SPRL	6.55	34215	122520	88305	2.58
SE(m)±	0.12	-	-	-	-
CD at 0.05	0.31	-	-	-	-
MSP of wheat 2018-19: Rs.1840/q, wheat straw income @ Rs.2000 ha^{-1}. Cost of cultivation includes-operational cost. Dh=dhaincha ; srf=surface, Sprl=sprinkler irrigation					

Table 19: Economic analysis of wheat crop under different CA techniques at Bahupur village in panipat district

Wheat Crop Economic analysis demo at Bahupur village-2018-19					
RCTs	Grain yield, tha^{-1}	Cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	B:C
CVW/TPR (CV)-srf	5.55	36578	104120	67542	1.85
CVW+RR/DSR(DH)-srf	5.85	36578	109640	73062	1.99
ZTW/DSR-srf	6.09	28578	114056	85478	2.99

ZTW/DSR-SPRL	5.54	34215	103936	69721	2.04
SE(m)±	0.13	-	-	-	-
CD at 0.05	0.32	-	-	-	-
MSP of wheat 2018-19: Rs.1840/q, wheat straw income @ Rs.2000 ha^{-1}. Cost of cultivation includes-operational cost					

- **Bahupur village-** Economic analysis of wheat crop observed (Table 19) that under ZTW cultivation under surface irrigation system, grain yield was 6.09 tha^{-1} with 2.99 B:C ratio was higher than conventional wheat sowing (CVW) sowing method. Lowest wheat grain yield was recorded in CVW sowing method with highest cost of cultivation along with lowest net income of Rs.67542.0. In mini sprinkler irrigation system 5.54 tha^{-1} grain yield was obtained which were statistically similar to CVW. This shows that ZTW wheat sowing method performed better than CVW sowing method.
- **Geong village-** Economic analysis of wheat crop (Table 20) observed that under ZTW cultivation under surface irrigation system, grain yield recorded 5.65 tha^{-1} with 2.71 B:C ratio, which was higher than CVW sowing method. Lowest wheat grain yield was recorded in CVW sowing method with highest cost of cultivation along with lowest net income of Rs.66990.0. Highest wheat grain yield 6.32 tha^{-1} was recorded in ZTW technology under mini sprinkler irrigation system which was statistically significant to CVW sowing method under surface irrigation method. This shows that ZTW wheat sowing method performed better than CVW sowing method under mini sprinkler irrigation method and surface irrigation system.

Table 20: Economic analysis of wheat crop under different CA techniques at Geong village in Kaithal district.

Wheat Crop Economic analysis demo at Geong village-2018-19					
RCTs	**Grain yield, tha^{-1}**	**Cost of cultivation ($Rs\ ha^{-1}$)**	**Gross income ($Rs\ ha^{-1}$)**	**Net income ($Rs\ ha^{-1}$)**	**B:C**
CVW/TPR (CV)-srf	5.52	36578	103568	66990	1.83
CVW+RR/DSR(DH)-srf	5.53	36578	103752	67174	1.84
ZTW/DSR-srf	5.65	28578	105960	77382	2.71
ZTW/DSR-SPRL	6.32	34215	118288	84073	2.46
SE(m)±	0.13	-	-	-	-
CD at 0.05	0.34	-	-	-	-
MSP of wheat 2018-19: Rs.1840/q, wheat straw income @ Rs.2000 ha^{-1}. Cost of cultivation includes-operational cost					

- **Shambhali-** Economic analysis of wheat crop (Table 21) observed that under ZTW cultivation under surface irrigation system, grain yield was 6.30 tha^{-1} with 3.13 B:C ratio, which was higher than CVW sowing method under surface irrigation method. Lowest wheat grain yield was recorded in CVW sowing method with highest cost of cultivation of Rs.36578.0 along with lowest net income of Rs.67542.0. However, in mini sprinkler irrigation system in ZTW obtained 5.54 tha^{-1} grain yields which were statistically similar to CVW sowing method. This shows that ZTW wheat sowing method performed better than CVW sowing method.

Table 21: Economic analysis of wheat crop under different CA techniques at Shambhali village in Karnal district

Wheat Crop Economic analysis demo at Shambhali village-2018-19					
RCTs	**Grain yield, tha-1**	**Cost of cultivation (Rs ha-1)**	**Gross income (Rs ha-1)**	**Net income (Rs ha-1)**	**B:C**
CVW/TPR (CV)-srf	6.29	36578	117736	81158	2.22
CVW+RR/DSR(DH)-srf	6.15	36578	115160	86582	3.03
ZTW/DSR-srf	6.30	28578	117920	89342	3.13
ZTW/DSR-SPRL	6.31	34215	118104	83889	2.45
SE(m)±	0.12	-	-	-	-
CD at 0.05	0.29	-	-	-	-
MSP of wheat 2018-19: Rs.1840/q, wheat straw income @ Rs.2000 ha-1. Cost of cultivation includes-operational cost					

High light of Wheat experiment at demonstration sites-

"ZTW in wheat crop in all the sites performed better as CVW sowing method but CVW faced the water lodging problems after irrigation/rainfall, while in ZTW this problem not observed and maintained healthy plant population and produced higher yield".

13. Output during period under report (Self-explanatory …)

(A) Special attainments/innovations-

1. Efficient irrigation water management in rice–wheat cropping system.
2. Crop residue management and higher water productivity
3. Standardization of Tillage management practices
4. Tangible and non-tangible benefits of conservation agriculture.

5. Soil properties changes under crop residue and conservation tillage under rice–wheat cropping system.
6. Popularization of CA technologies.

(B) Outputs (Achievements)-

1. Zero tillage in wheat with and without rice residue crop is promising and sustainable.
2. Rice straw either incorporation or retention (stables/mulch) both method are promising and economic for high wheat productivity.
3. DSR method with wheat residue incorporation is a better option with higher water productivity.
4. Sprinkler irrigation in wheat with zero tillage and rice residue mulch is economically feasible option for increasing water productivity and NUE. Mini sprinkler irrigation method in rice with DSR crop establishment technique is feasible option for increasing water productivity and NUE.
5. Drip irrigation method is feasible under zero tillage wheat sowing with 100% rice residue mulch, using Turbo seed drill machine for wheat seed sowing.
6. Drip irrigation method saved irrigation water and nitrogen in fertigation.
7. In rice crop drip irrigation method is feasible under reduced tillage with saving of irrigation water.
8. Crop residue management increased the carbon sequestration and carbon buildup rate and found helpful improving soil properties and crop yields.
9. Crop residue management avoid the burning and saved the environment from pollution.
10. Soil nutrient availability improved in the respective residue managed plots.

IISS

Demonstration of Best-Bet Conservation Agriculture Practices on Farmers' Fields in Vertisols of Central India

On farm demonstration of best-bet no tillage and reduced tillage based conservation agricultural practices were conducted at farmer's field in a participatory mode in four villages namely, Khamkheda, Rasla Khedi, Raipur and Karod khurd in Bhopal district. Demonstrations were conducted in 19 farmers' field with two predominant cropping systems being practiced in this belt viz., soybean-wheat and soybean-chickpea. Data for various crop growth parameters and yield attributes were recorded during the *kharif* and *rabi* seasons. Plant height, seed and straw yield and harvest index of soybean grown in different farmer's field during the *kharif* season of 2018 are depicted in Table 22. Crop performance as indicated through different growth and yield parameters showed wide variation among the farmers.

Table 22. Plant height, seed and straw yield and harvest index of soybean grown in different farmer's field during the *kharif* season of 2018.

Farmers name	Plant height (cm)		Seed yield q/ha		Straw Yield q/ha		HI (%)	
	No tillage	Reduced tillage	No tillage	Reduced tillage	No tillage	Reduced tillage	No tillage	Reduced tillage
JagJeevan Ahirwar	27.4	26.6	8.06	7.54	17.20	17.48	30.47	30.13
Himmat Singh	27.4	29.2	10.50	7.88	16.50	17.78	32.31	30.70
Ramsingh	28	29.6	11.21	7.09	16.98	17.78	29.45	28.51
Naval Singh	28.6	31.6	6.41	7.05	18.05	16.43	28.09	30.03
Azad Singh	30.8	29.2	7.09	6.30	17.15	17.43	26.87	26.55
Fool Singh	32.4	31	6.68	6.19	17.50	17.00	26.12	26.68
Goverdhan Singh	31.4	28.8	6.26	5.81	18.03	17.53	24.38	24.91
Vijay Malviya	38.2	37	14.25	12.94	29.53	27.85	30.47	31.72
Parvat Singh	48	39.6	17.95	16.25	36.20	41.00	30.98	28.38
Rajnarayan Yadav	32.2	31.4	7.01	5.81	18.03	18.63	24.38	23.79
Nandlal yadav	28.4	30.2	7.09	7.05	17.35	17.83	28.89	28.34

Deepak yadav	54.6	54.4	16.45	14.95	31.35	31.37	32.29	32.28
Santosh yadav	34	32.8	7.05	5.44	17.83	18.60	23.37	22.62
Rambabu yadav	28.8	31.6	7.46	6.64	17.78	18.00	27.19	26.94
Jeevan yadav	32.4	30.4	6.64	6.19	20.03	18.75	23.61	24.81
Chain singh	31.8	31	7.16	5.85	18.50	18.08	24.02	24.45
Jeevan jat	30.2	30	6.34	5.78	20.75	18.58	21.77	23.72
Bhagan singh	29.6	31.6	6.98	5.66	17.68	18.15	24.26	23.78
Harprasad	29.4	30	7.01	5.74	20.03	18.60	22.27	23.57
Average	**32.82**	**32.42**	**8.82**	**7.69**	**20.34**	**20.36**	**26.91**	**26.94**

In no-tillage the plant height of soybean among different farmers varied between 27.4 and 54.6 cm while in reduced tillage fields the plant height varied between 26.6 and 54.4 cm. The average seed yield of soybean under no tillage system (8.82 q/ha) was higher than that under the reduced tillage system (7.69 q/ha). The seed yield among different farmers varied from 6.26 to 17.95 q/ha in no tillage treatment while it varied from 5.66 to 16.25q/ha under the reduced tillage treatment. Similarly, in no tillage the straw yield among different farmers varied from 16.50 to 36.20 q/ha and in reduced tillage the straw yield among different farmers varied from 16.43 to 41.00q/ha. There was not much differences in plant height, straw yield and harvest index, however the there is significant difference in seed yield owing to higher seed index.

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Fig. 4. Soybean crop grown under no and reduced tillage system at farmer field

During *rabi* season farmers field demonstration with wheat and chickpea were carried out. Four different tillage system modules viz., no tillage, reduced tillage, improved conventional tillage and farmers practice, following standard package of practices were compared. Crop growth and yield parameters of wheat and chickpea are presented in Table 23 and 24. Grain yield of wheat among the four tillage treatments tested varied between 51.50 and 48.00 q/ha while for chickpea seed yield varied between 26.43 and 24.35 q/ha. Yield under no tillage and reduced tillage were slightly higher as compared to the yield under conventional tillage practices for both the *rabi* season crops. Crop performance as evident from plant height and yield parameters were slightly better in conservation tillage compared to the farmers' practice. Farmer's perceptions about this new package of practices are quite positive and they are ready to continue the CA practices in their field.

Table 23. Crop growth, yield and yield parameters of wheat under different tillage practices (2017-18)

Treatment	Plant height at harvest (cm)	Ear length (cm)	No. of tillers/m row length	Grain yield (q/ha)	Straw yield (q/ha)
No tillage	75.9	10.20	81.66	51.50	74.00
Reduced tillage	76.3	10.16	80.16	50.90	73.00
Improved conventional tillage	76.1	10.00	79.33	48.50	72.30
Farmer's practice	75.9	9.90	75.66	48.00	72.00

Table 24. Crop growth, yield and yield parameters of chickpea under different tillage practices (2017-18)

Treatment	Plant Height (cm)	No. of Branches / plant	Grains/ Pod	Grain yield (q/ha)	Straw yield (q/ha)
No tillage	48.20	10.33	1.15	18.37	26.43
Reduced tillage	47.95	9.50	1.12	17. 50	25.50
Improved conventional tillage	47.80	9.30	1.10	17.27	24.70
Farmer's practice	45.75	9.00	1.06	16.90	24.35

Kisan Divas was organized at Karond Khurd village to assess farmers experience and promote conservation agriculture in farmer's field.

A Kisan Divas was organized at Karod Khurd on 26.3.2019 under Consortia Research Platform on Conservation Agriculture (CRP on CA). All the scientists and other team members working under the CRP on CA platform at ICAR-IISS, Bhopal and progressive farmers from different villages participated in the Kisan Diwas. Scientists addressed to the farmers gathered from different villages and interacted with farmers and enquired about the problems of the villages in relation to conservation agriculture and the benefits to farmers with respect to better utilization of resources under conservation agriculture and also discussed about the way forward for higher adoption of this practice among the different farmers. Overwhelming response of the farmers was recorded with respect to crop performance and savings in terms of energy, resources and reduced cost in demonstration plots under conservation agriculture. However, farmers have some queries related to machinery requirements for conservation agriculture, their availability and cost also on issues related to crop establishment under residues in the field.

Fig. 2 Kisan Divas held at Karod Khurd on 26.3.2019

Publications:

CIAE

(i) Paper in research journals(National/Internationals)

Singh Dushyant,Nandede B.M., Raul A.K., Singh R.S. (2018) Effect of Heat Treatment on Wear Rate of Different Agricultural Grade Steels and Associated Cost Economics, Economic Affairs, Volume : 63 (1) pp 203-208.

K P Saha, **Dushyant Singh,** DilipJat and K P Singh (2018.) Performance Evaluation of tractor operated rotary assisted broad bed former cum seeder for wheat sowing" Journal of Agricultural Engineering, Vol. 55(3): July-September, PP 1-11

(ii) Technical/popular articles

- अनुरागपटेल, **n";r flg** एवंरामचन्द्र सिंह संरक्षण कृषि एक लाभकारीतकनीकी(2018) आधुनिक कृषिउपकरण, **cyfVu**नं., सी.आई.ए.ई./ए. एम.डी./2018/268, पेजनं. 36–39.
- अनुरागपटेल, **n";Ur flg** एवंनितिनकुमारभारती (सितम्बर,दिसम्बर, 2018)धानफसलअवशेषप्रबंधनतकनीकी।"कृषकचेतना", पेज नं0 61–62।
- अनुरागपटेल,**n";Ur flg** एवंरमेशकुमारसाहनी(सितम्बर 2018)।लेजरलैण्डलेंवलरसेलाभहीलाभ। "कृषकजगत", पेज नं0 05।

(iii) Book Chapters/ technical bulletins/ manual

- R. R. Potdar, P.S. Tiwari, and **Dushyant Singh**(2019) Operator's manual for tractor drawn pre-emergence herbicide strip applicator-cum-planter is under preparation.

RCER

- Kumar Rakesh, Mishra JS, Upadhyay PK and Hans H.2019.Rice fallows in the Eastern India: Problems and Prospects. *Indian Journal of Agricultural Sciences* **89** (4):567-77.
- Kumar Rakesh, Mishra JS, Rao KK, Kumar R, Singh SK and Bhatt BP.2018.Evaluation of crop establishment techniques in rice-fallows of Eastern Indo-Gangetic Plains. Published in the National Conference on Organic Waste management for Food and Environmental Security under theme Theme Crop Residue Management during Feb.08-10, 2018 held at ICAR IISS Bhopal, pp: 26.
- Mishra JS, Kumar Rakesh and Bhatt BP.2018.Low cost technologies for management of rice fallows in Eastern India. XXI Biennial National Symposium of Indian Society of Agronomy, 24-26 October, 2018 at MPAUT Udaipur, Rajasthan pp: 7-9.
- Mishra JS.2018.Concepts of conservation agriculture and its role in management of rice-fallows in the Eastern Indo-Gangetic Plains. In: Mishra JS, Bhatt BP, Kumar Rakesh and Koteswara Rao K (eds).*Conservation Agriculture: Mitigating Climate Change Effects & Doubling Farmers Income*, 269 p. ICAR Research Complex for Eastern Region, Patna, pp: 25-30.

DWR

Papers presented at scientific meetings:

- Oral presentation on "Weed management under conservation agriculture systems" on 9th NEE Congress-2018 on "Climate smart agriculture technologies: Innovations and interventions". 15-17 November, 2018 at Central Agricultural University, Gangtok, Sikkim, organized by Society of Extension Education, Agra.
- Oral presentation on "Weed dynamics and crop productivity in rice-wheat-greengram (R-W-G) cropping system under conservation agriculture in *vertisol*" in the session of Weed management in rainfed and irrigated rice-based cropping system at ISWS Golden Jubilee International Conference "Weeds and Society: Challenges and Opportunities" 21-24 November, 2018 Jabalpur India.
- Oral presentation on "*Improved weed management technologies: A way to achieve sustainable crop productivity and income*" on 25th Zonal workshop of KVKs Zone IX on 3rdSeptember 2018 at JNKVV, Jabalpur.
- Annual Review Meeting of AICRP on Weed Management on theme one "Weed management under conservation agriculture system" and theme 5 "On-farm research cum demonstration of weed management technology and their impact assessment" during June 2018 at GBPUA&T, Pantnagar (UK).

Research paper:

- Choudhary V.K., and Kumar, P.S. 2019. Weed prevalence, nutrient wash, water productivity and yield output of turmeric (*Curcuma longa* L.) under different land configuration and mulches. Journal of Cleaner Production. 210: 793-803. http://doi.org/10.1016/j.jclepro.2018.11.071. (NAAS: J145: 11.65).

Mentor

- Guided for three months to a Probationer Scientist (Agronomy), Mr. Jeetendra Kumar Soni, ICAR-RC-NEH Region, Umiam on weed management in wheat under conservation agriculture from 12 November 2018- 11 February 2019.

Success stories:

- Sharma, A.R., Singh P.K. and Choudhary, V.K. 2018, Crop cultivation under conservation agriculture: A viable option for upliftment of economic status of farmers. In Technical Bulletin No. 16. DWR Success Stories. pp 9-14. Published by ICAR-Directorate of Weed Research, Jabalpur.

Book Chapter:

- Choudhary, V.K., Chander, S., Chethan, C.R. and Kumar, B. 2019. Effect of seed priming on abiotic stress tolerance in plants. In (eds. Mirza Hasanuzzaman, Masayuki Fujita, Hirosuke Oku, M. Tofazzal Islam: Plant tolerance to environmental stress: Role of phytoprotectants).Publisher: CRC Press. ISBN 9781138559172 - CAT# K43393 pp. 29-46.
- Choudhary, V.K. and Kumar, S. 2018. Resource conservation and weed management through mulches. In: Fifty years of weed research in India (Eds. Sushil Kumar and Mishra, J.S.), Indian Society of Weed Science, Jabalpur, pp. 196-214.

Extension folders:

- Choudhary, V.K., Dubey, R.P., Chethan, C.R., Singh, P.K., Kailash Choukikar, Anjani Chaturvedi, and Sandeep Patel. 2019. Sunya jutai se grishmakalin mung ki kheti avam labh. pp. 1-6. Published by ICAR-Directorate of Weed Research, Jabalpur.

- Choudhary, V.K., Dubey, R.P., Chethan, C.R., Kailash Choukikar, Anjani Chaturvedi, and Sandeep Patel. 2019. Sunya jutai se gehun ki kheti avam labh. pp. 1-6. Published by ICAR-Directorate of Weed Research, Jabalpur.

Abstract published:

- Choudhary, V.K., Chander, S., Chauhan, A. and Singh, P.K. 2018. Weed dynamics and crop productivity in rice-wheat-greengram cropping system under conservation agriculture in vertisol. In: ISWS Golden Jubilee International Conference on "*Weeds and Society: Challenges and Opportunities*", ICAR-Directorate of Weed Research, Jabalpur, India during 21-24 November 2018. P.79 (O-50).
- Kumar, S., Singh, P.K., Chander, S., Choudhary, V.K. and Parey, S.K. 2018. Conservation agriculture versus conventional tillage: Impact of weed management with right dose of fertilizer on wheat yield. In: ISWS Golden Jubilee International Conference on "*Weeds and Society: Challenges and Opportunities*", ICAR-Directorate of Weed Research, Jabalpur, India during 21-24 November 2018. P.263 (P-127).
- Chaukikar, K., Kumar, S. Choudhary, V.K. and Dubey, R.P. 2018. Performance of wheat under the conservation agriculture at farmers‟ fields in Jabalpur, Madhya
- Pradesh. In: ISWS Golden Jubilee International Conference on "*Weeds and Society: Challenges and Opportunities*", ICAR-Directorate of Weed Research, Jabalpur, India during 21-24 November 2018. P.308 (P-172).
- Chauhan, A., Patel, A.K. and Choudhary, V.K. 2018. Tillage and weed management in soybean under conservation agriculture. In: ISWS Golden Jubilee International Conference on "*Weeds and Society: Challenges and Opportunities*", ICAR-

Popular article:
- Singh P.K., Gharde Y. and Choudhary V.K. 2018. Adoption of weed management technologies by farmers in India. Indian Farming (Special Issue) 68 (November): 83-87.
- Choudhary V.K., Kewat M.L. and Singh P.K. 2018 New approaches of weed management in soybean. Indian Farming (Special Issue) 68(November): 68- 72.
- Chethan C.R., Sarkar, Bikash, Singh P.K., Chander S., Ghosh, D., Choudhary V.K., and Reddy R.B. 2018. Use of efficient weeding tools to reduce farmers' drudgery. Indian Farming (Special Issue) 68(November): 24-28.
- Singh P.K., Choudhary V.K. and Gharde Y. 2018. *Sanrakshit Krishika Kharpatwar Prabandhan, Mrida Swasthya evam Fasa IUtpadan me Mahtwa. In: Trin Sandesh* (13) 1-11.
- Chauhan A., Kanthale A.K., Choudhary V.K. and Singh P.K. 2018 *Sanrakshit Kheti ke Sidhant avam labh. In Trin Sandesh* (13) 86-87.

Workshop cum field day:
- Organized a workshop-cum-meeting on weed management in conservation agriculture on 11 and 12 September 2018 at ICAR-DWR, Jabalpur.
- One day field day organized on Conservation agriculture at ICAR-Directorate of Weed Research, Jabalpur on 27 March 2019, where 50 farmers were benefitted.
- One day field day organized on Conservation agriculture at Baroda village of Panagar Locality of Jabalpur on 20 March 2019, where 60 farmers were benefitted.
- One day field day organized on Conservation agriculture at Silua village of Bargi Locality, Jabalpur on 21 February 2019, where 100 farmers were benefitted.
- One day field day organized on Conservation agriculture at Khaira village of Patan Locality, Jabalpur on 18 February 2019, where 100 farmers were benefitted.

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- **ChhokarR.S., R.K. Sharma, S.C. Gill, RK Singh, Vikas Joon, Mamta Kajla and Ankur Chaudhary. 2018.** Suitable wheat cultivars and seeding machines for conservation agriculture in rice-wheat and sugarcane-wheat cropping systems. Wheat and Barley Research. 10 (2): 78-88.

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- Rai, Vikas, Pramanik, P., Das, T.K., Aggarwal, P., Bhattacharyya, R., Krishnan, P., and Sehgal, V. 2019.Modelling soil hydrothermal regimes in pigeon pea under conservation agriculture using Hydrus-2D. *Soil and Tillage Research* 190:92-108.

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- Mondal, S., Das, T.K., Thomas, P., Mishra, A.K., Bandyopadhyay, K.K., Aggarwal, P. and Chakraborty, D. 2019. Effect of conservation agriculture on soil hydro-physical properties, total and particulate organic carbon and root morphology in wheat (Triticum aestivum) under rice (Oryza sativa)-wheat system. *Indian Journal of Agricultural Sciences* 89(1): 46–55.
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- Singh G., Bhattacharyya*, R., Das, T.K., Sharma, A.R., Ghosh, A., Das, S. and Jha, P. 2018. Crop rotation and residue management effects on soil enzyme activities, glomalin and aggregate stability under zero tillage in the Indo-Gangetic Plains. *Soil and Tillage Research* 184: 291-300.
- Das, T.K., Saharawat, Y.S., Bhattacharyya, R., Sudhishri, S., Bandyopadhyay, K. K.*, Sharma, A.R. and Jat, M. L. 2018. Conservation agriculture effects on crop and water productivity, profitability and soil organic carbon accumulation under a maize-wheat cropping system in the North-western Indo-Gangetic Plains. *Field Crops Research* 215:222-231.
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