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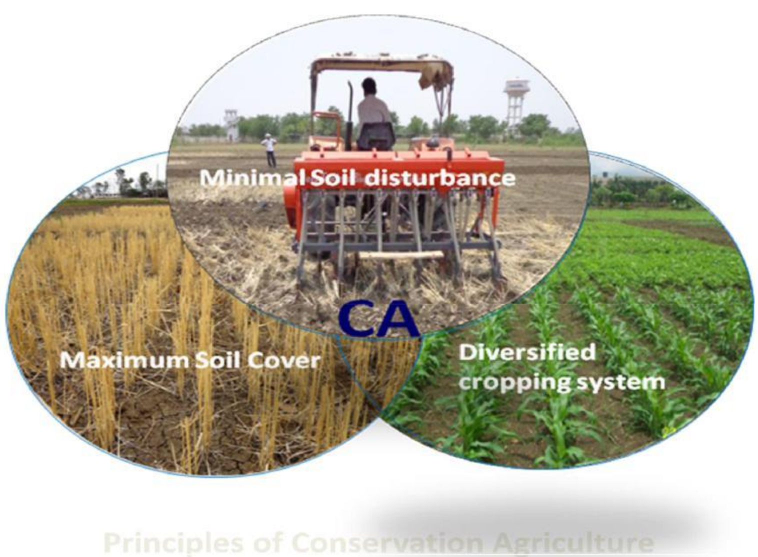
INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Consortia Research Platform
on
Conservation Agriculture

ANNUAL REPORT 2021



ICAR-Indian Institute of Soil Science
Nabibagh, Berasia Road, Bhopal
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1. Background

Agriculture is the most important sector in India; accounting for 18-19 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 315.7 million tonnes during 2021-22, 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. Agro forestry 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 CO2 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 CO2 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 residues usually requires more attention on the timing and placement of nutrients, and application of pesticides and irrigations.

Farmers' perception: Limiting 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

- Developing adaptable component technologies of CA on tillage, residue, water & nutrient management and their interactions with environment and management conditions.
- Studying soil biology and dynamics by exploring changes in community structure and dynamics of microbial population and microbial mediated processes.
- Quantifying tangible and non-tangible benefits of CA on soil, water, energy and climate by evaluating economic benefits and ecosystem services.
- Refinement and validation of CA technologies on a broader spatial scale especially to ward off residue burning problem including identification of adoption bottlenecks through on-farm participatory research.
- Enhanced capacity development of all stakeholders (farmers, service providers, students, scientists, policy makers, etc.), knowledge management, and institutional arrangement including enabling policies for accelerated adoption of CA.

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.

Research Highlight of CRP on Conservation Agriculture (2021)

Objective 1: Fine-tuning of Conservation Agricultural Practices in Irrigated Eco-systems

A. Tillage and Residue Management Practices

1. Rice-Wheat cropping system

IARI

It was observed from a long-term CA experiment (11 years) that a triple cropping system involving ZT DSR with summer mungbean (SMB) residue (MBR)- ZT wheat (ZTW) with rice residue (RR)– ZT summer mungbean (ZTSMB) with wheat residue (WR) was consistently superior to other CA systems and puddled transplanted rice (PTR) - conventional till wheat (CTW) system on system productivity and net returns. This system led to 20.9% higher wheat yield, 28.5% higher system productivity than TPR-CTW system, although it had 19.5% lower rice yield (Table 1.1; Fig 1.1-1.4). This triple ZT system could save almost 60 kg N/ha in rice-wheat system per year. This led to sustainable intensification of the RWS with a legume mungbean, which could be a superior crop diversification option in north-western Indo-Gangetic plains and proved to be a superior alternative and an important adaptation and mitigation strategy to climate change.

Table 1.1 CA effects on rice, wheat and system productivities in rice-wheat cropping system

Treatments	Rice productivity (t/ha)	Wheat productivity (t/ha)	SP (t/ha) with mungbean (WEY)	SP (t/ha) without mungbean (WEY)
ZT DSR – ZTW (Double ZT system)	6.45	5.89	12.04	12.04
ZT DSR+BM – ZTW	5.40	5.70	10.85	10.85
WR+ZT DSR - RR+ZTW	5.59	5.73	11.05	11.05
WR+ZTDSR+BM - RR+ZTW	5.41	5.96	11.11	11.11
ZT DSR – ZTW – ZT SMB (Triple ZT system)	5.63	6.04	14.97(3.56)*	11.40
MBR+ZT DSR - RR+ZTW -WR+ SMB	6.34	6.12	16.15(3.99)*	12.16
TPR-ZTW	7.62	5.49	12.75	12.75
TPR-CTW	7.88	5.06	12.57	12.57

*Wheat equivalent yield of mungbean grain yield (t/ha) in parentheses

Fig 1.1 DSR under triple ZT conditions

Fig 1.2 PTR (Puddled transplanted rice)

Fig 1.3 Wheat under ZT+riceresidue

Fig 1.4 Mungbean under ZT Flat Bed in rice-wheat-mungbean system

CSSRI

a) Puddled Transplanted Rice (PTR)

Higher grain yield (5.65 t ha^{-1}) was recorded under conventional puddle transplanted rice with wheat residue incorporation (PTR+RI) than without residue incorporation (5.41tha^{-1}). So, residue incorporation in conventional PTR rice increased the grain yield by 4.4% (Fig 1.7). During the year 2021, the PTR crop was heavily infested with false smut at grain filling stage which and its severity was much higher in PTR as compared to DSR crop. The high humidity and crop canopy due to frequent rainfall/irrigation coupled with high temperature increased its severity. This resulted in chalkiness of grains with reduced test weight and ultimately lower grain yield.

Fig 1.5 Experimental view of the puddled transplanted rice with wheat residue incorporation

Fig 1.6 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) Direct seeded rice under reduced tillage with wheat residue

Direct seeded rice under reduced tillage with wheat residue (RTDSR+RI) produced grain yield of 6.70 tha^{-1}, which was 23.8 and 17.9% higher in comparison to TPR (5.41 tha^{-1}) and direct seeded rice under reduced tillage without wheat residue (RTDSR) (5.68 tha^{-1}), respectively (Fig. 1.7). The rice crop in RTDSR was free from the false smut disease which leads to its higher grain yield than TPR.

c) Direct seeded rice under zero tillage with anchored wheat residue

Grain yield under zero tilled DSR with anchored wheat residue (ZTDSR+RR) was 4.83 tha^{-1} which was 10.7% lower than the TPR (5.41 $t\ ha^{-1}$) and 12.3% lower than the direct seed rice in zero tillage without wheat residue incorporation (ZTDSR; 5.51 $t\ ha^{-1}$) (Fig. 1.7). The lower yield in the ZTDSR+RI was mainly because of the higher weed population, lower plant density as compared to the PTR.

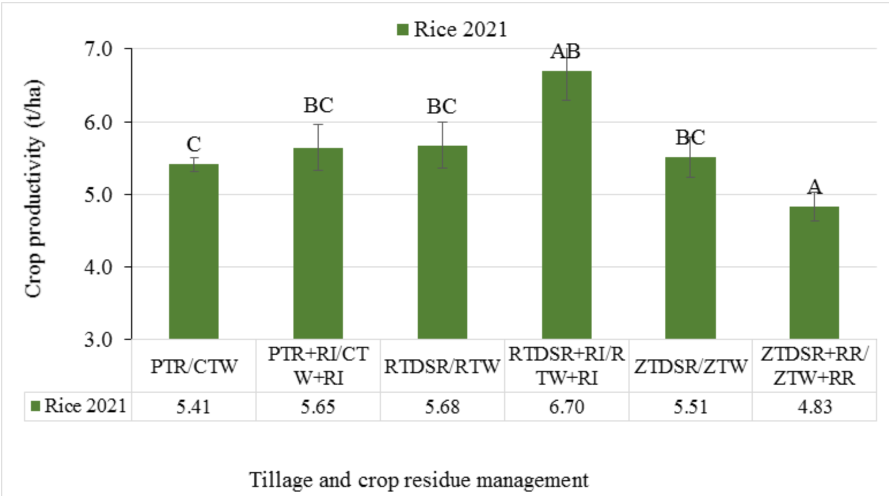


Fig 1.7 Effects of different tillage and residue management practices on rice grain yield during *kharif* 2021

(Note: **PTR-** Puddled transplanted rice; **RTDSR-** Direct seeded rice in reduced tillage; **ZTDSR-** Direct seeded rice in zero tillage; **CTW-** Conventional tilled wheat; **RTW-** Reduced tilled wheat; **ZTW-** Zero tilled wheat; **RI-** Residue incorporation; **RR-** Residue retention/anchored)

1) **Economic feasibility of rice crop during *Kharif* 2021**

During 2021, Arize 6129 rice variety was sown under PTR and DSR condition. Arize 6129 performed well under DSR condition. However, under PTR condition it is heavily infested with False smut disease which caused about 30-40% potential yield loss under PTR sowing.

The economic analysis of rice cultivation during *Kharif* 2021 is presented in Table 3. The B:C ratio of the TPR and DSR crop establishment techniques with or without residue incorporation varied from 1.77 to 2.30. It was maximum (2.30) in DSR under reduced tillage with residue incorporation(RTDSR+RI) with the highest grain yield of6.70 tha^{-1}.Minimum (1.77) B:C ratio was recorded in zero tilled DSR with anchored wheat residue (ZTDSR+RR) withlowest grain yield of 4.80 tha^{-1}.

1st option: Higher net income Rs. 78, 546 ha^{-1} was recorded in reduced tilled DSR with 1/3rd where residue incorporation (RTDSR+RI) followed by RTDSR without wheat residue incorporation (ZTDSR; Rs. 64,411 ha^{-1}), with 2.30, 2.18 B:C ratio (Table 1.2). 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, 2nd option was puddle transplanted rice with wheat residue incorporation (PTR+RI) which produced rice grain yield 5.65 tha^{-1} with net income of ₹57,163 ha^{-1} and B:C of 1.94 (Table 1.2). 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 1.2 Economic analysis of rice under different tillage and residue management practices during *Kharif* 2021

Economic analysis of rice 2021							
PTR and DSR crop establishment techniques							
RCTs	**Grain yield (t ha^{-1})**	**Cost cultivation (Rs. ha^{-1})**	**Gross income (Rs. ha^{-1})**	**Net income (Rs. ha^{-1})**	**B:C**	**Change over conventional**	
						Net income	**Percentage change**

						difference	
PTR/CTW	5.41	55683	113585	57903	2.04		
PTR+RI/CTW+RI	5.65	61016	118179	57163	1.94	-739	-1.3
RTDSR/RTW	5.68	54380	118791	64411	2.18	6509	11.2
RTDSR+RI/RTW+RI	6.70	60213	138759	78546	2.30	20643	35.7
ZTDSR/ZTW	5.51	51830	115484	63654	2.23	5751	9.9
ZTDSR+RR/ZTW+RR	4.83	57663	102193	44530	1.77	-13373	-23.1
MSP of Rice 2021 is taken Rs. 1960/q and rice straw @ Rs. 7500/ha. Cost of cultivation includes only operational cost (B-1)							

(Note: **PTR-** Puddled transplanted rice; **RTDSR-** Direct seeded rice in reduced tillage; **ZTDSR-** Direct seeded rice in zero tillage; **CTW-** Conventional tilled wheat; **RTW-** Reduced tilled wheat; **ZTW-** Zero tilled wheat; **RI-** Residue incorporation; **RR-** Residue retention/anchored)

Although, rice crop in *kharif* 2021 was heavily infested with the false smut and caused 30-40% yield loss in PTR. However, overall, DSR under reduced tillage with residue incorporation (RTDSR+RI) performed better than rest of the treatments. In case of PTR, wheat residue incorporation enhances the crop yield and based on the previous year experience it found to be productive technology 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 PTR as well as in DSR.

Effects of tillage on grain yield of wheat

The experiment of wheat under basic research trial is continuing and data presented in Fig 1.8 and Table 1.3.The highest (5.96 t ha^{-1}) yield of wheat was reported under zero tilled wheat with rice residue retention (ZTW+RR) which was significantly higher by 16.9% as compared to conventional tilled wheat (CTW; 5.10 t ha^{-1}). Similarly, wheat yield in reduced tilled wheat with rice residue incorporation (RTW+RI) was 5.66 t ha^{-1} which was 10.9% higher than CTW (5.10 t ha^{-1}). Among the different tillage treatments, grain yield of wheat was increased by 6.1 and 7.1% in reduced tillage (RTW) and zero tillage (CTW) compared to conventional tillage (CTW; 5.10 t ha^{-1}). It is clear from the results that zero/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. Results indicate that wheat grain yield increased under both the conservation tillage treatments, i.e., reduced tillage and zero tillage. Grain yield obtained under zero tillage and reduced tillage without residue was statistically similar to each other.

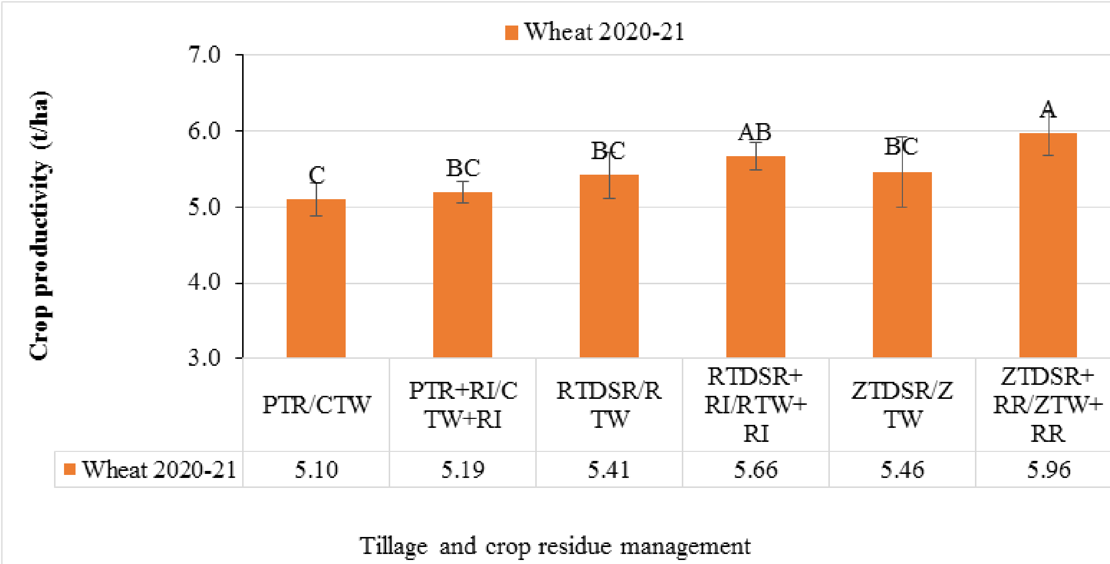


Fig 1.8 Effects of tillage and residue management practices on wheat grain yield during *rabi* 2020-21.

(**Note**: **PTR**- Puddled transplanted rice; **RTDSR**- Direct seeded rice in reduced tillage; **ZTDSR**- Direct seeded rice in zero tillage; **CTW**- Conventional tilled wheat; **RTW**- Reduced tilled wheat; **ZTW**- Zero tilled wheat; **RI-** Residue incorporation; **RR-** Residue retention/ anchored)

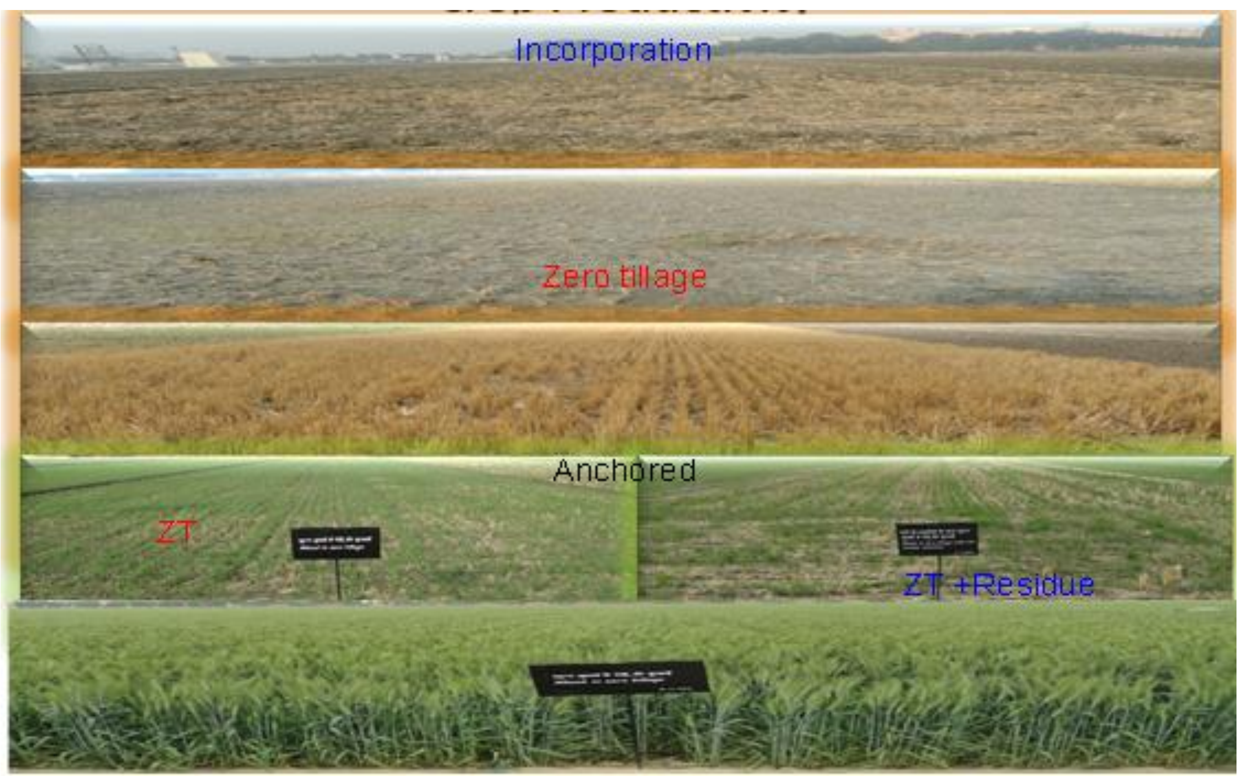


Fig 1.9 Experimental view of wheat germination under rice residue incorporation/anchored and zero tillage conditions.

b) Economic of wheat crop during *rabi* 2020-21

The economic analysis of wheat crop during 2020-21 presented in Table 1.3. The B:C ratio of wheat crop under different crop establishment techniques, varied from 2.49 to 3.54. Highest (3.54) B:C ratio was reported in zero tilled wheat in anchored rice residue (ZTW+RR). Net income under zero tilled wheat with anchored rice residue was 34.0% higher than conventional tilled wheat sowing (CTW). Result showed that sowing of wheat under different treatments i.e., conventional tillage with residue incorporation (CTW+RI), reduced tillage (RTW) or zero tillage (ZTW) observed economically feasible and sustainable as compared to the CTW. The possible reasons behind this is that organic matter 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 (ZTW) was found more profitable as compared to CTW and RTW practices. Cost of cultivation was lower under ZTW as compared to CTW and RTW tillage practices.ZTW sowing will improve soil heath, checks air pollution and improves crop productivity.

Table 1.3 Economic analysis of wheat crop under different tillage and crop residue management practices during *rabi* 2020-21

Wheat 2020-21 (HD2967)							
RCTs	**Grain yield (t ha^{-1})**	**Cost cultivation (Rs. ha^{-1})**	**Gross income (Rs. ha^{-1})**	**Net income (Rs. ha^{-1})**	**B:C**	**Change over conventional**	
						Net income difference	**Percentage change**
PTR/CTW	5.10	45665	118151	72486	2.59		
PTR+RI/CTW+RI	5.19	48165	119978	71813	2.49	-673	-0.9
RTDSR/RTW	5.41	40665	124348	83683	3.06	11197	15.4
RTDSR+RI/RTW+RI	5.66	43165	129310	86145	3.00	13659	18.8
ZTDSR/ZTW	5.46	35665	125261	89596	3.51	17110	23.6
ZTDSR+RR/ZTW+RR	5.96	38165	135284	97119	3.54	24633	34.0
Whereas, MSP of wheat @ Rs. 1975/q in 2020-21 and wheat straw @ Rs.20,000/ha; B:C=Gross income/Cost of cultivation							

(**Note**: **PTR**- Puddled transplanted rice; **RTDSR**- Direct seeded rice in reduced tillage; **ZTDSR**- Direct seeded rice in zero tillage; **CTW**- Conventional tilled wheat; **RTW**- Reduced tilled wheat; **ZTW**- Zero tilled wheat; **RI-** Residue incorporation; **RR-** Residue retention/ anchored)

The result showed 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 (ZTW+RR) 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.

c) Economic analysis of rice–wheat system

The economic analysis of rice-wheat system under different tillage and residue management practices during the year 2020-21 is given in Table 1.5. Overall, cost of cultivation of rice crop was 21.9% - 51.1% higher than wheat crop among the different treatment of the tillage and residue management. 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 both the crops.

Total cost of cultivation of rice-wheat system varied from Rs. 87,495 ha^{-1} in zero tilled DSR followed by zero tilled wheat system without crop residue incorporation (ZTDSR/ZTW)to Rs. 1,09,181 ha^{-1} in conventional practices of rice and wheat with residue incorporation (PTR+RI/CTW+RI).Maximum net return of Rs. 1,64,690 ha^{-1} was recorded in RTDSR+RI/ZTW+RI while lowest was in conventional practices or rice and wheat (TPR/CTW; Rs.1,28,976 ha^{-1}). The B:C ratio was highest in ZTDSR/ZTW (2.75), followed by RTDSR+RI/ZTW+RI (2.59) and RTDSR/ZTW (2.56). Zero tillage wheat with rice residue anchors in rice-wheat cropping system calculated 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.

"Zero tilled wheat (ZTW) sowing with rice residue incorporation/anchors after the reduced tillage DSR (RTDSR) and zero tillage DSR (ZTDSR) was found better option for sustainable, profitable and eco-friendly crop production"

Table 1.4 Rice–wheat cropping system economic analysis under different tillage and crop residue management practices during 2020-21

RCTs	**Grain yield ($t\ ha^{-1}$)**	**Cost cultivation ($Rs.\ ha^{-1}$)**	**Gross income ($Rs.\ ha^{-1}$)**	**Net income ($Rs.\ ha^{-1}$)**	**B:C ratio**	**Change over conventional**	
						Net income difference	**Percentage change**
PTR/CTW	10.51	101348	231736	130388	2.29		
PTR+RI/CTW+RI	10.84	109181	238157	128976	2.18	-1412	-1.1
RTDSR/RTW	11.09	95045	243139	148094	2.56	17705	13.6
RTDSR+RI/RTW+RI	12.36	103378	268068	164690	2.59	34302	26.3
ZTDSR/ZTW	10.97	87495	240745	153250	2.75	22861	17.5
ZTDSR+RR/ZTW+RR	10.80	95828	237477	141649	2.48	11260	8.6
Whereas, MSP of Rice 2021 is taken Rs. 1960/q and rice straw @ Rs. 7500/ha. MSP of wheat @ Rs. 1975/q in 2020-21 and wheat straw @ Rs.20,000/ha; B:C= Gross income/Cost; Cost of cultivation includes only operational cost (B-1)							

(**Note**: **PTR-** Puddled transplanted rice; **RTDSR-** Direct seeded rice in reduced tillage; **ZTDSR-** Direct seeded rice in zero tillage; **CTW-** Conventional tilled wheat; **RTW-** Reduced tilled wheat; **ZTW-** Zero tilled wheat; **RI-** Residue incorporation; **RR-** Residue retention/ anchored)

IIWBR

A long term experiment has been initiated involving two tillage (CT and ZT+R), three manuring treatments (no, sesbania, greengram) and two weed control options (weedy check and weed free) in cropping system i.e. rice-wheat (R-W). The experiment was started in 2020 with rice. For rice, the cultivar grown was HKR 47. For wheat, in rice-wheat system, timely sown wheat variety DBW 222 was sown during the first week of November. The green manure crop sesbania and greengram were sown during the last week of April. In CT, treatment, incorporation was done using the Rotary Tiller. Whereas, in CA, these crops were burned down with the mixture of glyphosate + 2,4-D at 45-50 days. One month old rice seedlings were transplanted at 20 cm row to row spacing and 10 cm plant to plant spacing after ponding of water for two days in ZT and CT conditions (Fig 1.10). In each tillage and green manure combination option, two sub plots of weed control (weedy and weed free control) were kept.

In rice-wheat system, wheat grain yield was similar under CA (56.02 q/ha) and CT (57.34 q/ha) system (Fig 1.10). The effect of manuring on wheat was not distinctly visible and long term continuation may result some desirable effect on system productivity**.**

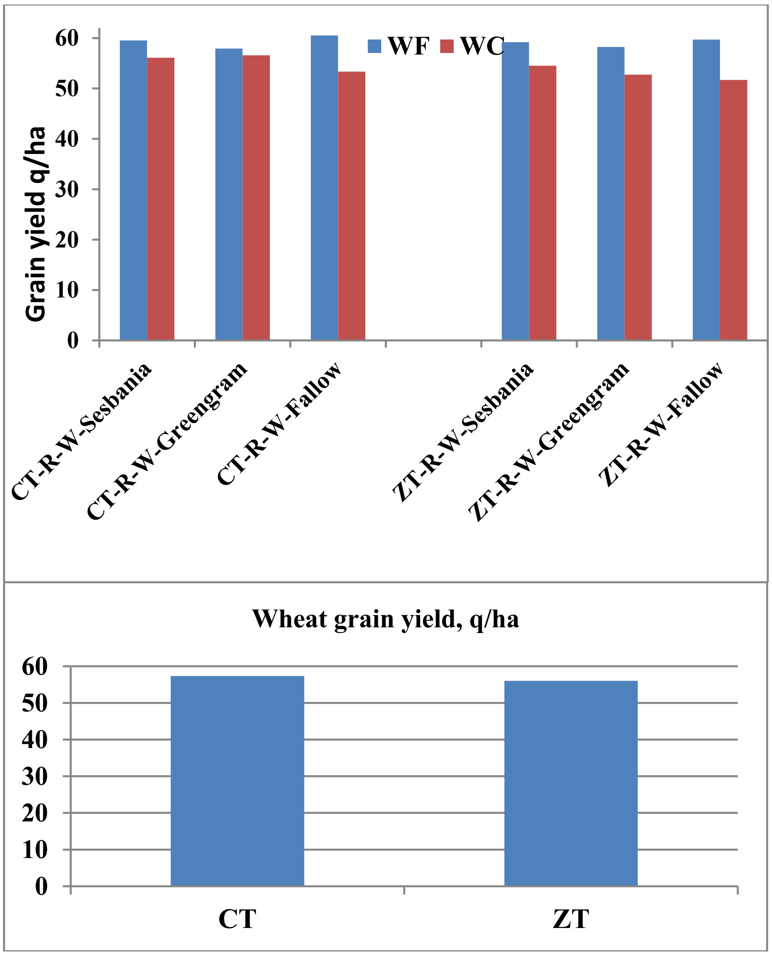


Fig 1.10 Effect of tillage and manuring on wheat yield in rice-wheat system

Fig 1.11 Rice (Direct-seeded) (*Kharif*, 2021)

2. Rice- Fellow cropping system

RCER

A field investigation on long term conservation agriculture was initiated during *Kharif* 2016 in rice-fallows experiment block of ICAR-Research Complex for Eastern Region, Patna, India (25º35′ N, 85º05′ E and 51 m AMSL). Soil sampling was done by core sampling method and initial soil properties of experimental plots were determined following standard methods. Present study was laid out with broad aims of identifying suitable CERM techniques and potential winter crops for improving soil health, reducing soil degradation, improving system productivity, SOC stock and biological attributes of rainfed rice-fallow. Experimentation was conducted in split-plot design and each treatment was replicated thrice, having CERM in main-plot and post-rainy season/winter crops in sub-plot. CERM practices i.e. ZTDSR, CTDSR, and TPR along with anchored crop residue 30% RT (R_+) and without residue/control (R-) were considered for evaluation. Short duration rice cv. Swarna Shreya (120 days) was grown during rainy season, while post-rainy season crops i.e., chickpea, lentil, safflower, linseed and mustard were raised on residual soil moisture to diversify existing rice-fallows. Glyphosate (41%

EC) @ 1.5 l ha^{-1} was used for managing pre-established weeds after rice harvest. Before planting of winter crop, seeds were primed with water (soaking of seed for 12 hrs) to achieve the better germination. Post-rainy crops were planted by ZT-happy seeder. Foliar spraying of 2% urea was done in all post-rainy season crops at the reproductive stage.

System productivity

To intensify rice-fallows system by suitable post-rainy/winter crops, short duration and high yielding rice cv. "Swarna Shreya" was grown in diverse CERM method during rainy season (June to October). CERM practices significantly affected grain yield. Among CERM methods, TPR had the highest grain yield, which was 32.2 and 19.1% higher in comparison to ZTDSR and CTDSR production systems, respectively. Post-rainy season crops following ZTDSR/CTDSR practices performed better in terms of crop yield. Crop productivity of all post-rainy season crops declined when planted after TPR and reductions in yield were 32.2, 36.2, 45.8, 18.8 and 14.9% in chickpea, lentil, safflower, linseed and mustard, respectively, compared to ZTDSR system (Table 1.5). System productivity was increased from 5.0-5.35to 7.53-8.71Mg ha^{-1}through inclusion of post rainy/winter crops during fallow period. System productivity was maximum in TPR production system. Though the post-rainy season crops yielded more when planted after ZTDSR/CTDSR, better rice yield in TPR led to overall more system productivity, but being at par with ZTDSR. Comparatively lower rice yield under ZTDSR production system was recompensed by better yields of post-rainy crops during the fallow.

Table 1.5 Effect of crop establishment and residue management (CERM) and winter season crops on grain yield, rice equivalent yield (REY) and system productivity (SREY) under rainfed rice-fallow agro-ecosystem of eastern India

CERM		Rice yield (t ha^{-1})	Seed yield (Mg ha^{-1})					Rice equivalent yield (Mg ha^{-1})					Mean	System productivity (Mg ha^{-1})					Mean
			Chickpea	Lentil	Safflower	Linseed	Mustard	Chickpea	Lentil	Safflower	Linseed	Mustard		R-C	R-L	R-SF	R-Li	R-M	
ZTDSR	R^-	3.79^{F}	1.77^{B}	1.76^{B}	1.63^{B}	1.07^{C}	1.56^{C}	4.62±0.4	4.55±0.39	4.54±0.21	2.01±0.12	3.69±0.09	3.88^{B}	8.41±0.33	8.35±0.33	8.34±0.22	5.8±0.17	7.49±0.15	7.74^{C}
	R^+	4.04^{E}	2.01^{A}	1.99^{A}	1.87^{A}	1.27^{A}	1.75^{A}	5.24±0.37	5.11±0.36	5.21±0.29	2.38±0.08	4.14±0.10	4.41^{A}	9.27±0.30	9.15±0.30	9.25±0.25	6.41±0.13	8.17±0.14	8.48^{AB}
CTDSR	R^-	4.19^{D}	1.54^{C}	1.51^{C}	1.26^{D}	0.98^{DE}	1.47^{E}	4.01±0.21	3.88±0.22	3.51±0.11	1.84±0.12	3.48±0.02	3.34^{C}	8.2±0.23	8.07±0.24	7.7±0.17	6.03±0.18	7.67±0.13	7.53^{C}
	R^+	4.50^{C}	1.76^{B}	1.73^{B}	1.45^{C}	1.16^{B}	1.65^{B}	4.59±0.28	4.43±0.26	4.05±0.18	2.17±0.13	3.91±0.13	3.83^{B}	9.09±0.30	8.93±0.28	8.55±0.20	6.67±0.20	8.41±0.20	8.33^{B}
TPR	R^-	5.00^{B}	1.34^{D}	1.29^{D}	1.14^{E}	0.93^{E}	1.37^{F}	3.50±0.16	3.31±0.17	3.17±0.17	1.75±0.01	3.24±0.09	2.99^{D}	8.50±0.19	8.31±0.20	8.17±0.20	6.74±0.11	8.24±0.15	7.99^{C}
	R^+	5.35^{A}	1.52^{C}	1.47^{C}	1.26^{D}	1.04^{CD}	1.51^{D}	3.98±0.17	3.77±0.19	3.53±0.16	1.94±0.02	3.57±0.10	3.36^{C}	9.33±0.20	9.12±0.21	8.87±0.19	7.29±0.10	8.92±0.15	8.71^{A}
Mean		4.48	1.66	1.63	1.43	1.08	1.55	4.32^{a}	4.18^{b}	4.00^{c}	2.01^{e}	3.67^{d}		8.80^{A}	8.65^{B}	8.48^{C}	6.49^{E}	8.15^{D}	
LSD		CERM	CERM					CERM		WC		CERM*WC		CERM		WC		CERM*WC	
(*p=0.05*)		0.08	0.08	0.07	0.07	0.06	0.03	0.08		0.12		0.21		0.08		0.16		0.25	

Jharkhand & Chhattisgarh

Evaluation of CA practices in rice-fallows: CA practices were evaluated during 2020-21 in farmer's field at two location *viz.* Chene, Ranchi, Jharkhand and Kandora, Jashpur, Chhattisgarh. CA practices comprised of zero-tillage transplanted rice with mulch (ZTT-M), zero-tillage transplanted rice without mulch (ZTT-NM), zero-tillage direct seeded rice with mulch (ZTDSR-M), zero-tillage direct seeded rice without mulch (ZTDSR-NM) and farmer's practice without mulch (FP-NM) were evaluated on winter crops i.e. lentil (KLS-218), mustard (Pusa-26) and linseed (BAU 06-03) after harvesting of rice. Black gram, green gram and cow pea after harvest of Rabi crops were also evaluated. Rice straw used as mulch was applied @ 5 t/ha at sowing of winter crops with the respective treatments.

Experimental Site 1: Chene, Namkum, Ranchi, Jharkhand
Evaluation of CA practices on productivity of rice in eastern India
CA practices was evaluated during 2020-21 in farmer's field at two locations viz., Chene, Ranchi, Jharkhand and Kandora, Jaspur, Chhattisgarh. CA practices comprised of zero-tillage transplanted rice with mulch (ZTT-M), zero-tillage transplanted rice without mulch (ZTT-NM), zero-tillage direct seeded rice with mulch (ZTDSR-M), zero-tillage direct seeded rice without mulch (ZTDSR-NM) and farmer's practice without mulch (FP-NM) were evaluated on rice with genotypes *viz.* Naveen, Lalat, IR-64 and Sahbhagi. Rice grain yield was significantly higher of 5.12 t/ha in ZTT-M over all other CA and farmer's practices (Table 1.6). Farmer's practice registered grain yield of 4.2 t/ha. Among the genotypes, Naveen recorded the highest grain yield of 4.85 t/ha.

Table 1.6 Effect of CA practices on yield attributes of rice (Mean data of 2021)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)
CA practices			
FP	4.20	6.0	10.2
ZTDSR	4.69	5.9	10.59
ZT Transplant	5.12	6.5	11.62
LSD (p≤0.05)	0.276	0.396	0.510
Genotypes			
V1: Naveen	4.85	6.12	10.97
V2: Lalat	4.47	5.98	10.45
V3: IR 64	4.36	5.14	9.5
V4: Sahabhagi	3.89	5.71	9.6
LSD (p≤0.05)	0.355	0.457	0.607

3. Maize-Wheat Cropping System (MWS)
IARI
Under the CA-based maize-wheat system, all the CA-based ZT permanent broad, narrow, and flat beds with residue resulted in significantly higher yields of maize, wheat and system productivity than CT (Table 1.7; Fig 1.12). However, in contrast ZT permanent broad bed with residue with 100% N led to significantly higher maize yield by 19.9%, wheat yield by 28.6% and system productivity by 24.2% than CT system. This practice with 75% N was comparable with it, leading to a saving of 25% N. This CA-based maize-wheat system could be a promising crop diversification option for rice-wheat system and an important adaptation and mitigation strategy to climate change.

Table 1.7 CA effects on crop and system productivities in maize-wheat cropping system

Treatments	Maize (t/ha)	Wheat yield (t/ha)	SP (WEY) (t/ha)
CT	5.63	4.89	10.03
PNB	6.09	5.31	10.88
P NB+R+75 N	6.31	5.61	11.37
PNB+R+100 N	6.48	5.92	11.85
P BB	6.18	5.40	11.05
P BB+R+75 N	6.49	5.82	11.76
P BB+R+100 N	6.75	6.29	12.46
ZT FB	6.10	5.39	10.96
ZT FB+R+75 N	6.41	5.71	11.57
ZT FB+R+100N	6.62	6.13	12.18
SEm±	0.17	0.20	0.30
LSD (P=0.05)	0.51	0.59	0.88

Fig 1.12 Wheat under ZT-Narrow Bed+ maize residue with 75%N and 100% N

IIWBR

Performance of CA and CT maize-wheat- system with sesbania and greengram manuring

A long term experiment has been initiated involving two tillage (CT and ZT+R), three manuring treatments (no, sesbania, greengr am) and two weed control options (weedy check and weed free) in cropping system i.e. maize-wheat. The experiment was started in 2020 with maize crop. In maize-wheat- The green manure crop sesbania and greengram were sown during the last week of April. In CT, treatment, incorporation was done using the Rotary Tiller. Whereas, in CA, these crops were burned down with the mixture of glyphosate + 2,4-D at 45-50 days. The maize and wheat were sown using the Turbo Happy Seeder. In each tillage and green manure combination option, two sub plots of weed control (weedy and weed free control) were kept.

In maize-wheat cropping system, the wheat yields were similar under CT and CA system under weed free situations (Fig 1.13). Whereas, in presence of weeds the marginal yield advantage was observed.

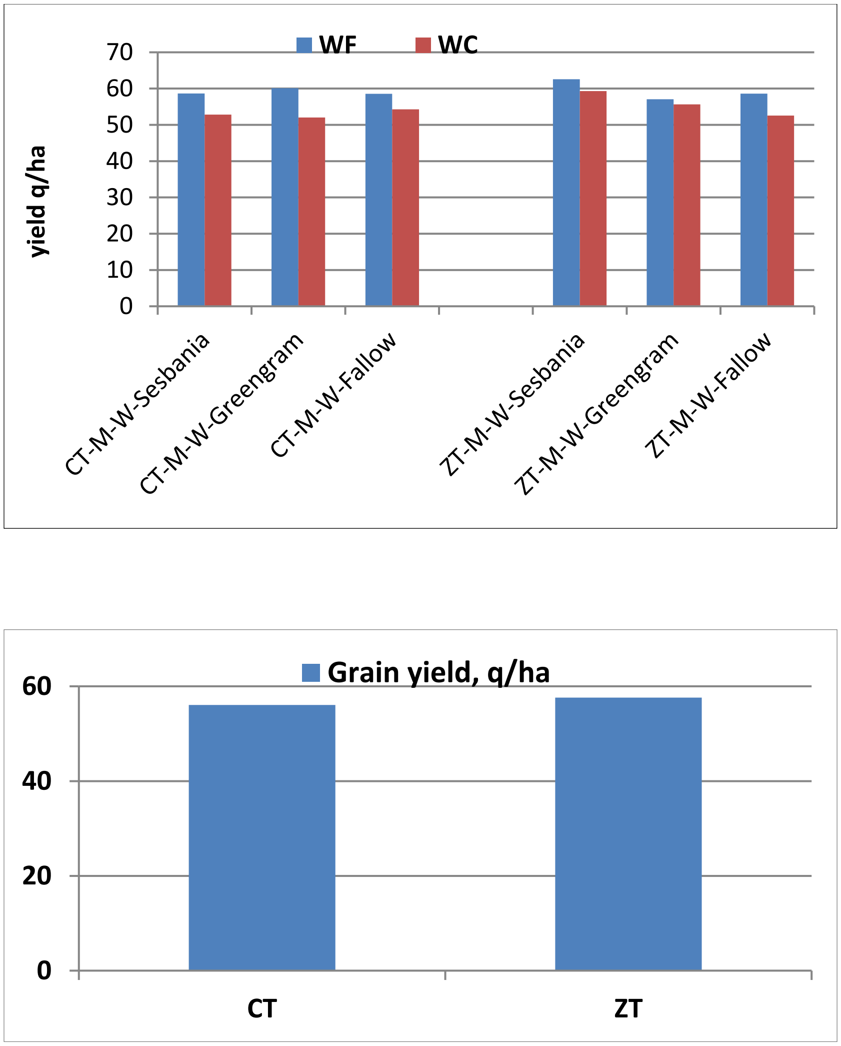
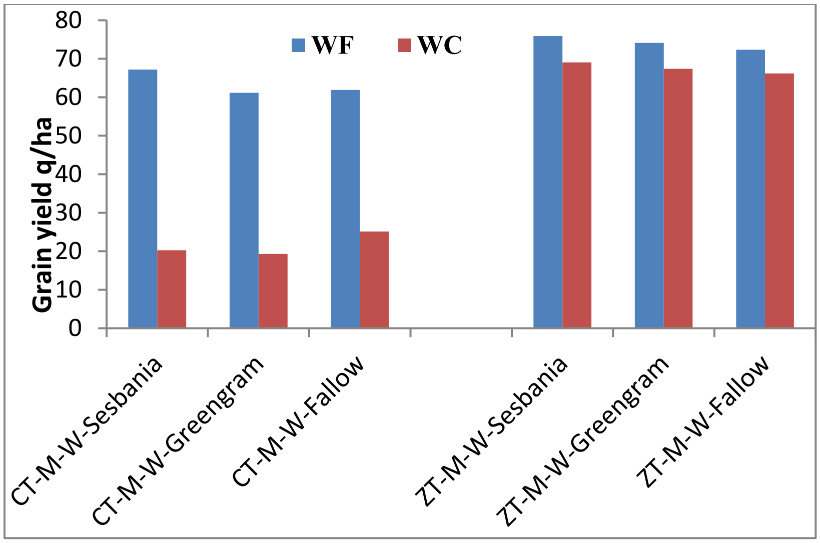


Fig 1.13 Effect of tillage and manuring on wheat yield in maize-wheat system

The maize yield was higher in CA system both in the presence and absence of weeds (Fig 1.14). The higer maize yield in CA in weedy conditions was due to effective control of weeds particularly the *Cyperus rotundus* due to use of glyphosate as pre-planting option along with lesser effect of intensive rainfall.



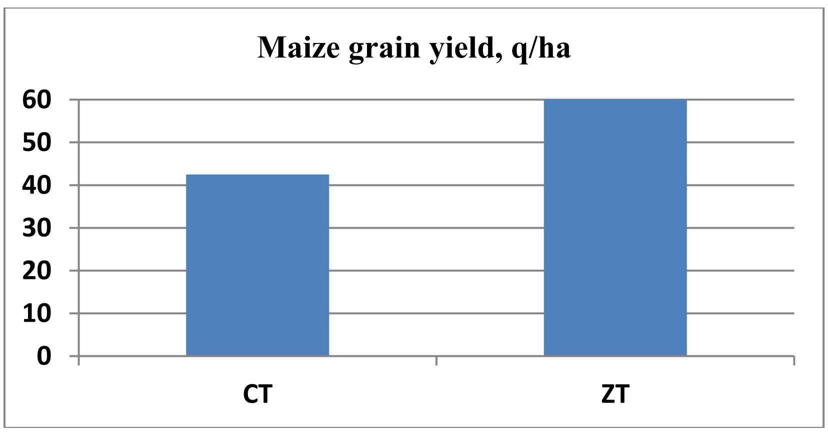


Fig 1.14 Effect of tillage and manuring on maize yield in maize-wheat system

4. Maize-Wheat-Green gram cropping system

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 DBW 222 (2020-21) was sown on November 8, 2020 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 (175 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 pinoxaden 50 g/ha fb metsulfuron 4 g/ha were applied at 35 fb 40 DAS. The recommended dose of $N:P_2O_5:K_2O$ 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-1 revealed that the effect of nutrient management was significant, whereas the effect of tillage and residue management and their interactions were non-significant except for grain yield. Among four nutrient management options minimum yield was recorded in unfertilized control plots having a mean yield of 16.61 q/ha. The poor yield in this treatment was due to lesser yield attributes mainly the effective tillers. The wheat grain yield was maximum (61.64 q/ha) when FYM @ 10 t/ha was applied along with Rec. NPK. However, statistically this treatment was at par with Recommended NPK application. The unfertilized plots were having the lowest 1000 grains weight. Among tillage and residue management options, CT wheat had lowest 1000 grains weight.

Table 1.8 Effect of tillage, residue and nutrient management in wheat under Maize-wheat system during 2020-21

Tillage and residue management	Plant height, cm	Earhead length, cm	Tillers/m^2	Yield q/ha	1000 grain weight, g	Protein (%)
ZT	92.0	9.9	413.5	46.13	41.98	10.7
ZT+R*	95.8	10.4	424.6	48.60	42.34	11.0
CT	95.9	10.0	404.6	46.26	41.06	10.3
CT+RI*	97.2	10.0	407.9	47.39	42.67	10.4
CD at 5%	NS	NS	NS	NS	NS	NS
Nutrient management						
Control	71.8	8.1	313.5	15.42	41.04	9.5
N Alone	95.8	10.6	404.8	68.56	43.91	11.0
Rec. NPK	105.0	10.8	463.1	72.55	44.52	10.8
Rec. NPK+ FYM 10t/ha	108.2	10.8	469.2	73.50	44.97	11.2
CD at 5%	3.68	0.54	32.42	1.56	NS	0.34

*R=Residue Retention and RI= Residue incorporation

Residue Incorporation

ZT-Wheat

Fig 1.15 Long term maize-wheat experiment's treatments
CA-Wheat (Wheat in full maize residue)

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. In ZT and CA pre-planting glyphosate was also applied at 1.2% spray solution. Maize hybrid DKC 9144 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 (79.95 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 (Fig 1.16). The yield recorded in CT plots were 67.83 q/ha. Among nutrient management treatments, unfertilized plots recorded significantly lowest yield (40.08 q/ha).

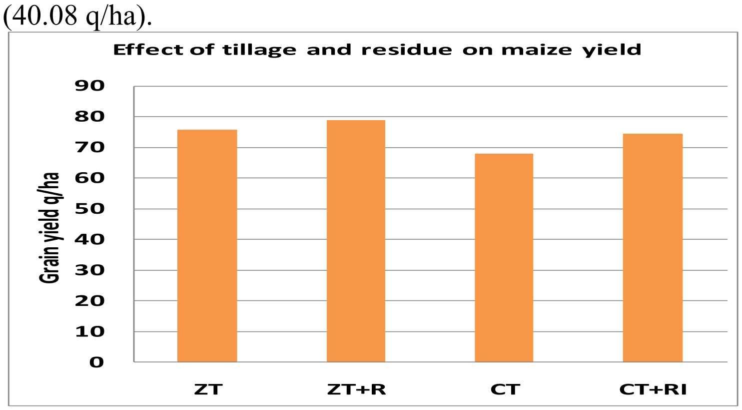


Fig 1.16 Effect of tillage and residue on maize yield

5. Cotton-Wheat cropping system (CW)

IARI

Under the CA-based cotton-wheat system, all the CA-based ZT permanent broad, narrow, and flat beds with residue resulted in significantly higher yields of cotton, wheat and system productivity than CT. However, in contrast to previous years where ZT permanent broad bed was superior, this year the ZT flat bed with residue with 100% N led to significantly higher cotton yield by 77.6%, wheat yield by 26% and system productivity by 81.4% than CT system(Table 1.9; Fig 1.17-1.19). This practice with 75% N was comparable to it, leading to a saving of 25% N. This CA-based cotton-wheat system could be a promising crop diversification option for rice-wheat system and an important adaptation and mitigation strategy to climate change.

Table 1.9 CA effects on crop and system productivities in cotton-wheatcropping system

Treatments	Cotton yield (t/ha)	Wheat yield (t/ha)	SP (WEY) (t/ha)
CT	1.52	4.62	8.99
PNB	1.93	4.91	10.49
PNB+R+75 N	1.83	4.95	10.24
PNB+R+100 N	1.77	5.05	10.15
PBB	1.74	5.22	10.23
P BB+R+75 N	1.85	5.26	10.61
P BB+R+100 N	2.10	5.41	11.47
ZT FB	2.59	5.52	12.98
ZT FB+R+75 N	2.30	5.77	12.40
ZT FB+R+100N	2.70	5.82	13.61

Fig 1.17 Zero-tillage cotton under broad bed with residue

Fig 1.18 Zero-tillage wheat under narrow bed with residue

Fig 1.19 Zero-tillage wheat under broad bed with residue

6. pigeon pea-wheat system (PWS)

IARI

Under the CA-based pigeon pea -wheat system, all the CA-based ZT permanent broad, narrow, and flat beds with residue resulted in significantly higher yields of pigeon pea, wheat and system productivity than CT (Table 1.10; Fig 1.20 & 1.21). However, in contrast ZT permanent broad bed with residue led to significantly higher pigeon pea yield by 60.5% and system productivity by 29.4% but wheat yield was 11.3% higher in ZT flat bed with residue than CT system. This practices was also comparable when it practiced with 75% N, leading to a saving of 25% N. This CA-based pigeon pea-wheat system could be a promising crop diversification option for rice-wheat system and an important adaptation and mitigation strategy to climate change.

Table 1.10 CA effects on crop and system productivities in pigeon pea-wheat cropping system

Treatment	Pigeon pea yield (t/ha)	Wheat yield (t/ha)	SP (WEY) (t/ha)
CT FP	1.34	5.14	9.18
ZT NB	1.76	5.25	10.56
ZT NB+R	1.90	5.41	11.14
ZT BB	2.01	5.29	11.33
ZT BB+R	2.15	5.42	11.88
ZTFB	1.81	5.60	11.06
ZT (FB+R)	1.92	5.72	11.51

Fig 1.20. Wheat under ZT-Narrow Bed+ maize residue with 75%N and 100% N

Fig 1.21. Wheat under ZT-Broad Bed + pigeon pea residue

7. Maize (Mz)-Mustard (Ms) System
IARI

Similar to rice-wheat system, the performances of the CA practices in a maize-mustard system indicated that a triple cropping system involving zero-tillage maize (ZTMZ) with summer mungbean residue (SMBR) – zero-tillage mustard (ZTMSD) with maize residue (MZR)- zero-tillage summer mungbean (ZTSMB) with mustard residue (MR) was consistently superior to conventional tillage system (CTMZ-CTMSD) on system productivity and net returns. This system led to 16.9% higher maize yield, 26.8% higher mustard yield and 64.9% higher system productivity than CTMZ-CTMSD system (Table 1.11). This system may be considered as alternate diversified option of conventional rice –wheat and an important adaptation and mitigation strategy to climate change.

Table 1.11 CA effects on crop and system productivities in maize-mustard cropping system

Treatments	Maize yield (t/ha)	Mustard yield (t/ha)	SP (MzEY) with mungbean(t/ha)	SP(MzEY) without mungbean (t/ha)
ZTMZ-ZTMSD	5.05	2.36	10.98	10.98
ZTMZ+BM-ZTMSD	5.19	2.42	11.27	11.27
MR+ZTMZ-MZR+ZTMS	6.37	2.70	13.16	13.16
MR+ZTMZ+BM-MZR+ZTMSD	5.68	2.85	12.84	12.84

ZTMZ-ZTMSD-ZTSMB	6.27	2.48	16.50 (4.01)*	12.49
SMBR+ZTMZ-MZR+ZTMSD-MR+ZTSMB	6.60	2.84	18.31 (4.56)*	13.75
CTMZ-ZTMSD	5.92	2.51	12.21	12.21
CTMZ-CTMSD	5.48	2.24	11.10	11.10

*Maize equivalent yield of mungbean grain yield (t/ha) in parentheses

8. Sugarcane Cropping System

NIASM

Optimizing planting techniques, micro irrigation and residue management practices for better productivity in sugarcane cropping system

Water stress is considered to have most significant effects on sugarcane productivity owing to its high water demand. Thus an existing field experiment on integrating CA components with micro-irrigation and planting techniques (*Cv.* MS-10001) in split-plot design with three replications was continued in third year (2020-21) ratoon crop. Combination of planting techniques and micro-irrigation were kept as main plot treatments *viz.,* M_1: Parallel planting of each plant in single rows spaced at 150 cm with surface drip irrigation (PSR-150 cm + SDI); M_2: Parallel planting of each plant of paired rows by maintaining spacing of 210 cm between the pairs and 90 cm between the rows with SDI (PPR-210 cm × 90 cm + SDI); M_3: Zigzag planting of each plant of paired rows by maintaining spacing of 225 cm between the pairs and 75 cm between the rows with SDI (ZPR-225 cm × 75 cm + SDI); M_4: ZPR-240 cm ×60 cm + SDI; M_5: ZPR-225 cm × 75 cm + sub surface drip irrigation (SSDI); M_6: ZPR-240 cm × 60 cm + SSDI and M_7: ZPR-210 cm × 90 cm + SDI. Two sub plot treatments of soil surface cover management practices *viz.,* S_1: Residue mulching-covering of soil surface with a live mulch of mungbean (*Var.* BM-2003-2) followed by retention of mungbean residue and trash as mulch and S_2: No (without) residue (trashes were burnt) were accommodated. An absolute control surface irrigation management (Farmer practices, M_8) with trash retention and burning was also maintained to compare the treatment effects.

The results of pooled analysis (2018-19, 2019-20 and 2020-21) showed significantly higher improvement in cane yields under sub-surface drip irrigation with live/trash mulch in both plant and ratoon cane. Comparing all the treatment combinations, pooled interaction of M_5 (ZPR-225 cm × 75 cm + SSDI) with mulch recorded maximum cane yield (150.3 t ha^{-1}) followed by M_6 (ZPR-240 cm × 60 cm + SSDI) with mulch (142.0 t ha^{-1}) while the farmer practices plot recorded minimum cane yield production i.e. 125.3 t ha^{-1} in trash retention and 106.3 t ha^{-1} in burn. Overall, planting geometry zig-zag parallel row, ZPR (225 cm × 75 cm) + sub surface drip irrigation (SSDI) resulted in higher 5.5% and 16.6% cane yields as compared to parallel single row (PSR)-150 cm + surface drip irrigation (SDI) and PSR (150 cm) + surface irrigation (SI) methods, respectively (Fig1.22). This indicated that yields of paired row planted sugarcane could be improved significantly with adoption of zigzag planting, micro-irrigation techniques and retaining the trash on soil surface. Covering of soil surface with live mulch of mungbean followed by retention of mungbean residue and trash improved the cane yields on an average by 10.6-23% as compared to without residue-retained treatment. The results of water productivity (WP) clearly indicated that the subsurface drip irrigation (SSDI) was superior over the conventional flood irrigation and surface drip irrigation (SDI) method. Maximum WP (0.90 Mg ha cm^{-1}) was recorded in M_5S_1 treatment (ZPR-225 cm × 75 cm + SSDI with mulch) followed by 0.80 Mg ha cm^{-1} in M_6S_1 (ZPR-240 cm × 60 cm + SSDI); whereas minimum WP was recorded in farmer practices plots. WP significantly increased due to the trash management and subsurface irrigation system, which considerably contributed in reducing water loss through evapotranspiration and delivering water directly to the rooting zone. The WP in mulch was 8.86% higher over non-mulch of SSDI, 10% over SDI and 31.03% over SI (Fig 1.23). Implementation of the CA practices in sugarcane cropping system favoured the accumulation of Soil Microbial Biomass Carbon (SMBC), which could be attributed to the addition of carbon substrates in the soil mainly through the retention of sugarcane trash. The treatment M_5S_1 exhibited highest dehydrogenase activity (260.00 µgTPE g $soil^{-1}$ day^{-1}) and soil biomass carbon (385 µg g $soil^{-1)}$ as compared to the rest of the treatments, which could be attributed to the plating geometry and subsurface drip irrigation technique through higher availability of soil-moisture for optimal microbial activity. Planting geometry and trash management had a significant influence on available nutrient status of soil after harvest of sugarcane. Zigzag paired row (225 cm × 75 cm) planting geometry along with SSDI and trash-retention (M_5S_1) exhibited maximum organic carbon, OC (0.75%), available N (180 kg ha^{-1}), P (18.46 kg ha^{-1}) and K (530 kg ha^{-1}) status of soil after harvest of crop. It may be happen due to continuous mulching of crop residue with minimum volatilization losses. The incorporation of crop residue in conjunction with SSDI significantly enhances the sustainability and stability with respect to productivity of sugarcane based cropping system.

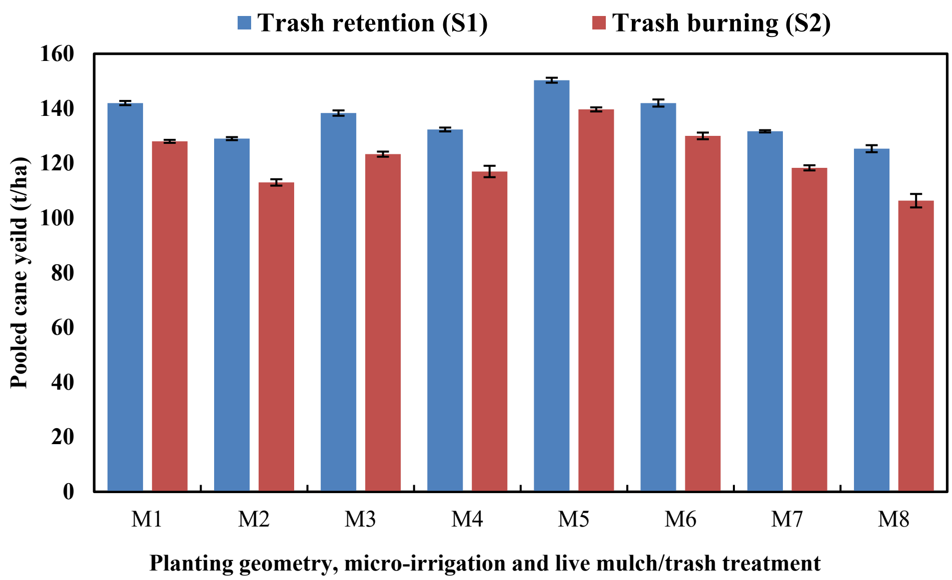


Fig 1.22 Effect of planting geometry, micro-irrigation and trash management on pooled cane yield of planted and ratoon sugarcane

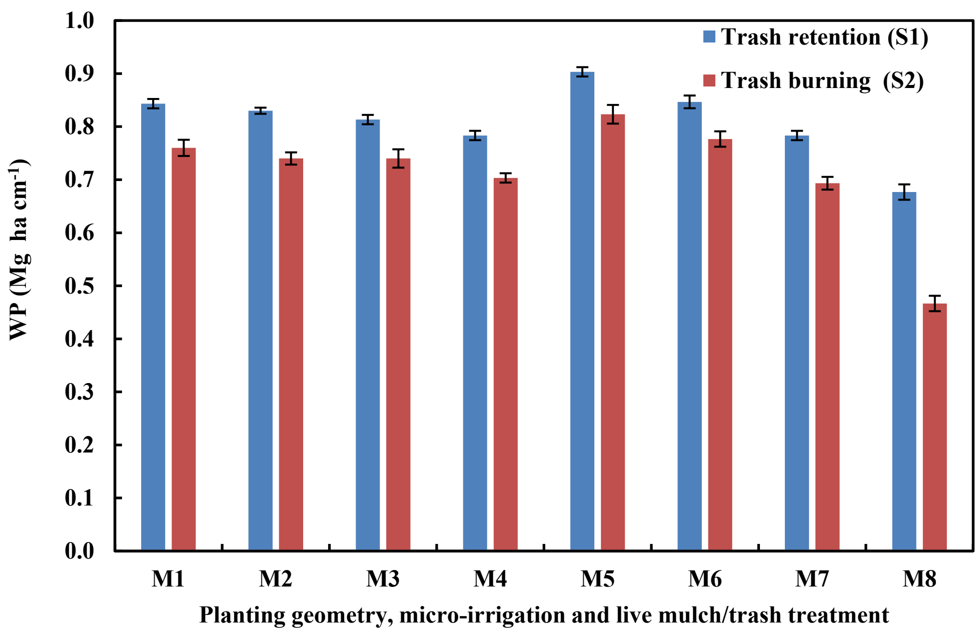


Fig 1.23 Effect of planting geometry, micro-irrigation and trash management on WP of planted and ratoon sugarcane

In consideration of our experiences and results of above mentioned experiment, another field experiment was initiated during the year 2021 to optimize the effect of zigzag paired row planting, subsurface drip irrigation and intercropping (groundnut-fenugreek) with aim of enhancing productivity of sugarcane cropping system. For this sugarcane seedlings of Cv. Co-86032 were transplanted into eight main plot treatments *viz.,* M1: Zigzag paired row (ZPR) (60 cm-plant spacing ,150 cm-row spacing) + Sub-surface drip irrigation (SSDI); M2: ZPR (75 cm, 150 cm) + SSDI; M3: ZPR (60 cm, 210 cm) + SSDI; M4: ZPR (75 cm, 210 cm) + SSDI; M5: ZPR (60 cm, 225 cm) + SSDI; M6: ZPR (75 cm, 225 cm) + SSDI; M7: ZPR (60 cm,180cm) + SSDI; M8: ZPR (75 cm,180 cm) + SSDI. Two soil cover treatments included S1: Groundnut residue + sugarcane trash and S2: without residue were accommodated in sub-plots. An absolute control surface irrigation management practices was also maintained to compare the treatment effects. The preliminary results showed that 39.5 and 51.3% improvement in yields of groundnut and fenugreek was recorded in M5S1 treatments in comparison to M3S2, respectively indicating possibility of improving productivity sugarcane cropping system using intercrop. However, yields responses of sugarcane yet to be analyse since main crop is not ready to harvest.

		
Intercrop 1: groundnut	Soil cover with groundnut residue	Intercrop-2: fenugreek

1. ***Sugarcane responses to tillage, crop residue and nutrient management practices***

Among the sugarcane management operations; excessive tillage, burning of crop residue and excess use of nitrogenous fertilizers are considered to be main contributors for soil degradation, greenhouse gas emission and nutrient loss. To address this problem, long term experiment (initiated 2018) using variety MS-10001 was continued as 2^{nd} ratoon crop in year 2020-21 in split plot design with the main treatments *viz.,* M_1: Laser land levelling (LLL) + conventional tillage (CT) + 10% of recommended dose of fertilizers (RDF; 300:115:115; N: P: K; kg ha^{-1}) applied as basal and remaining 90% doses of fertilizers applied through fertigation; M_2: LLL + reduced tillage (RT) by excluding deep tillage + 10% of RDF as basal and 90% through fertigation; M_3: LLL + RT + 10% of RDF as basal, 40% through band placement (by SORF) and remaining 50% through fertigation; M_4: Conventional sugarcane management practices i.e. farmers practice. Two soil surface cover management practices *viz.,* S_1: Residue covering of soil surface with a live mulch of mungbean (*Var.* BM-2003-2) followed by retention of mungbean residue and trash as mulch and S_2: without residue were accommodated in sub-plots.

The results of fresh planted sugarcane showed that there was no significant difference in cane yields under conventional tillage (157.1 t ha^{-1}, M_1) and reduced tillage practices (162.2 t ha^{-1}, M_2) practices. It revealed that reduced tillage could be adopted without compromising the cane yields. Furthermore, application of 40% of RDF through band placement (through SORF) and 50% of RDF through fertigation (M_3) improved the cane yield (170.0 t ha^{-1}) significantly over the application of 90% RDF through fertigation. The yields improvement with M_3 over M_1, M_2 and conventional sugarcane management practices (M_4) treatments were 5.7, 10.5 and 26.4%, respectively (Fig 1.24). This might be due to the 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. The pooled data (1^{st} and 2^{nd} ratoon sugarcane during 2018-2021) indicated that individual and interaction effects all treatment combinations were found significant (Fig.4).

In ratoon sugarcane, maximum yield (153.5 t ha^{-1}) was recorded in reduced tillage, trash retention with placement of 50% of RDF as basal by using SORF and remaining 50% by fertigation ($M_3S_1N_2$) followed by 75% of RDF as basal by using SORF and remaining 25% by fertigation ($M_3S_1N_3$, 149.8 t ha^{-1}).

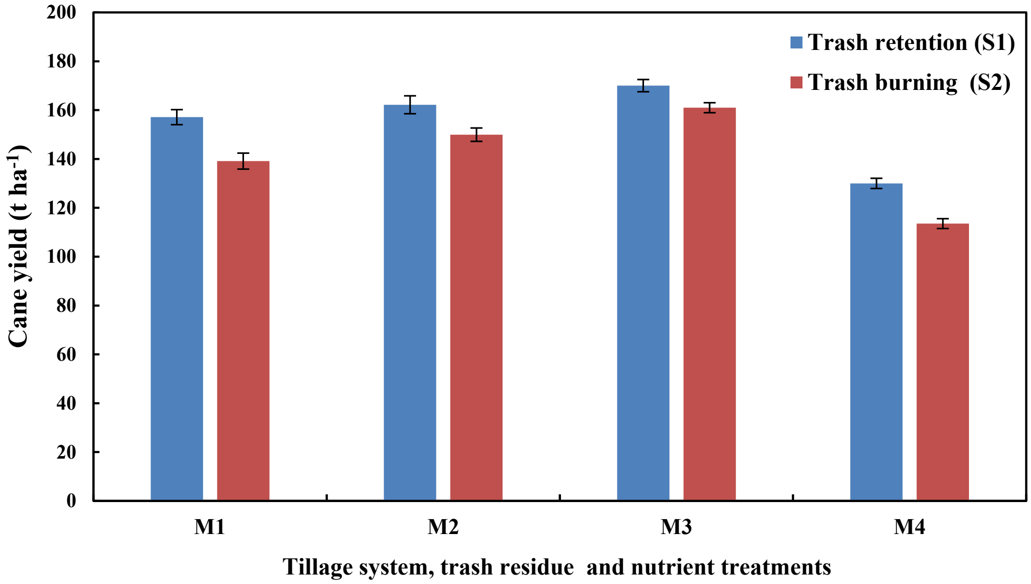


Fig 1.24 Effect of tillage, residue and nutrient management practices on fresh cane yields

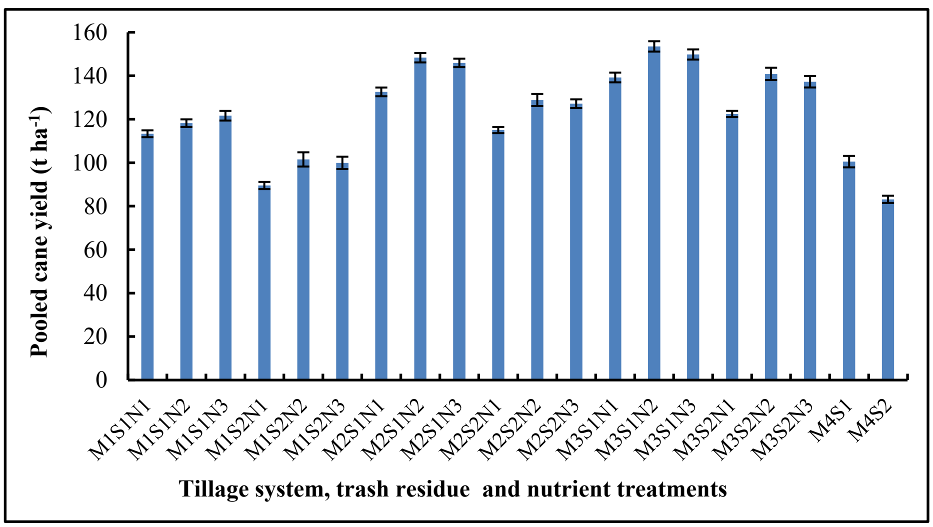


Fig 1.25 Interaction effect of tillage, residue and nutrient management on ratoon cane yields

B. Weed Management Practices in Conservation Agriculture

1. Rice Wheat Cropping System

IARI

Weed dynamics in CA-based RW, CW, PW and MW systems

Direct-seeded rice (DSR) witnessed insurgence of weed species such as Dactylocteniuma egyptium, Dinebraretroflexa, Leptochloa chinensis, and Eleusine indica, which were not found in PTR, whereas C. difformis, C. iriawere found only in TPR. The application of pyrazosulfuron at 0.025 kg/ha PE followed by (fb) cyhalofop-butyl at 0.100 kg/ha at 20 DAS fbbispyribac-Na at 0.025 kg/ha at 25 DAS could control grassy (by 72%), broad-leaved (by 60%) and sedge (by 43%) weeds and increase rice yield by 125%. Cyperus esculentus a perennial sedge gradually superseded /outwitted perennial sedge Cyperus rotundus (which was present from the beginning in CA system) and was most dominant weed in DSR, cotton, maize, and pigeon pea crops in varying intensity (Table 1.13; Fig 1.26 & 1.27). Medicago denticulata an annual weed occurred in very high density in mustard under maize-mustard system(Table 1.12; Fig 1.28 & 1.29), and another annual weed, Malva parviflora was seen first time in wheat under the maize-wheat-mungbean system in sandy loam soil. Medicago denticulata was controlled by pendimethalin @ 1.0 kg/ha and Malva parviflora was controlled by pre-mix carfentrazone + metsulfuron.

Table 1.12 Cyperus esculentus population (no./m^2) in wheat–based systems

Treatments	*Cyperus esculentus* population (no./m^2) in wheat – based systems		
	Cotton-wheat	Maize-wheat	Pigeon pea -wheat
CT	900	568	208
PNB+R	769	526	51
PBB+R	140	257	21
PFB+R	849	188	16

Fig 1.26 *Cyperus esculentus* infestation in maize

Fig 1.27. *Cyperus esculentus* infestation in cotton

Table 1.13 Medicago denticulate density in mustard under CA-based maize-mustard system (11thyr)

Treatment	*Medicago denticulate* density (no./m^2)*
ZTMz-ZTMs	19.8 (393)
ZTMz+BM-ZTMs	19.3 (384)
MsR+ZTMz-MzR+ZTMs	21.5 (473)
MsR+ZTM+BM-MzR+ZTMs	19.9 (398)
ZTMz-ZTMs-ZTMb	1.0 (0)
MBR+ZTMz-MzR+ ZTMs- MsR+ ZTMb	1.0 (0)
CTMz-ZTMs	1.0 (0)
CTMz-CTMs	1.0 (0)
LSD (P=0.05)	3.92
*Transformed data; Figures in parentheses are original values	

Fig 1.28 ***Medicago denticulata*germination after maize harvest in zero-tillage with residue plot**

Fig 1.29 ***Medicago denticulata*in festation in zero-tillage mustard with residue plot under maize-mustard cropping system**

DWR

Twelve OFR trials were undertaken on weed management in direct-seeded rice during *Kharif,* 2021. Weed management through herbicides with recommended dose of fertilizer was compared with the farmers practice. The major weed flora observed was *Cyperus rotundus, Cyperus iria, Echinochlo acolona, Dinebra retroflexa, Paspaladium* sp.*, Phyllanthus niruri* and *Commelina communis.* 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-emergence at 18 DAS) was more effective (weed biomass 39.0 g/m^2; grain yield 4.16 t/ha; B: C 2.75) than farmers practice (high seed rate + unbalanced fertilizer without proper weed management) (weed dry weight, 63.9 g/m^2; grain yield 3.55 t/ha; B:C 2.21) (Table 1.14).

Table 1.14 Weed management, productivity and economics of OFR treatments in direct-seeded rice during *Kharif,* 2021

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Grain yield (t/ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C
RDF+CA+WM	37.9	39.0	74.2	4.16	77720	49474	2.75
FP	47.5	63.9	58.3	3.55	67770	37031	2.21
RDF+CA+Weedy	107.7	156.2		2.19	39322	13780	1.52
SEm±	1.39	3.91	2.10	0.05	1015	1013	0.04
LSD (p=0.05)	4.28	12.05	6.46	0.16	3127	3120	0.11

CA: Conservation agriculture; FP: Farmers Practice; RDF: Recommended dose of fertilizer; WCE: Weed control efficiency; WM: Weed management

3. Rice-Wheat-Green gram based Cropping system (RWG)

Study on weed management in long term rice-wheat-greengram cropping system under conservation agriculture was initiated during 2012 and here the detailed findings of the system are presented, those are-

Rice 2020,

Relative density and biomass of weeds

Rice field was severely infested with a wide range of weeds, at 60 DAS, the relative density of weeds *Echinochloa colona* (27%), *Cyperus iria* (24%) and *Digitaria sanguinalis* (17%) were the major weeds, with the progress of time, the weed-like *Alternanthera sessilis* (9%), *Phyllanthus urinaria* (7%), *Dinebra retroflexa* (7%), *Commelina communis* (4%), *Physalis minima* (4%) and *Caesulia axillaris* (1%) were become dominant. Likewise, relative weed biomass followed a similar trend with *Echinochloa colona* (30%), *Cyperus iria* (23%) and *Digitaria sanguinalis* (18%) were the dominant weeds, with the progress of time, the weed-like *Alternanthera sessilis* (12%), *Dinebra retroflexa* (8%), *Commelina communis* (3%), *Physalis minima* (3%), *Phyllanthus urinaria* (3%) and *Caesulia axillaris* (1%) were other weed biomass recorded (Figure 1.30 a & b).

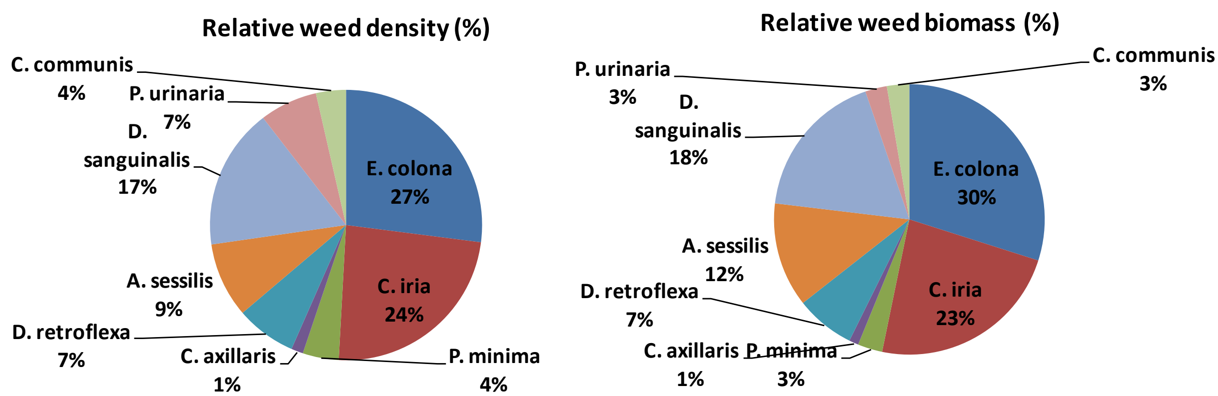


Fig 1.30 The relative density (a) and biomass (b) of weeds in rice at 60 DAS

Weed density and biomass at 60 DAS

The highest weed density was recorded in ZT DSR-ZT-ZT (110 no./m^2) followed by CT DSR-CT-ZT (97 no./m^2), whereas the lowest weed density was recorded with TPR-CT-ZT (27 no./m^2). The lower weed density in TPR-CT-ZT was mainly due to puddle field where existing weeds were incorporated and transplanting of 21 days old seedlings and also with the presence of a 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 (159 no./m2), whereas the lowest weed density was recorded with integrated weed management (application of bispyribac sodium 25 g/ha *fb* fenoxaprop 60 g/ha *fb* HW) (24 no./m^2). Continuous application of bispyribac sodium 25 g/ha *fb* HW in rice recorded weed density of 51 no./m^2, this was considerably lower than the weedy check but was less pertinent to

IWM (Table 1.15). The higher weed density in continuous bispyribac was due to poor control of grasses and some of the broadleaved weeds.

The highest weed biomass was recorded with DSR ZT-ZT-ZT (61 g/m^2) followed by DSR CT-CT-ZT (49.9 g/m^2). The lowest weed biomass was recorded with TPR-CT-ZT (9.9 g/m^2). Rests of the treatments were between these, yet their effect was less pertaining to TPR-CT-ZT system. Among weed management practices, the lowest weed biomass recorded in integrated weed management (herbicide rotation bispyribac sodium 25 g/ha *fb* fenoxaprop 60 g/ha *fb* HW) (7.0 g/m^2) followed by continuous bispyribac sodium 25 g/ha *fb* HW (21 g/m^2). Continuous application of bispyribac was the next best treatment, as it controls the wide range of weeds, but some of the grassy and BLWs could not be controlled, which offered competition to the crop. The highest weed biomass was recorded with a weedy check (90.1 g/m^2) (Table 1.16).

Table 1.15 Crop establishment methods and weed management practices influences weed density and biomass in rice under rice-wheat-greengram system

Treatment	Grasses			BLWs			Sedges	Total
	E. colona	*D. retroflexa*	*D. sanguinalis*	*P. minima*	*A. sessilis*	*P. urinaria*	*C. iria*	
DSR CT+S-CT-ZT	3.8(21.1)	2.62(7.6)	4.26(20.2)	2.76(7.3)	3.18(11)	2.66(6.8)	3.86(17.7)	9.19(96.6)
DSR CT+R+S-CTR-ZTR	3.55(16.6)	2.45(6.3)	3.54(14.7)	2.45(5.8)	2.87(8.4)	2.5(5.9)	3.57(14.3)	8.25(76.3)
DSR ZT+S-ZT-ZT	4.22(24.7)	2.7(8.3)	4.18(20.4)	2.51(6.2)	3.46(12.2)	3.03(9.3)	4.11(22.1)	9.7(110.1)
DSR ZT+R+S-ZTR-ZTR	3.83(18.8)	2.4(6.3)	3.77(16.3)	1.99(3.7)	2.78(8)	2.84(8.2)	3.21(13.1)	8.37(80)
TPR-CT-ZT	2.3(7)	1.4(1.8)	2.14(4.4)	0.96(0.6)	1.82(3.2)	0.71(0)	2.55(7.8)	4.74(26.7)
CD (p=0.05)	0.60**	0.23**	0.60**	0.29**	0.25**	0.32**	0.32**	0.37**
Weedy check	6.58(44.5)	3.33(11.3)	5.1(27.5)	2.58(6.9)	3.93(15.7)	2.96(9.7)	5.9(35.5)	12.35(158.7)
Bispyribac *fb* HW	2.58(6.5)	2.43(5.8)	3.91(15.5)	2.05(4.3)	2.42(5.7)	2.11(4.5)	2.35(5.3)	7.01(51.1)
Bispyri *fb* fenoxa *fb* HW	1.46(1.9)	1.19(1.1)	1.73(2.7)	1.78(3)	2.12(4.4)	1.98(3.9)	2.13(4.3)	4.79(23.9)
CD(p=0.05)	0.29**	0.40**	0.40**	0.37**	0.40**	0.27**	0.27**	0.35**
T x W	0.65**	ns	0.89**	ns	ns	0.61*	0.6**	0.77**
DSR CT+S-CT-ZT	3.04(13.3)	1.92(3.9)	3.04(10.9)	1.61(2.2)	2.55(7.6)	1.29(1.3)	2.75(9.1)	6.31(49.9)
DSR CT+R+S-CTR-ZTR	2.78(9.9)	1.7(2.8)	2.49(7.4)	1.45(1.7)	2.21(5.2)	1.16(0.9)	2.46(6.9)	5.48(36.2)
DSR ZT+S-ZT-ZT	3.43(16.4)	2.03(4.6)	3.09(12)	1.61(2.3)	2.78(8.4)	1.44(1.8)	3.12(12.9)	6.93(61)
DSR ZT+R+S-ZTR-ZTR	3.02(11.7)	1.78(3.3)	2.73(8.9)	1.28(1.2)	2.16(5.1)	1.31(1.4)	2.29(6.5)	5.68(40)

TPR-CT-ZT	1.76(3.6)	0.99(0.5)	1.32(1.4)	0.78(0.1)	1.30(1.4)	0.71(0)	1.54(2.5)	2.84(9.9)
CD (p=0.05)	0.46**	0.29**	0.38**	0.13**	0.16**	0.11**	0.22**	0.23**
Weedy check	5.23(28.3)	2.48(6.2)	3.93(16.5)	1.67(2.5)	3.46(12.3)	1.57(2.2)	4.27(18.9)	9.22(90.1)
Bispyribac fb HW	1.99(3.7)	1.72(2.7)	2.7(7.3)	1.25(1.2)	1.68(2.5)	1(0.5)	1.62(2.3)	4.48(21)
Bispyri fb fenoxa fb HW	1.18(21.1)	0.86(0.3)	0.97(0.5)	1.12(0.8)	1.46(1.8)	0.97(0.5)	1.41(1.6)	2.64(7)
CD (p=0.05)	0.22**	0.23**	0.28**	0.18**	0.27**	0.10**	0.17**	0.22**
T x W	0.48**	0.51**	0.62**	ns	0.61**	0.22**	0.37**	0.49**

Weed control efficiency and index

Among crop establishment methods the highest weed control efficiency (WCE) and weed control index (WCI) was recorded in TPR-CT-ZT system (75.8 and 83.8%, respectively) which was considerably higher than other establishment methods. However, the next best establishment method was CT DSR-R+S-CTR-ZTR (30.3 and 40.7%, respectively) followed by ZT DSR+R+S-ZTR-ZTR system over ZT DSR+S-ZT-ZT system. Among weed management integrated weed management (herbicide rotation bispyribac sodium 25 g/ha *fb* fenoxaprop 60 g/ha *fb* HW recorded higher WCE (83.8%) and WCI (92.2%) followed by continuous use of bispyribac *fb* HW over weedy check (Figure 1.31 a & b).

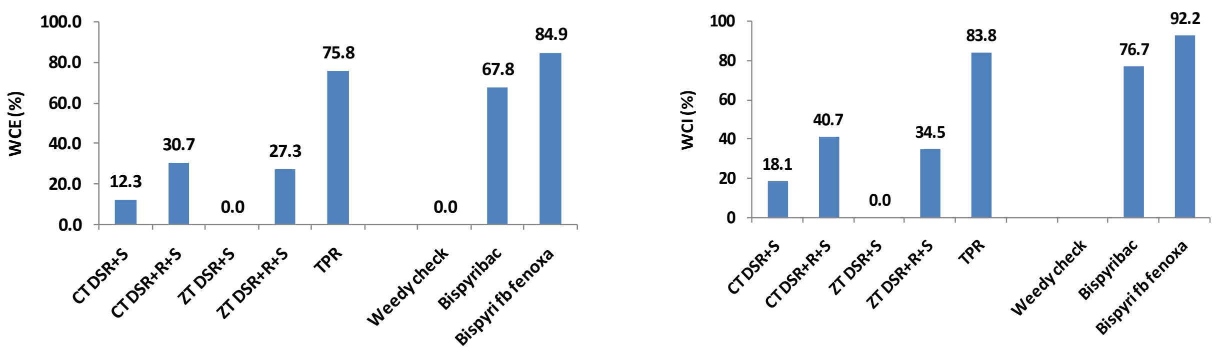


Fig 1.31 The weed control efficiency (%) (a) and Weed control index (%) (b) in rice at 60 DAS

Wheat 2020-21,

Relative weed density and biomass

In the study area of wheat field at 60 DAS comprised with the relative density of weeds i.e. *Medicago polymorpha* (63%), *Avena ludoviciana* (24%), whereas rest of the weeds like *Convolvulus arvensis, Chenopodium album, Sonchus oleraceus, Lathyrus aphacea, Paspaladium* sp., *Sporobolus diander, D. sanguinalis, Physalis minima* were minor weeds present (Figure 1.32 a & b). The relative weed biomass followed the trend of relative density and recorded highest with *Medicago polymorpha* (65%), *Avena ludoviciana* (23%) and rest were minor weeds. It was noticed that *Digitaria sanguinalis, Echinochloa colona,* and *Alternathera sessilis* were late-emerging weeds in wheat.

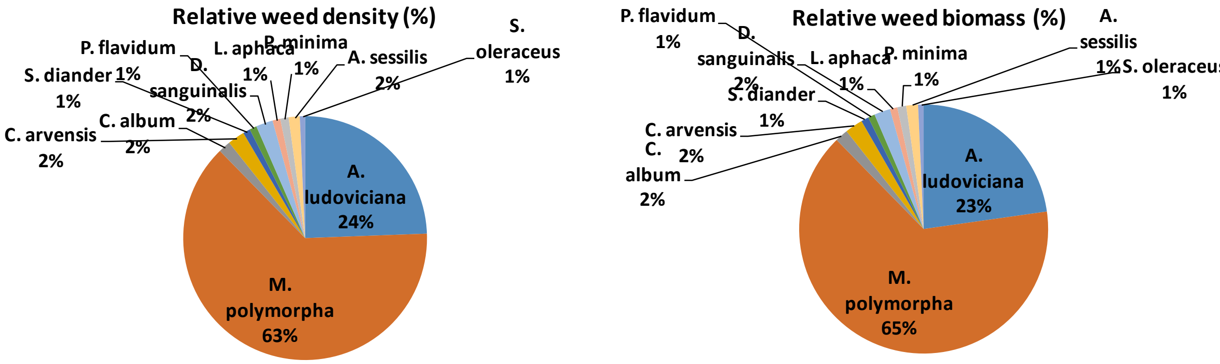


Fig 1.32 The relative density (a) and biomass (b) of weeds in wheat at 60 DAS

Weed density and biomass at 60 DAS

At 60 DAS, under crop establishment methods, the total weed density and biomass were recorded higher in TPR-CT-ZT with 158.7 #/m^2 and 71.9 g/m^2, respectively. The lowest total weed density and biomass were measured in DSR ZTR-ZTR-ZTR with 102.9 #/m^2 and 41.3 g/m^2, respectively (Table 2). The weed density and biomass of *Avena ludoviciana* and *Medicago polymorpha* was significantly higher in TPR-CT-ZT and lowest in DSR ZT+R+S-ZTR-ZTR whereas, *Chenopodium album* was recorded the highest under DSR CT+S-CT-ZT (4.1 #/m^2 and 1.5 g/m^2, respectively) and lowest in DSR ZT+R+S-ZTR-ZTR. In general, ZT plots were more with *Avena ludoviciana* and *Medicago polymorpha*, whereas, *Convolvulus arvensis* was more in CT plots.

Among weed management practices, weedy check recorded the highest total weed density and biomass with 326 #/m^2 and 151 g/m^2, respectively and the lowest in herbicide rotation [clodinafop propargyl + metsulfuron-methyl at 60+4 g/ha (pre-mix)] followed by recommended herbicide [mesosulfuron+iodosulfuron12+2.4 g/ha (pre-mix)] (Table 1.16). Likewise, weed control efficiency (WCE) was recorded the highest with DSR ZT+R+S-ZTR-ZTR (35%) followed by DSR CT+R+S-CTR-ZTR (25%) over TPR-CT-ZT. Likewise, WCI followed the trend of WCE and the highest with DSR ZT+R+S-ZTR-ZTR (43%) followed by DSR CT+R+S-CTR-ZTR (31%) over TPR-CT-ZT. The rest of the crop establishment methods has recorded considerably higher WCE and WCI, yet their effect was less in response to DSR ZT+R+S-ZTR-ZTR. Application of clodinafop propargyl + metsulfuron-methyl at 60+4 g/ha (pre-mix) recorded the highest WCE (96%) followed by mesosulfuron + iodosulfuron 12+2.4 g/ha (94%) over weedy check (Fig 1.33a & b).

Table 1.16 Crop establishment methods and weed management practices influences weed density and biomass in wheat under rice-wheat-greengram system

Treatment	Grasses		BLWs					Total
	A. ludoviciana	*D. sanguinalis*	*M. polymorpha*	*C. album*	*C. arvensis*	*L. aphaca*	*A. sessilis*	
DSR CT+S-CT-ZT	4.9(11.8)	2.49(6.4)	7.18(82.2)	2.09(4.1)	1.91(3.6)	1.88(3.1)	1.74(2.7)	10.32(140.7)
DSR CT+R+S-CTR-ZTR	4.09(8.4)	2.41(5.8)	6.78(77.6)	1.72(2.7)	1.77(2.9)	1.67(2.3)	1.33(1.3)	9.31(119.7)
DSR ZT+S-ZT-ZT	4.45(9.4)	2.67(7.2)	6.99(81.7)	1.88(3.2)	1.97(3.9)	1.64(2.3)	1.51(1.9)	9.92(132.1)

DSR ZT+R+S-ZTR-ZTR	3.89(7.1)	2.44(6)	6.18(65.7)	1.65(2.4)	1.31(1.4)	1.39(1.6)	1.23(1.1)	8.57(102.9)
TPR-CT-ZT	5.53(16.5)	2.29(5.1)	7.47(89.2)	2.03(3.9)	2.21(4.8)	1.94(3.3)	1.95(3.6)	10.99(158.7)
CD (p=0.05)	0.42**	ns	ns	ns	0.46*	0.27**	0.24**	0.83**
Weedy check	8.11(28.3)	3.33(10.7)	14.79(220.2)	2.39(5.3)	2.5(6.1)	1.94(3.3)	1.83(3.1)	18(326.1)
Mesosulfuron+iodosulfuron 12+2.4 g/ha	3.06(2.2)	2.2(4.5)	3.3(10.7)	1.74(2.6)	1.64(2.3)	1.68(2.4)	1.47(1.8)	6.21(38.7)
Clodinafop+ metsulfuron 60+4 g/ha	2.55(1.5)	1.85(3.1)	2.67(6.9)	1.51(1.9)	1.36(1.5)	1.49(1.9)	1.36(1.5)	5.25(27.7)
CD (p=0.05)	0.42**	0.34**	0.69**	0.23**	0.29**	0.22**	0.24**	0.59**
T x W	ns	ns	ns	ns	ns	ns	ns	ns
DSR CT+ S-CT-ZT	2.93(30.9)	1.54(2.3)	4.59(37.7)	1.35(1.5)	1.32(1.4)	1.18(0.9)	1.18(1)	6.26(59.4)
DSR CT+R+S-CTR-ZTR	2.45(22.2)	1.46(1.9)	4.29(34.4)	1.15(0.9)	1.14(0.9)	1.08(0.7)	0.95(0.4)	5.55(49.3)
DSR ZT+S-ZT-ZT	2.7(24.2)	1.65(2.6)	4.5(37.1)	1.25(1.2)	1.35(1.6)	1.11(0.8)	1.05(0.7)	6.07(56)
DSR ZT+R+S-ZTR-ZTR	2.29(20.1)	1.44(1.8)	3.91(28.6)	1.11(0.8)	0.99(0.5)	0.97(0.5)	0.91(0.4)	5.07(41.3)
TPR-CT-ZT	3.45(39.1)	1.48(1.9)	4.96(43.7)	1.37(1.5)	1.46(1.9)	1.26(1.1)	1.35(1.5)	6.94(71.9)
CD (p=0.05)	0.29**	ns	ns	ns	0.24*	0.13**	0.14**	0.57**
Weedy check	5.3(66.5)	2.23(4.5)	10.2(104.7)	1.73(2.5)	1.81(2.9)	1.37(1.4)	1.37(1.5)	12.24(151)
mesosulfuron+iodosulfuron 12+2.4 g/ha	1.62(9.1)	1.24(1.1)	1.73(2.6)	1.05(0.6)	1(0.5)	1.03(0.6)	0.97(0.5)	3.09(9.3)
Clodinafop+mets	1.37(6.3)	1.08(0.7)	1.42(1.6)	0.96(0.4)	0.94(0.4)	0.95(0.4)	0.92(0.4)	2.6(6.5)

ulfuron 60+4 g/ha								
CD (p=0.05)	0.24**	0.15**	0.46**	0.13**	0.14**	0.09**	0.12**	0.40**
T x W	0.53**	ns	ns	ns	ns	ns	ns	ns

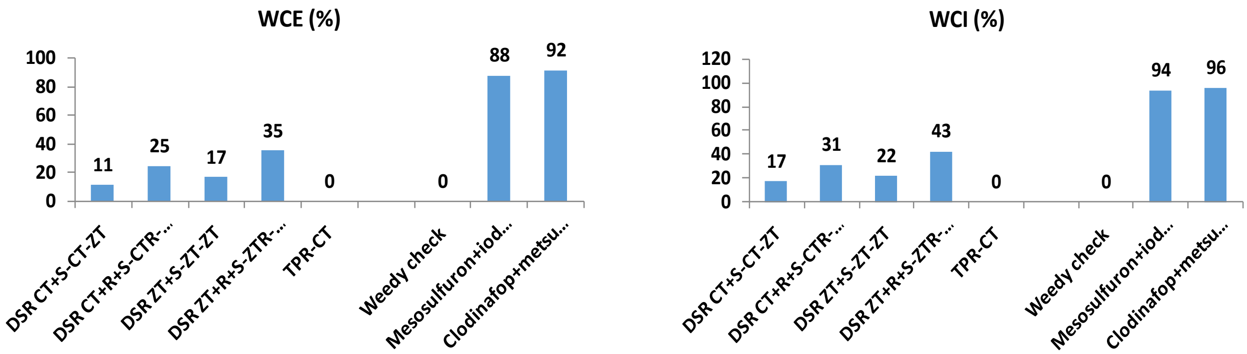


Fig 1.33 The weed control efficiency (%) (a) and weed control index (%) (b) in wheat at 60 DAS

Greengram 21,
Relative weed density and biomass,

At 45 days after sowing (DAS), the relative weed density of weeds in the study area was *Echinochloa colona* (45%)*, Dinebra retroflexa* (30%), *Cyperus rotundus* (9%)*, Paspalidium flavidum* (5%) and other weeds like*, Physalis minima, Alternanthera sessilis, Trianthema procumbens etc.* Likewise, relative weed biomass recorded the highest *Echinochloa colona* (45%)*, Dinebra retroflexa* (29%), *Cyperus rotundus* (8%)*, Physalis minima* (5%), *Alternanthera sessilis* (4%), *Paspalidium flavidum* (3%) and other weeds (Figure 1.34a & b).

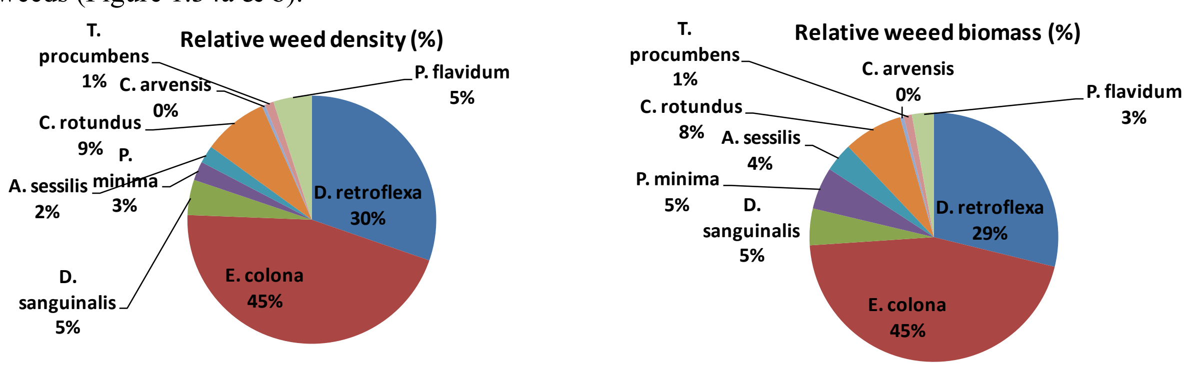


Fig 1.34 The relative density (a) and biomass (b) of weeds in greengram at 45 DAS

Weed density and biomass

At 45 DAS, the highest weed density and biomass were recorded in TPR-CT-ZT (82.6 no./m^2 and 90.3 g/m^2, respectively) followed by DSR CT+S-CT-ZT and DSR ZT+S-ZT-Z. The fewer weed density and lesser biomass were recorded with DSR ZT+R+S-ZTR-ZTR (36.4 no./m^2 and 39.5 g/m^2, respectively). The lower weed density and biomass 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. This treatment has a lesser weed density and biomass resulting in lower weed seed rain, which further lowered the establishment of weeds (Table 1.17).

Among weed management practices, weedy check recorded the highest weed density and biomass (113.3no./m^2 and 143.3 g/m^2, respectively), whereas the lowest weed density and biomass was recorded with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (22.6no./m^2 and 13.5 g/m^2, respectively). Application of pendimethalin at 678 g/ha has considerably suppressed the weed density and biomass (31.9 no./m^2 and 27.2 g/m^2, respectively), yet their effect was less pertaining to pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (Table 1.17).

Table 1.17 Crop establishment methods and weed management practices influences weed density and biomass in greengram under rice-wheat-greengram system

Treatment	Grasses				BLWs			Sedge	Total
	D. retroflexa	*E. colona*	*D. sanguinalis*	*P. flavidum*	*P. minima*	*A. sessilis*	*C. arvensis*	*C. rotundus*	
DSR CT+S-CT-ZT	3.54(14.9)	4.14(20.9)	2.56(6.4)	2.08(4)	1.57(2.1)	1.69(2.4)	1.43(1.8)	2.11(4.9)	7.24(58.6)
DSR CT+R+S-CTR-ZTR	2.19(6.3)	3.96(20.7)	2.32(5.3)	1.6(2.2)	1.44(1.7)	1.6(2.1)	1.49(1.9)	1.83(3.6)	6.24(44.2)
DSR ZT+S-ZT-ZT	2.75(8.2)	4.2(24.8)	2.87(8.2)	1.77(2.9)	1.54(2.1)	1.67(2.3)	1.82(3.2)	2.16(5.3)	7.08(57.8)
DSR ZT+R+S-ZTR-ZTR	2.23(5.9)	3.16(13.2)	2.78(7.8)	1.41(1.8)	1.13(0.9)	1.53(1.9)	1.53(2.2)	1.42(2.2)	5.71(36.4)
TPR-CT-ZT	4.38(23.1)	4.98(32.3)	2.21(4.9)	2.29(5.1)	1.66(2.4)	1.83(2.9)	1.16(1.1)	2.97(9.3)	8.46(82.6)
CD (p=0.05)	0.85**	ns	ns	0.34**	0.32*	0.09**	ns	ns	1.06**
Weedy check	4.71(25.5)	7.07(53.5)	3.3(10.7)	2.3(5.1)	1.89(3.2)	1.95(3.3)	1.55(2.3)	2.77(8.3)	10.47(113.3)
Pendimethalin	2.49(6.1)	2.97(8.7)	2.35(5.2)	1.68(2.5)	1.36(1.4)	1.53(1.9)	1.65(2.5)	1.62(2.9)	5.64(31.9)
Pendimethalin *fb* HW	1.86(3.4)	2.23(4.9)	2(3.7)	1.51(2)	1.16(0.9)	1.51(1.8)	1.26(1.3)	1.9(4)	4.73(22.6)
CD (p=0.05)	0.76**	0.94**	0.35**	0.30**	0.21**	0.14**	ns	0.58**	0.79**
T x W	ns	ns	ns	ns	ns	ns	ns	ns	ns
DSR CT+S-CT-ZT	3.67(16.7)	4.1(23.2)	2.49(6.6)	1.62(2.3)	2(4.4)	1.72(3.1)	1.4(1.8)	2.08(4.9)	7.17(64.1)
DSR CT+R+S-CTR-ZTR	2.27(7.2)	3.98(23.5)	2.28(5.5)	1.31(1.4)	1.81(3.2)	1.61(2.6)	1.43(1.7)	1.79(3.5)	6.22(49.1)
DSR ZT+S-ZT-ZT	2.81(8.9)	4.21(28)	2.81(8.6)	1.4(1.6)	2.03(4.6)	1.68(2.8)	1.74(3.2)	2.11(5.2)	7.05(63.7)
DSR	2.32(6.7	3.21(15.2)	2.71(8)	1.2(1.1)	1.42(1.9	1.54(2.	1.33(1.	1.4(2.1	5.6(3

ZT+R+S-ZTR-ZTR	)				)	3)	5)	)	9.5)
TPR-CT-ZT	4.54(26)	4.99(36.7)	2.17(5)	1.78(3)	2.14(5.1)	1.83(3.5)	1.09(0.9)	2.84(8.8)	8.4(90.3)
CD (p=0.05)	0.29**	ns	ns	0.11**	0.24*	0.14**	ns	ns	0.57 **
Weedy check	5.11(30.2)	7.87(66.3)	3.72(13.7)	1.99(3.6)	2.97(8.7)	2.69(6.8)	1.77(3.3)	2.91(9.2)	11.79(143.3)
Pendimethalin	2.52(6.3)	2.6(6.6)	2.18(4.4)	1.3(1.3)	1.61(2.2)	1.26(1.1)	1.46(1.8)	1.64(3)	5.21(27.2)
Pendimethalin *fb* HW	1.74(2.9)	1.82(3.1)	1.57(2.1)	1.09(0.7)	1.06(0.7)	1.08(0.7)	0.96(0.5)	1.58(2.5)	3.67(13.5)
CD (p=0.05)	0.24**	0.46**	0.13**	0.09**	0.14**	0.11**	0.15**	0.10**	0.40 **
T x W	0.53**	ns	ns	ns	ns	ns	ns	ns	ns

Weed control efficiency and index

The lower weed density and biomass in DSR ZT+R+S-ZTR-ZTR resulted into achieve 56% WCE and WCI over TPR-CT-ZT (Fig 1.35a & b). Similarly, pendimethalin 678 g/ha *fb* hand weeding at 30 DAS recorded with the highest WCE and WCI (80 and 90.6%, respectively) followed by pendimethalin 678 g/ha.

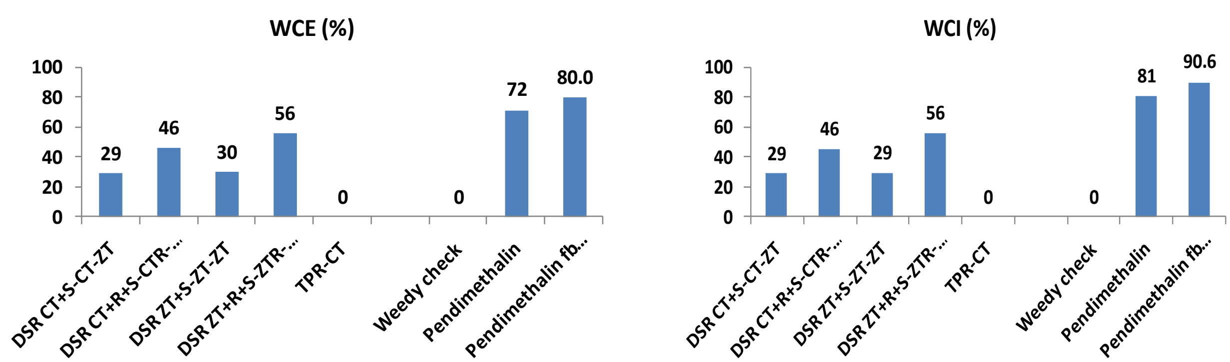


Fig 1.35 The weed control efficiency (%) (a) and weed control index (%) (b) in greengram at 45 DAS

System crop, water and energy productivity

Lower weed biomass and higher WCE helped in harvesting higher grain and straw yield in TPR-CT-ZT (2223 kg/ha) followed by DSR CT+R+S-CTR-ZTR (1400 kg/ha). The lowest grain yield was recorded in DSR ZT+S-ZT-ZT (918 kg/ha). Contrarily, in wheat the highest crop yield was harvested with DSR ZT+R+S-ZTR-ZTR (4119 kg/ha), whereas, in greengram DSR CT+S-CT-ZT recorded the highest seed yield (1011 kg/ha), followed by DSR CT+R+S-CTR-ZTR and DSR ZT+R+S-ZTR-ZTR, respectively in wheat and greengram (Table 1.18). The system productivity followed the trend of the economic yield of the crop and recorded the highest in ZT+R+S-ZTR-ZTR (9038.5 kg/ha) followed by DSR CT+R+S-CTR-ZTR (8777.2 kg/ha). The lowest system productivity was recorded with DSR CT+R+S-CTR-ZTR (8411.9 kg/ha) and was close to TPR-CT-ZT. The irrigation water productivity and total water productivity were highest with ZT+R+S-ZTR-ZTR (29.6 and 4.4 kg/ha/mm, respectively) followed by DSR CT+R+S-CTR-ZTR. The lowest water productivity was recorded in TPR-CT-ZT (16.0 and 3.7 kg/ha/mm, respectively). Moreover, total energy productivity was recorded higher under DSR CT+S-CT-ZT and DSR ZT+S-ZT-ZT (0.13 kg/MJ) (Table 1.18).

Among weed management practices, weedy check has the lowest crop yield in rice, wheat and greengram (412, 2496 and 647.4 kg/ha, respectively). The highest crop yield was recorded in integrated weed management with herbicide rotation (1917, 4411 and 1103 kg/ha, respectively) followed by recommended herbicides (Table 1.18). The system productivity followed the trend of the economic yield of crop and recorded the highest in integrated weed management with herbicide rotation (10836.5 kg/ha) followed by recommended herbicides (9557.5 kg/ha). The lowest system productivity recorded with weedy check (5548.7 kg/ha). The irrigation water productivity and total water productivity were highest with integrated weed management with herbicide rotation (28.3 and 5.1 kg/ha/mm, respectively) followed by recommended herbicides. The lowest water productivity was recorded in weedy check (14.5 and 2.6 kg/ha/mm, respectively). Likewise, total energy productivity was recorded higher under integrated weed management with herbicide rotation (0.09 kg/MJ) (Table 1.18).

Table 1.18 Crop, water and energy productivity influenced by crop establishment methods and weed management practices in rice-wheat-greengram cropping system

Treatment	**Yield (t/ha)**				**System productivity REY (kg/ha)**		**Water productivity (kg/ha/mm)**			**Energy productivity (kg/MJ)**
	Rice	**Wheat**	**Greengram**				**Irrigation**	**Total water**		
Crop establishment methods (T)										
DSR CT+S-CT-ZT	1013.4	3435.7	1010.8		8545.4		21.6	4.0		0.13
DSR CT+R+S-CTR-ZTR	1399.6	3943.1	831.3		8777.2		25.4	4.2		0.04
DSR ZT+S-ZT-ZT	918.4	3784.8	904.9		8411.9		25.1	4.0		0.13
DSR ZT+R+S-ZTR-ZTR	1094.4	4118.7	930.1		9038.5		29.6	4.4		0.04
TPR-CT-ZT	2223.7	3105.6	766.5		8464.9		16.0	3.7		0.10
CD (p=0.05)	118.2**	177.4**	20.9**		264.7**		0.70**	0.12**		0.002**
Weed management practices (W)										
Weedy check	411.8	2496.1	647.4		5548.7		14.5	2.6		0.08
Recommended herbicides	1660.1	4125.5	916.1		9557.5		25.0	4.5		0.08
Integrated weed management	1917.7	4411.0	1102.7		10836.5		28.3	5.1		0.09
CD (p=0.05)	87.3**	160.5**	14.4**		195.1**		0.49**	0.09**		0.002**
T x W	195.1**	358.9*	32.2**		436.3**		1.09**	0.20**		0.005**

4. Maize-Wheat cropping system (MWS)
DWR
Malva parviflora is a newly insurgent weed and highly persistent and consistent in wheat under zero-till residue-laden conditions in a 10-year old conservation agriculture (CA) based maize-wheat cropping system. It is very difficult to control with usual herbicides. Therefore, weed management was studied in wheat under CA-based maize-wheat system. Four weed control treatments (Table 1.19) were adopted. Results revealed that the tank mix application of carfentrazone 0.020 kg/ha + metsulfuron-methyl 0.004 kg/ha at 30 DAS was highly effective towards reducing the population of *Malva parviflora* and other weeds and their dry weight and observed higher weed control index and wheat yield. This herbicide treatment resulted in ~31% higher wheat yield over un-weeded control.

Table 1.19 *Malva parviflora* management in wheat under CA-based maize-wheat system

Treatments	**Malva parviflora population before spray (no./m2)**	**Malva parviflora population after spray (no./m2)**	**Weed control efficiency**	**Dry wt. (g/m^2)**
Sulfosulfuron +metsulfuron	4	4	0	45
Carfentrazone + metsulfuron	16	0	100	0
Clodinafop + metsulfuron	6	6	0	49
UWC	8	8	0	70
Weed free control	0	0	100	0

Maize (*Kharif,* 2021)
Seven OFR trials were conducted on weed management in maize during *Kharif,* 2021. The major weed flora observed was *Commelina benghalensis, Cyperus* spp., *Dinebraret roflexa, Echinochloa colona, Ecliptaalba* and *Euphorbia geniculata*. Lower weed density (22.5 no./m^2) and dry weight (32.05 g/m^2) in maize were observed 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 than farmers practice (Table 1.20). Grain yield of maize was observed as 7.37 t/ha in CA practice with improved weed management technique. Higher net return (Rs.136292/ha) and B: C (3.87) was recorded with the same treatment as compared to the farmer's practice.

Table 1.20 Weed management, productivity and economics of OFR treatments in maize during *Kharif,* 2021.

Treatment	**Weed density (no./m^2)**	**Weed biomass (g/m^2)**	**WCE (%)**	**Grain yield (t/ha)**	**Gross return (Rs./ha)**	**Net return (Rs./ha)**	**B: C**
RDF+CA+WM	34.8	29.7	82.6	7.37	136292	101470	3.87
FP	65.4	76.1	63.4	5.53	102384	64326	2.69
RDF+CA+Weedy	167.9	215.5		2.37	45752	22875	1.44

CA: Conservation agriculture; FP: Farmers Practice; RDF: Recommended dose of fertilizer; WCE: Weed control efficiency; WM: Weed management

7. Soybean-Wheat-Greengram Cropping System
DWR
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-

Soybean 2020,

Relative density and biomass of weeds

Soybean field was severely infested with a wide range of weeds, at 60 DAS, the relative density of weeds *Echinochloa colona* (26%), *Dinebra retroflexa* (24%) *Alternanthera sessilis* (13%) and *Commelina communis* (8%)*,* *Digitaria sanguinalis* (7%), *Phyllanthus urinaria* (7%), *Euphorbia geniculata* (5%), *Cyperus rotundus* (5%), *Physalis minima* (3%) and *Eclipta alba* (2%) were become dominant. Likewise, relative weed biomass followed the similar trend with *Echinochloa colona* (33%), *Dinebra retroflexa* (29%), *Alternanthera sessilis* (19%), *Commelina communis* (6%), *Digitaria sanguinalis* (5%), *Physalis minima* (3%), *Euphorbia geniculata* (2%), *Cyperus rotundus* (2%) and *Eclipta alba* (2%) were other weed biomass (Fig 1.36 a & b).

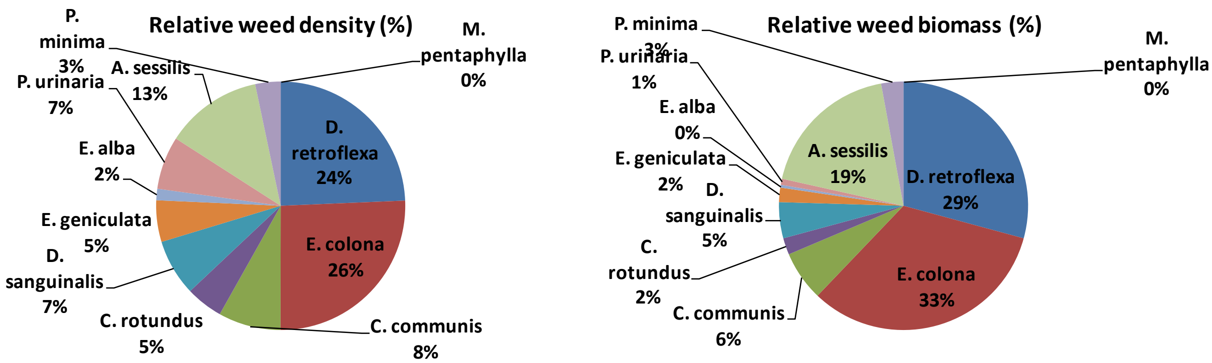


Fig 1.36 The relative density (a) and biomass (b) of weeds in soybean at 60 DAS

Weed density and biomass at 60 DAS

The highest weed density was recorded in ZT-ZT-ZT (113.8 no./m^2) followed by CT-CT-ZT (104.8 no./m^2), whereas the lowest weed density was recorded with ZTSR-ZTWR-ZTGR (74.4 no./m^2). The lower weed density in ZTSR-ZTWR-ZTGR was mainly due to the mulching effect. As mulch restricted the light not to reach to ground thereby lesser weed establishment which was not present with CT and ZT without crop residues. Among weed management practices, weedy check recorded the highest weed density (205.8 no./m^2), whereas the lowest weed density was recorded with integrated weed management (application of metribuzin 500g/ha *fb* HW) (26.4 no./m^2) followed by sequential application of pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha. Application of imazethapyr + imazamox 70 g/ha in soybean also recorded fewer weeds of 112.5 no./m^2, this was considerably lower than the weedy check but was less pertinent to IWM (metribuzin *fb* HW) and pendimethalin 678 g /ha *fb* imazethapyr 100 g/ha (Table 1.22).

The highest weed biomass was recorded with ZT-ZT-ZT (57.3 g/m^2) followed by CT-ZT-ZT (49.7 g/m^2). The lowest weed biomass was recorded with ZTSR-ZTWR-ZTGR (30.5 g/m^2). Rests of the treatments were between these, yet their effect was less pertaining to ZTSR-ZTWR-ZTGR system. Among weed management practices, the lowest weed biomass recorded in integrated weed management (application of metribuzin 500g/ha *fb* HW (5.6 g/m^2) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha. Imazethapyr + imazamox 70 g/ha recorded weed biomass of 48 g/m^2, this was considerably lower than the weedy check but was less pertinent to IWM and sequential application of herbicides. The highest weed biomass was recorded with a weedy check (117.7 g/m^2) (Table 1.21).

Table 1.21 Crop establishment methods and weed management practices influences weed density and biomass in soybean under rice-wheat-greengram system

Treatment	Grassy weeds			BLWs			Sedge	Total
	D. retroflexa	*E. colona*	*D. sanguinalis*	*C. communis*	*E. geniculata*	*A. sessilis*	*C. rotundus*	
CT-CT-	5.3(30.9	4.21(19.	2.38(5.6)	2.49(6.5	2.29(5.5	3.12(10.	3.66(14.	9.69(104.8)

ZT	)	7)		)	)	3)	7)	
CT-ZT-ZT-	5.63(34.2)	4.48(21.6)	2.31(5.3)	2.4(6.1)	2.19(5)	2.62(7.9)	3.91(16.4)	9.86(106.9)
ZTGR-ZT-ZTWR	5.7(36.8)	3.85(16.4)	2.68(7.5)	2.3(5.9)	1.82(3.4)	2.36(6.4)	2.39(6.1)	8.9(91.1)
ZT-ZTSR-ZTWR	5.64(34.7)	4.34(22.3)	2.73(7.8)	2.89(9.2)	2.02(4.5)	2.57(8.9)	2.43(5.8)	9.53(103.9)
ZTGR-ZTSR-ZTWR	4.52(25.8)	3.28(12.8)	2.41(6.3)	2.34(6.3)	1.91(3.8)	2.23(5.9)	2.3(5.7)	7.73(74.4)
ZT-ZT-ZT	5.97(38.5)	4.76(26.2)	3.05(9.7)	2.61(7.4)	2.15(5)	2.57(8.8)	2.66(6.9)	10.06(113.8)
LSD (p=0.05)	0.33**	0.39**	0.21**	0.28**	0.24**	0.25**	0.24**	0.22**
Imaze+imaza	6.55(44.2)	4.64(21.8)	2.82(7.7)	2.69(7)	2.19(4.4)	2.4(5.7)	3.42(12.4)	10.53(112.5)
Pendi *fb* imaze	4.15(17.2)	3.35(11.3)	2.13(4.2)	1.87(3.1)	1.58(2.1)	1.93(3.4)	2.39(5.7)	7.18(52)
Metri *fb* HW	3.26(10.5)	2.17(4.3)	1.67(2.3)	1.44(1.7)	1.12(0.8)	1.3(1.3)	1.76(2.7)	5.13(26.4)
Weedy check	7.87(62)	6.45(41.9)	3.77(13.9)	4.02(15.8)	3.36(10.9)	4.69(21.8)	3.99(16.1)	14.35(205.8)
CD (p=0.05)	0.35**	0.29**	0.17**	0.23**	0.16**	0.24**	0.26**	0.34**
T x W	0.86**	0.70**	0.41**	ns	ns	0.59**	0.62**	0.84**
CT-CT-ZT	3.9(18.4)	3.06(11.6)	1.42(1.8)	1.58(2.4)	1.21(1.1)	2.72(8.2)	1.68(2.8)	6.27(48.7)
CT-ZT-ZT-	4.2(20.4)	3.19(12.4)	1.38(1.7)	1.56(2.4)	1.16(1)	2.35(6.6)	1.79(3.1)	6.39(49.7)
ZTGR-ZT-ZTWR	3.9(19.1)	2.67(9)	1.5(2.1)	1.46(2.2)	1.01(0.6)	2.04(4.9)	1.18(1.1)	5.59(40.7)
ZT-ZTSR-ZTWR	4.25(21)	3.23(14.6)	1.61(2.6)	1.89(3.8)	1.11(0.9)	2.37(7.9)	1.3(1.3)	6.5(54.2)
ZTGR-ZTSR-ZTWR	3.12(13.6)	2.12(6.2)	1.33(1.6)	1.4(2)	1.03(0.7)	1.87(4.3)	1.12(0.9)	4.58(30.5)
CT-CT-ZT	4.49(22.3)	3.62(17.6)	1.63(2.6)	1.75(3.2)	1.2(1.1)	2.26(7)	1.3(1.3)	6.84(57.3)
LSD (p=0.05)	0.26**	0.25**	0.09**	0.14**	0.06**	0.21**	0.08**	0.23**
Imaze+imaza	4.82(24)	3.2(10.3)	1.57(2)	1.68(2.5)	1.13(0.8)	2.12(4.4)	1.56(2.2)	6.83(48)
Pendi *fb* imaze	2.72(7.3)	1.94(3.5)	1.06(0.6)	1.12(0.8)	0.89(0.3)	1.59(2.1)	1.1(0.8)	4.01(16.2)
Metri *fb* HW	1.86(3.1)	1.07(0.7)	0.88(0.3)	0.86(0.3)	0.77(0.1)	1.01(0.6)	0.89(0.3)	2.43(5.6)
Weedy check	6.5(41.98)	5.72(33.12)	2.4(5.3)	2.76(7.2)	1.68(2.4)	4.36(18.9)	2.04(3.8)	10.84(117.7)
CD (p=0.05)	0.25**	0.19**	0.07**	0.12**	0.05**	0.19**	0.09**	0.25**

T x W	0.61**	0.47**	0.18**	0.29**	0.13**	0.49*	0.22**	0.62**

Weed control efficiency and index

Among crop establishment methods the highest weed control efficiency (WCE) and weed control index (WCI) was recorded in ZTSR-ZTWR-ZTGR system (35 and 47%, respectively) which was considerably higher than other establishment methods. However, the next best establishment method was ZT-ZTWR-ZTGR (20 and 29%, respectively) followed by ZTSR-ZTWR-ZT system over ZT-ZT-ZT system. Among weed management integrated weed management (metribuzin 500 g/ha *fb* HW) recorded higher WCE (87%) and WCI (95%) followed by pendimethalin 678 g *fb* imazethapyr 100 g/ha and imazethapyr + imazamox 70 g/ha over weedy check (Fig 1.37a & b).

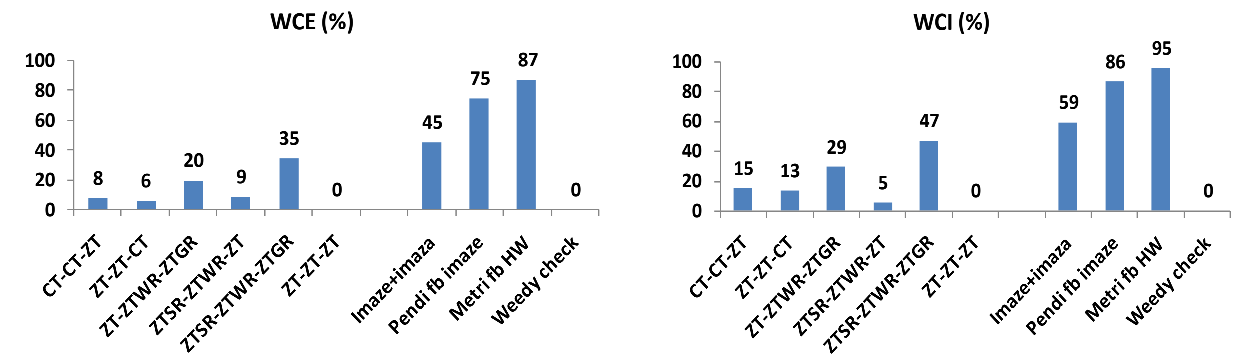


Fig 1.37 The weed control efficiency (%) (a) and weed control index (%) (b) of soybean at 60 DAS

Wheat 2020-21,

Relative weed density and biomass,

In the study area of wheat field at 60 DAS comprised with the relative density of weeds i.e. *Medicago polymorpha* (46%)*, Avena ludoviciana* (11%), whereas rest of the weeds like *Cichorium intybus, Dicanthium annulatum, Cyperus rotundus, Solanum nigram, Cynodon dactylon, Convolvulus arvensis, Digiteria sanguinalis, Chenopodium album* were minor weeds present (Fig 1.38a & b). The relative weed biomass followed the trend of relative density and recorded highest with *Medicago polymorpha* (47%)*, Avena ludoviciana* (11%) and rest of the weeds were present with lesser biomass. It was noticed that *Digitaria sanguinalis, Echinochloa colona,* and *Alternathera sessilis* were late-emerging weeds in wheat.

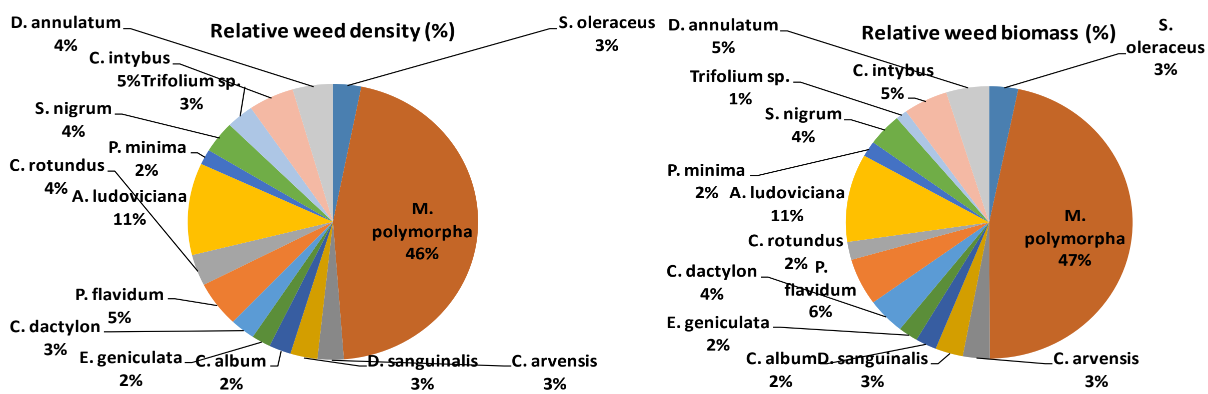


Fig 1.38 The relative density (a) and biomass (b) of weeds in wheat at 60 DAS

Weed density and biomass at 60 DAS

At 60 DAS, under crop establishment methods, the total weed density and biomass were recorded higher in ZT-ZT-ZT with 173.3 no./m^2 and 97.5 g/m^2, respectively. The lowest total weed density and biomass were measured in ZTSR-ZTWR-ZTGR with 92.1 #/m^2 and 41.9 g/m^2, respectively followed by ZTSR-ZTWR-ZT and ZT-ZTWR-ZTGR (Table 1.22).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 217.7 #/m^2 and 117.5 g/m^2, respectively and the lowest in clodinafop propargyl + metsulfuron-methyl at 60+4 g/ha (pre-mix) followed by mesosulfuron + iodosulfuron 12+2.4 g/ha (pre-mix)] (Table 13). Likewise, weed control efficiency (WCE) was recorded the highest with ZTWR-ZTGR-ZTSR (57.1%) followed by ZTWR-ZT-ZTSR (47.6%) and ZTWR-ZTGR-ZT (37.0%) over ZT-ZT-ZT. Likewise, WCI followed the trend of WCE and the highest with ZTWR-ZTGR-ZTSR (46.8%) followed by ZTWR-ZT-ZTSR (38.3%) and ZTWR-ZTGR-ZT (31.2%) over ZT-ZT-ZT. The rest of the crop establishment methods has recorded considerably higher WCE and WCI. Application of clodinafop propargyl + metsulfuron-methyl at 60+4 g/ha (pre-mix) recorded the highest WCE (77.7%) followed by mesosulfuron + iodosulfuron12+2.4 g/ha (63.2%) over weedy check (Fig 1.39a & b).

Table 1.22 Crop establishment methods and weed management practices influences weed density and biomass in wheat under soybean-wheat-greengram system

Treatment	Grasses				BLWs			Total
	A. ludoviciana	*D. sanguinalis*	*D. annulatum*	*P. flavidum*	*M. polymorpha*	*S. nigrum*	*C. intybus*	
CT-CT-ZT	2.7(9)	2.03 (4.3)	0.95 (0.6)	3.01 (8.8)	7.41(61.1)	1.95 (3.5)	1.86 (3.7)	10.36 (117.2)
CT-ZT-ZT	3.07 (12.3)	2.23(4.9)	1.78(2.8)	3.11 (9.4)	8.07(70.4)	1.91(3.3)	2.11 (4.6)	11.22 (135.6)
ZTGR-ZT-ZTWR	2.93 (9.4)	2.34(5.1)	2.77(7.4)	2.79 (7.7)	7.13(56)	1.96(3.5)	2.03 (4.2)	10.55 (119.1)
ZT-ZTSR-ZTWR	2.82(8.7)	2.21(4.5)	2.62(6.8)	2.85 (7.9)	6.62(47.5)	1.94(3.4)	2.01 (4.1)	10.05 (107)
ZTGR-ZTSR-ZTWR	2.39 (6.3)	2.13(4.1)	2.69 (7.2)	2.8 (7.7)	5.98 (38.5)	1.91 (3.3)	1.97 (4)	9.33 (92.1)
ZT-ZT-ZT	3.64 (14.6)	2.57(6.3)	3.03(9)	3.19 (10.1)	8.82(81.4)	2.62 (6.6)	2.66 (7.4)	12.82 (173.3)
CD (p=0.05)	0.40**	0.18*	0.41**	0.19**	0.40**	0.12**	0.15**	0.39**
Sulfosulfuron	3.13(9.6)	2.44(5.5)	2.34(5.8)	2.99 (8.5)	8.48(72)	2.07 (3.9)	2.31 (4.9)	11.85 (141.1)
Iodo+mesosulfuron	2.24 (4.7)	2.24(4.6)	2.04(4.2)	2.72 (7)	6.11(37.7)	1.94 (3.3)	1.9 (3.2)	9.17(84.4)
Clodina+metsulfuron	1.43 (1.9)	1.7(2.7)	2.03 (4.3)	2.43 (5.6)	4.61(22.2)	1.97 (3.5)	1.04 (0.7)	7.22(53)
Weedy check	4.89 (23.9)	2.63(6.7)	2.83 (8.2)	3.7 (13.3)	10.15 (104.7)	2.22(4.9)	3.17 (9.9)	14.66 (217.7)
CD (p=0.05)	0.20**	020**	0.23**	0.24**	0.45**	0.21**	0.21**	0.47**
T x W	0.49**	0.49**	ns	ns	ns	0.51**	ns	ns
CT-CT-ZT	2.06(4.9)	1.58(2.3)	0.91(0.5)	2.24(4.7)	5.45(32.5)	1.48(1.8)	1.46(2)	7.59(62.9)
CT-ZT-ZT	2.33(6.7)	1.72(2.7)	1.64(2.3)	2.37(5.3)	6(38.8)	1.51(1.8)	1.62(2.5)	8.36(75.6)
ZTGR-ZT-ZTWR	2.19(5.1)	1.74(2.6)	2.1(4)	2.05(3.9)	5.08(28.4)	1.49(1.8)	1.57(2.3)	7.56(61.4)
ZT-ZTSR-	2.12(4.6	1.58(2)	2.05(3.8	2(3.6)	4.47(21.4	1.41(	1.56(	6.94(51.1)

ZTWR	)		)		)	1.5)	2.2)	
ZTGR-ZTSR-ZTWR	1.82(3.4)	1.49(1.8)	2(3.8)	1.92(3.3)	3.93(16.5)	1.36(1.4)	1.53(2.1)	6.26(41.9)
ZT-ZT-ZT	2.69(7.8)	2.05(3.8)	2.46(5.7)	2.46(5.8)	6.61(45.8)	2.08(4)	1.99(3.9)	9.62(97.5)
CD (p=0.05)	0.27**	0.16**	0.27**	0.15**	0.29**	0.12**	0.09**	0.29**
Sulfosulfuron	2.33(5.1)	1.81(2.8)	1.94(3.7)	2.19(4.4)	6.03(36.6)	1.57(2)	1.75(2.6)	8.52(73.3)
Iodo+mesosulfuron	1.68(2.4)	1.71(2.5)	1.6(2.3)	1.99(3.5)	4.33(18.9)	1.49(1.8)	1.42(1.6)	6.53(43.3)
Clodina+metsulfuron	1.14(1)	1.28(1.3)	1.67(2.6)	1.77(2.7)	3.29(11.2)	1.46(1.7)	0.89(0.3)	5.08(26.2)
Weedy check	3.66(13.2)	1.98(3.6)	2.23(4.8)	2.74(7.1)	7.37(55.6)	1.7(2.6)	2.42(5.5)	10.75(117.5)
CD (p=0.05)	0.14**	0.15**	0.15**	0.17**	0.30**	0.16*	0.15**	0.33**
T x W	0.34**	0.37*	ns	ns	0.72*	0.38**	ns	ns

Weed control efficiency

The lower weed density and biomass in ZTR-ZTR-ZTR resulted in achieving 57.1 and 46.8% WCE and WCI, respectively over ZT-ZT-ZT (Fig 1.39a & b). Similarly, pendimethalin 678 g/ha *fb* hand weeding at 30 DAS recorded with the highest WCE and WCI (77.7 and 75.9%, respectively) followed by pendimethalin 678 g/ha.

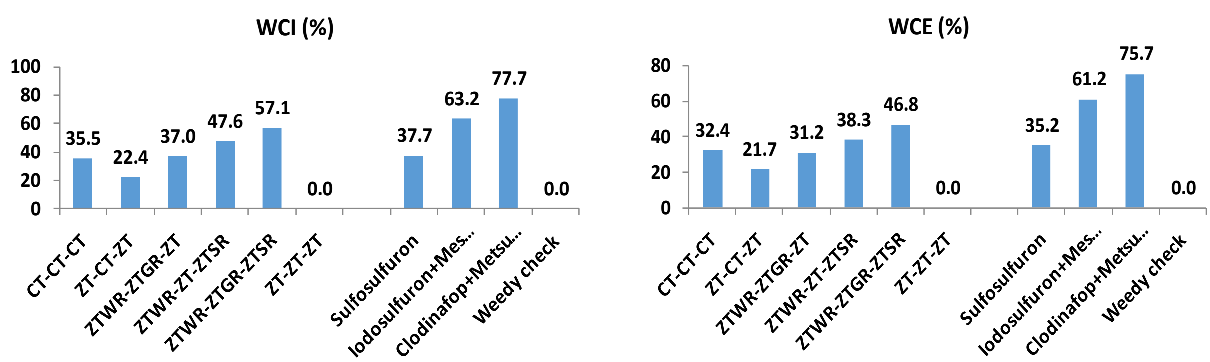


Fig 1.39 The weed control efficiency (%) (a) and weed control index (%) (b) in soybean at 60 DAS

Greengram 21,

Relative weed density and biomass,

At 45 days after sowing (DAS), the relative weed density of weeds in the study area were *Paspalidium flavidum* (34%), *Digitaria sanguinalis* (19%), *Echinochloa colona* (12%), *Dinebra retroflexa* (11%), *Cyperus rotundus* (10%), *Physalis minima* (6%), *C. communis* (3%), *E. geniculata* (2%), *D annulatum, C. arvensis,etc.* Likewise, relative weed biomass recorded the highest *Digitaria sanguinalis* (29%), *Paspalidium flavidum* (18%), *Dinebra retroflexa* (13%) *Echinochloa colona* (11%), *Cyperus rotundus* (7%), and other weeds (Figure 1.40a and b).

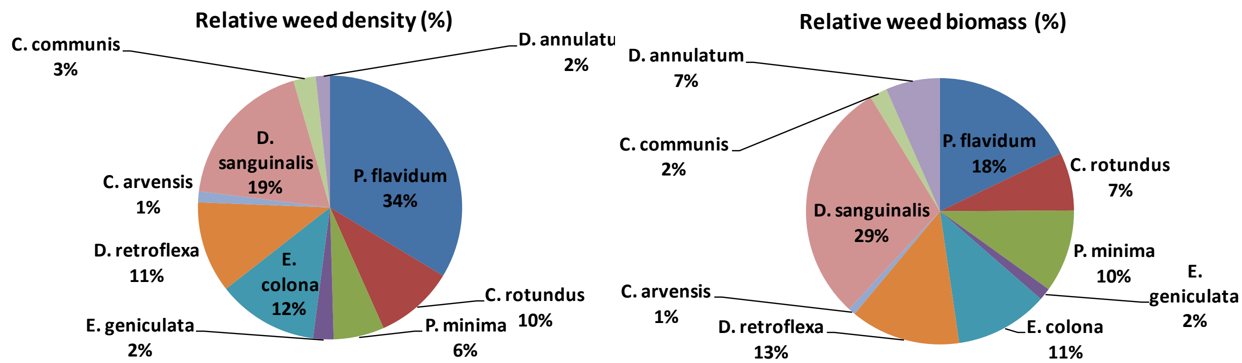


Fig 1.40 The relative density (a) and biomass (b) of weeds in soybean at 60 DAS

Weed density and biomass

At 45 DAS, the highest weed density and biomass were recorded in ZT-ZT-ZT (100.6 no./m^2 and 104.2 g/m^2, respectively) followed by ZTGR-ZTSR-ZTWR and ZT-ZTSR-ZTWR. The fewer weed density and lesser biomass were recorded with CT-CT-ZT (66.3 no./m^2 and 86.9 g/m^2, respectively). The lower weed density and biomass in CT-CT-ZT was mainly due to the manipulation of land disturbed the roots of older weeds, which were not done under ZT with and without residue. This treatment has a lesser weed density and biomass resulting in lower weed seed rain, which further lowered the establishment of weeds (Table 1.23).

Among weed management practices, weedy check recorded the highest weed density and biomass (152.3 no./m^2 and 238.4 g/m^2, respectively), whereas the lowest weed density and biomass was recorded with pendimethalin 678 g/ha *fb* hand weeding at 30 DAS (31.6 no./m^2 and 25.2 g/m^2, respectively) followed by pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha. Application of pendimethalin at 678 g/ha has considerably suppressed the weed density and biomass, yet their effect was less pertaining to pendimethalin 678 g/ha *fb* hand weeding at 30 DAS and pendimethalin 678 g/ha *fb* imazethapyr 100 g/ha (Table 1.23).

Table 1.23 Crop establishment methods and weed management practices influences weed density and biomass in greengram under soybean-wheat-greengram system

Treatment	Grasses					BLW	Sedge		Total
	P. flavidum	*E. colona*	*D. annulatum*	*D. retroflexa*	*D. sanguinalis*	*P. minima*	*C. rotundus*		
Weed density (#/m^2)									
Crop establishment methods (T)									
CT-CT-ZT	3.28(13.3)	3.15(12.6)	1.64(2.6)	2.02(4.5)	3.96(15.7)	2.79(9.3)	2.09(4.3)		7.77(66.3)
CT-ZT-ZT	3.53(15.2)	3(13)	1.85(3.5)	2.17(5.2)	3.64(14)	2.22(6.5)	2.14(4.5)		7.78(66.7)
ZTGR-ZT-ZTWR	4.16(19.7)	2.86(12.3)	1.96(3.8)	2.46(6.5)	3.72(17.3)	2.14(6.2)	2.96(10)		8.73(82.5)
ZT-ZTSR-ZTWR	4.15(19.8)	3.37(15.3)	2.05(4.1)	2.5(6.7)	3.29(13.8)	2.03(4.8)	3.19(11.5)		8.83(83.3)
ZTGR-ZTSR-ZTWR	4.28(23.2)	2.26(7.7)	2.17(4.6)	2.55(7.7)	4.24(20.7)	2.03(4.8)	3.49(13.2)		9.06(89.8)
ZT-ZT-ZT	4.59(25.8)	2.4(8)	2.66(7.2)	2.75(8.7)	4.86(24.2)	1.82(4)	3.62(13.5)		9.7(100.6)

CD (p=0.05)	ns	ns	0.0.53*	ns	ns	ns	0.95*		1.25*
Weed management practices (W)									
Pendimethalin	4.04(17.1)	2.86(10.6)	2.28(5.4)	2.41(5.7)	3.96(17.1)	2.32(5.9)	3.42(12.1)		8.98(81.5)
Pendimethalin *fb* Imaze	3.25(10.7)	2.46(7.4)	2.11(4.5)	1.96(3.6)	3.64(14.8)	1.85(3.7)	3.03(9.8)		7.72(60.7)
Pendimethalin *fb* HW	2.31(6.4)	1.14(1.3)	1.83(3.3)	1.51(2.2)	2.79(9.2)	1(0.7)	2(4.3)		5.61(31.6)
Weedy check	6.41(43.8)	4.9(26.7)	1.99(4)	3.76(14.7)	5.42(29.3)	3.52(13.3)	3.21(11.8)		12.27(152.3)
CD (p=0.05)	0.94**	01.04**	ns	0.52**	0.90*	0.71**	0.69**		0.63**
T x W	ns	ns	ns	ns	ns	ns	ns		ns
Weed biomass (g/m^2)									
Crop establishment methods (T)									
CT-CT-ZT	2.64(9.1)	3.12(14.3)	3.26(13.1)	2.21(6.3)	4.32(21.8)	3.34(15.7)	1.84(3.4)		8.3(86.9)
CT-ZT-ZT	2.74(9.7)	3.11(15.2)	3.76(17.6)	2.3(6.8)	4.11(20.9)	2.83(13)	1.89(3.6)		8.52(90.3)
ZTGR-ZT-ZTWR	3.23(12.9)	2.75(12.4)	4.01(19)	2.62(8.7)	4.37(28.4)	2.48(10.1)	2.57(7.9)		9.45(104.2)
ZT-ZTSR-ZTWR	3.21(12.8)	3.2(14.9)	4.29(20.4)	2.66(8.7)	3.98(24.9)	2.35(8.6)	2.74(8.9)		9.46(104.2)
ZTGR-ZTSR-ZTWR	3.37(15.7)	2.26(8.5)	4.58(23.3)	2.78(11)	4.86(31)	2.48(8.7)	3.07(10.8)		9.96(114.8)
ZT-ZT-ZT	3.58(17.2)	2.48(9.4)	5.69(35.8)	2.95(11.9)	5.38(34.1)	2.29(7.9)	3.13(10.9)		10.96(133.8)
CD (p=0.05)	ns	ns	0.13*	ns	ns	ns	0.81*		1.47*
Weed management practices (W)									
Pendimethalin	3.29(11.2)	2.84(10.5)	4.86(27.9)	2.47(6)	4.59(23.3)	2.55(7.3)	3.23(10.7)		10.02(102.4)
Pendimethalin *fb* imazethapyr	2.03(3.8)	1.95(4.2)	4.42(22.1)	1.75(2.7)	3.25(11.6)	1.75(3.2)	2.3(5.4)		7.41(56.7)
Pendimethalin *fb* HW	1.51(2.2)	0.93(0.5)	3.56(14.6)	1.2(1.1)	1.92(3.9)	0.85(0.3)	1.32(1.4)		4.96(25.2)
Weedy check	5.68(34.4)	5.58(34.7)	4.22(21.5)	4.93(25.7)	8.25(68.7)	5.35(31.8)	3.32(12.7)		15.38(238.4)
CD (p=0.05)	0.72**	0.98**	ns	0.60**	0.86**	0.89**	0.62**		0.75**
T x W	ns	ns	ns	ns	ns	ns	ns		ns

Weed control efficiency and index

The lower weed density and biomass in CT-CT-ZT resulted in to achieve 34% WCE and 35% WCI over ZT-ZT-ZT (Fig 1.41a & b). Similarly, pendimethalin 678 g/ha *fb* hand weeding at 30 DAS recorded with the highest WCE and WCI (79 and 89%, respectively) followed by pendimethalin 678 g/ha.

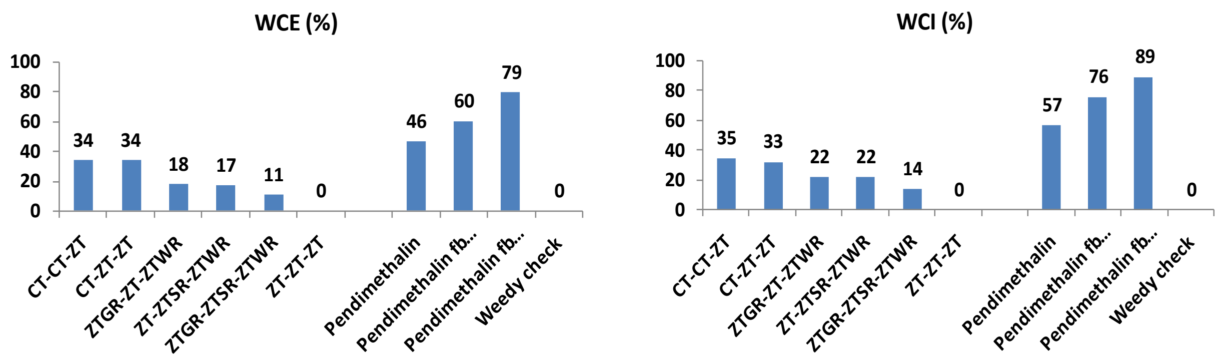


Fig 1.41 The weed control efficiency (%) (a) and weed control index (%) (b) in greengram at 45 DAS

C. Water Management Practices in Conservation Agriculture

Rice Wheat Cropping System
CSSRI

Data are given in Table 9 for the comparison of different irrigation systems in rice crop during *kharif* 2021. Results of micro-irrigation systems and surface irrigation systems are discussed below as:

a) Mini sprinkler irrigation system in rice crop

Results on irrigation system through mini sprinkler irrigation system showed that 6.10 and 6.50 tha^{-1} grain yield was obtained in DSR with reduce tillage (RTDSR) and RTDSR with 33% wheat residue incorporation (RTDSR+RI) during *Kharif* 2021 (Table 1.24). During 2021, 12.7 and 20.1% higher yield of DSR was reported in RTDSR and RTDSR+RI, respectively under mini sprinkler irrigation system as compared to PTR (5.41 t ha^{-1}). Higher grain yield of direct seeded rice under mini-sprinkler irrigation was recorded in comparison to DSR in surface irrigation method (SIS-RTDSR; 5.58 t ha^{-1}), which was about 9.3 and 16.5% higher in MSIS-RTDSR and MSIS-RTDSR+RI treatments, respectively. Mini sprinkler fertigation method in rice saved 26.3% nitrogen of recommend dose (40 kg) and increase nitrogen use efficiency from 36.1 kg grain kg^{-1} N applied in TPR to 59.1 kg grain kg^{-1} N applied in MSIS-RTDSR. Mini-sprinkler in RTDSR (MSIS-RTDSR) saved about 62% of irrigation water as compared to transplanted rice. The saving of irrigation water is very high and it was mainly because of the high (1129 mm) amount of rainfall received during the RTDSR growing period in 2021. The irrigation water productivity ranged from1.20to 1.28 kg m^{-3}.

Fig 1.42 Zero tilled wheat sowing using happy seeder in rice residue under mini sprinkler irrigation method

Table 1.24 Effect of different irrigation systems on rice grain yield, irrigation water requirement, water productivity, saving of water, and nitrogen use efficiency during *kharif* 2021.

RCTs	**PTR/CTW**	**DRIP-RTDSR/ ZTW+RM**	**SIS-RTDSR/ ZTW+RM**	**MSIS-RTDSR/ ZTW+RM**	**MSIS-RTDSR+RI/ ZTW+RM**
Mode of irrigation	Surface T_1	Drip T_7	Surface T_8	Mini –Sprinkler T_9	Mini –Sprinkler T_{10}
Irrigation criteria	1DADPW	(Previous 3days CPE) At 2 days interval	Small soil cracks with surface dryness	(Previous 2days CPE) Alternate day	(Previous 2 days CPE) Alternate day
Grain yield (t ha^{-1})	5.41	5.98	5.58	6.50	6.10
Irrigation water applied (ha-mm)	1341	392	926	507	507
Rainfall received (mm)	794	1129	1129	1129	1129
Total water (Irrigation+rainfall; ha-mm)	2134	1521	2055	1636	1636
Irrigation water productivity (kg m^{-3})	0.40	1.53	0.60	1.28	1.20
Total water productivity (kg m^{-3})	0.25	0.39	0.27	0.40	0.37
Irrigation water saving (%)	-	70.8	30.9	62.2	62.2
N applied (kg ha^{-1})	150	150	150	110	110
NUE (kg grain kg^{-1} nitrogen)	36.1	39.9	37.2	59.1	55.5
% Saving of N	-	-	-	26.7	26.7
DADPW: Day after disappearing of ponded water; **CPE**= Cumulative pan evaporation criteria used for irrigation through mini sprinkler system; NUE= Nitrogen use efficiency					

(**Note: PTR**- Puddled transplanted rice; **RTDSR**- Direct seeded rice in reduced tillage; **CTW**- Conventional tilled wheat; **ZTW**- Zero tilled wheat; **RI-** Residue incorporation; **RM-** Residue mulch; **DRIP-** Drip irrigation system; **SIS-** Surface irrigation system; **MSIS-** Sprinkler irrigation system)

b) Drip irrigation system in rice crop

During *kharif* 2021, 5.98 t ha^{-1} rice yield was reported under drip irrigation system with DSR in reduced tillage (DRIP-RTDSR) (Table 1.24). Rice yield under DRIP-RTDSR was 10.5% higher than the conventional PTR (5.40 t ha^{-1}). Similarly, it was 7.2% higher than the RTDSR under surface irrigation system (SIS-RTDSR).Data showed that when rice was grown under 50% reduce tillage with zero tillage seed drill machine under drip irrigation system (DRIP-RTDSR) saved about 70% of irrigation water as compared to PTR along with 1.53 kg m^{-3} irrigation water productivity and 39.9 kg grain kg^{-1} N NUE.

c) Surface irrigation in rice crop

DSR with reduced tillage under surface irrigation method (SIS-RTDSR) produced grain yield of 5.58 t ha^{-1} (Table 1.24). Grain yield in DSR under surface irrigation method (SIS-RTDSR) was higher than the PTR and lower than the RTDSR in mini sprinkler irrigation system with 0.60 kg m^{-3} irrigation water productivity. Likewise, NUE was 37.2 kg grain kg^{-1} N in 2021 under surface irrigation method.

d) Economic analysis of rice crop under different irrigation systems during 2021

The economic analysis of rice crop grown with different irrigation systems during 2021 is presented in (Table 1.25). The B:C ratio of various system varied from 2.02 to 2.36 under different wheat crop establishment techniques and irrigation methods. B:C ratio of sprinkler irrigation system varied from 2.02 to 2.36.

Table 1.25 Economic analysis of rice crop under different irrigation methods during *Kharif* 2021

RCTs	Grain yield (t ha^{-1})	Cost cultivation (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C	Change over conventional	
						Net income difference	% change
PTR/CTW	5.41	55683	113585	57903	2.04		
DRIP-DSR/ZTW+RM	5.98	59067	124733	65666	2.11	7763	13.4
SIS-DSR/ZTW+RM	5.58	53880	116831	62951	2.17	5049	8.7
MSIS-DSR/ZTW+RM	6.50	57119	134839	77720	2.36	19817	34.2
MSIS-DSR+RI/ZTW+RM	6.10	62952	127121	64169	2.02	6267	10.8
MSP of Rice 2021 is taken Rs. 1960/q and rice straw @ Rs. 7500/ha. Cost of cultivation includes only operational cost (B-1)							

(Note: PTR- Puddled transplanted rice; RTDSR- Direct seeded rice in reduced tillage; CTW- Conventional tilled wheat; ZTW- Zero tilled wheat; RI- Residue incorporation; RM- Residue mulch; DRIP- Drip irrigation system; SIS- Surface irrigation system; MSIS- Sprinkler irrigation system)

1) Irrigation systems in wheat crop

The results of micro-irrigation systems (drip and mini sprinkler) in zero tilled wheat with rice residue mulch (ZTW+RM) during 2020-21is given in (Table 1.26) as given below:

a) Mini sprinkler irrigation system in wheat

Zero tilled wheat with 100% rice straw mulch under mini sprinkler irrigation system (MSIS-ZTW+RM) produced grain yield of 5.54 t ha^{-1} (T10) to 5.67 t ha^{-1} (T9) which was significantly higher from 8.6 to 11.2% as compared to conventional tilled wheat (CTW; 5.10 t ha^{-1}) (Table 1.26) Sprinkler irrigation system in wheat saved 29% of irrigation water over the surface irrigation method with 3.05 – 3.12 kg m^{-3} irrigation water productivity. Thus, the mini-sprinkler method may be feasible for wheat production.

b) Drip irrigation system in wheat

The grain yield of zero tilled wheat under drip irrigation (DRIP-ZTW+RM) was 5.68 tha^{-1},which was statistically significant by 11.45% as compared to CTW (5.10 t ha^{-1}) (Table 1.26). Saving of irrigation water under drip irrigation was about 36% as compared to conventional method with 3.48 kg m^{-3} of irrigation water productivity. Further, drip irrigation saved about 10% of irrigation water as compared to mini-sprinkler irrigation method.

c) Surface irrigation system in wheat

Surface irrigation system in wheat with 100% rice residue mulch (SIS-ZTW+RM) produced grain yield of5.55 tha^{-1} (Table 1.26). It is observed that retention of 10% rice residue mulch in wheat crop with different irrigation methods maintained the favourable soil temperature and moisture condition to facilitate the better wheat germination, growth and yield during the wheat crop growth period. It is observed that retention of 10% rice residue mulch in wheat crop with different irrigation methods showed that 100% rice residue mulch 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.

Table 1.26 Effect of different irrigation systems on wheat yield, irrigation water requirement, water productivity, saving of water and nitrogen use efficiency during *rabi*2020-21.

RCTs	Conventional wheat sowing	Zero tilled wheat with100% rice mulch			
Treatments	PTR/CTW	DRIP-RTDSR/ ZTW+RM	SIS-RTDSR/ ZTW+RM	MSIS-RTDSR/ ZTW+RM	MSIS-RTDSR+RI/ ZTW+RM
Mode of irrigation	Surface (T_1)	Drip (T_7)	Surface (T_8)	Mini – Sprinkler(T_9)	Mini – Sprinkler(T_{10})
Irrigation criteria	Growth stages	(Previous 7 days CPE)	Growth stages	(Previous 7 days CPE)	(Previous 7 days CPE)
Grain yield (tha^{-1})	5.10	5.68	5.55	5.67	5.54
Irrigation water applied (ha-mm)	256	163	256	182	182
Rainfall received (mm)	67	67	67	67	67
Total water (Irr. +rainfall; ha-mm)	322	230	322	248	248
Irrigation water productivity (kg m^{-3})	1.99	3.48	2.17	3.12	3.05
Total water productivity (kg m^{-3})	1.58	2.47	1.72	2.29	2.23

Irrigation water saving (%)	-	36.2	0.0	29.0	29.0
N applied (kg ha^{-1})	150	150	150	80	80
NUE (kg grain kg^{-1} nitrogen)	34.0	37.9	37.0	70.9	69.3
% Saving of N	-	0.0	0.0	46.7	46.7
CPE= Cumulative potential evaporation					

(Note: PTR- Puddled transplanted rice; **RTDSR**- Direct seeded rice in reduced tillage; **CTW**- Conventional tilled wheat; **ZTW**- Zero tilled wheat; **RI-** Residue incorporation; **RM-** Residue mulch; **DRIP-** Drip irrigation system; **SIS-** Surface irrigation system; **MSIS-** Sprinkler irrigation system)

d) Economic analysis of wheat crop under different irrigation methods during 2020-21

The economic analysis of wheat cultivation under different irrigation methods during 2020-21 is presented in (Table 1.27). The B:C ratio varied from 2.45–2.91 under different wheat crop establishment techniques and irrigation methods. Maximum B:C ratio (2.91) was computed under zero tilled wheat with rice residue mulch under surface irrigation system (SIS-ZTW+RM). Similarly, B:C ratio of sprinkler irrigation system varied from 2.49 to 2.54. The 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 CT and RT tillage practices.

Table 1.27 Economic analysis of wheat crop grown during *rabi*2020-21 under different irrigation method

Wheat 2020-21 (HD2967)							
RCTs	Grain yield (t ha^{-1})	Cost cultivation (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C	Change over conventional	
						Net income difference	%change
PTR/CTW	5.10	45665	118151	72486	2.59		
DRIP-DSR/ZTW+RM	5.68	52852	129729	76877	2.45	4391	6.1
SIS-DSR/ZTW+RM	5.55	43665	127162	83497	2.91	11011	15.2
MSIS-DSR/ZTW+RM	5.67	50904	129483	78579	2.54	6093	8.4
MSIS-DSR+RI/ZTW+RM	5.54	50904	126964	76060	2.49	3574	4.9
Whereas, MSP of wheat @ Rs. 1975/q in 2020-21 and wheat straw @ Rs.20,000/ha; B:C= Net income/Cost							

(**Note: PTR**- Puddled transplanted rice; **RTDSR**- Direct seeded rice in reduced tillage; **CTW**-Conventional tilled wheat; **ZTW**- Zero tilled wheat; **RI**- Residue incorporation; **RM-** Residue mulch; **DRIP-** Drip irrigation system; **SIS-** Surface irrigation system; **MSIS-** Sprinkler irrigation system)

It was observed that cost of cultivation of wheat crop was lower in zero tillage wheat as compared to CT 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. ZTW with rice residue mulch was relatively better thanCTW 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 regions 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 1.28). The results on characterization of hydraulic parameters of installed sprinkler irrigation system shows that out of three operating pressures 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 1.28 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 showed 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 1.26 & 1.28) 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.

i) Observations recorded under sprinkler irrigation system

The following observations recorded in rice crop at blooming stage

- Sprinkler irrigation at the time of flowering reduced the grain setting.
- 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.
- 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.

ii) Highlight of sprinkler irrigation system in rice-wheat system

Sprinkler irrigation system in DSR under reduced tillage with wheat residue incorporation or without crop residue followed by zero tilled wheat with rice residue mulched 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

During 2021, 5.98 t ha^{-1} rice yield was reported under drip irrigation system with DSR in reduced tillage (DRIP-RTDSR) (Table 1.25). When rice was sown with zero tillage seed drill machine under 50% reduce tillage and irrigated with drip irrigation system (DRIP-RTDSR) produced 7.2% higher rice yield and saved about 70% of irrigation water as compared to PTR along with 1.53 kg m^{-3} irrigation water productivity and 39.9 kg grain kg^{-1} N NUE.

Surface irrigation method in rice crop required huge amount of irrigation water in comparison to the drip irrigation in rice crop. Therefore, in the water scarcity region it could be a feasible technique for rice production

(ii) Wheat with drip irrigation system

- **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)** The grain yield of zero tilled wheat under drip irrigation (DRIP-ZTW+RM) was 5.68 t ha^{-1}, which was statistically significant by 11.45% as compared to CTW (5.10 t ha^{-1}) (Table 11). Saving of irrigation water under drip irrigation was about 36% as compared to conventional method with 3.48 kg m^{-3} of irrigation water productivity. Further, drip irrigation saved about 10% of irrigation water as compared to mini-sprinkler irrigation method.
- **c)** Results on the irrigation systems as given in Table 1.25 & 1.27 indicates that pressurized irrigation methods are water saver in comparison to surface irrigation method in partially reclaimed sodic soil with sandy loam texture.

D. Nutrient Management Practices in Conservation Agriculture
CSSRI

Nitrogen use efficiency under different irrigation systems
Application of nitrogen fertilizer/urea by using leaf colour chart, always maintained at LCC No 4/5. The nitrogen through urea was applied via fertilizer tank @ 2.5 kg with irrigation water on scheduled day. The results of nitrogen use efficiency (NUE) for wheat crop presented in Table 1.27

I. Nitrogen use efficiency vs Mini sprinkler irrigation system
Nitrogen use efficiency in mini sprinkler irrigation system was almost doubled than the CTW (34.0 kg grain kg^{-1} N applied) and it varied from 69.3 to 70.9 kg grain kg^{-1}N applied. Fertigation in mini sprinkler irrigation used 80 kg N ha^{-1} which was about 46% lower than the recommended dose nitrogen (150 kg urea ha^{-1}) as compared to conventional tilled wheat (CTW).

II. Nitrogen use efficiency vs drip irrigation method in wheat crop
Nitrogen use efficiency in drip irrigation system was 37.9 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 (Table 1.27).

III. Nitrogen use efficiency vs surface irrigation method in wheat crop
Under surface irrigation method nitrogen use efficiency was 37.0 kg grain kg^{-1} N in zero tilled wheat sown by Turbo/happy seeder in 100% rice crop residue mulch (SIS-CTW+RM), 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.

Rainfed Ecosystem / Dryland Ecosystem

A. Tillage and Residue management

1. Pigeonpea+Setaria system

CRIDA

A) Developing and validating location specific conservation agriculture technologies Strategies to enhance crop residue retention under Rainfed Agriculture

The crop residues in rainfed regions were low due to poor crop yields, the low residue production in rainfed regions, single cropping season in rainfed regions, besides this the crop residues have competing use for fodders. Hence experiments were initiated in different cropping systems to enhance the crop residues to the soil.The experiment were initiated in 2009 with pigeon pea - castor rotation system. The experiment was laid out in split plot design with tillage treatments as main plots and harvesting heights as sub plots. This year without changing the lay out it is proposed to change the sole cropping system to intercropping system. The space between widely spaced crops like pigeonpea and castor was more hence to utilize the space and increase residue to the soil. It is proposed to change the castor to cereal cropping system. This year pigeonpea + setaria intercropping system was sown after castor on different levels of castor residues with different tillage practices like 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) and different residue levels by harvesting castor crop at different heights (0 cm, 10 cm and 30 cm) to increase the residue contribution to the field. In the subplots the intercrop foxtail millet was introduced in 10 and 30 cm. The fox tail millet was also harvested at 10 and 30 cm levels as per the treatments.

Zero tillage recorded 20 and 18 % higher pigeonpea equivalent yields as compared to conventional and reduced tillage respectively. The pigeonpea equivalent yields in 10 and 30 cm recorded significantly higher yield as compared to no residues. 10 and 30 cm height crop residues recorded 55 and 54 % higher yield as compared to no residue (Fig 1.43).

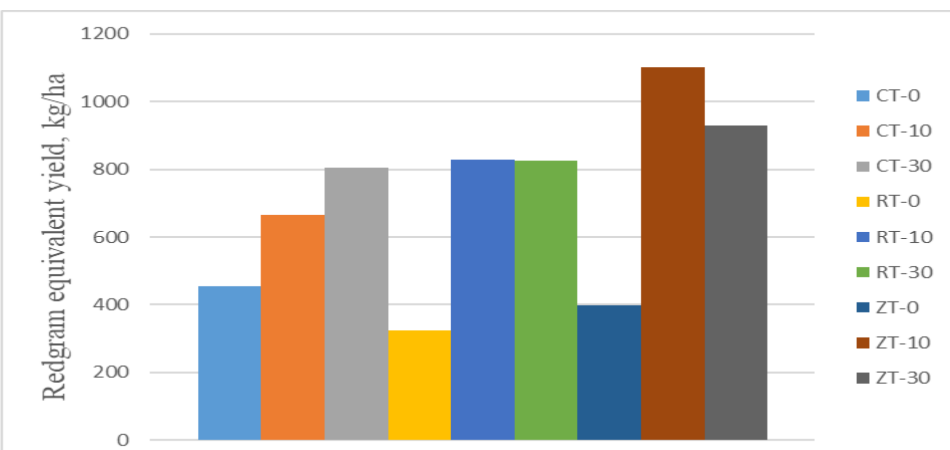


Fig 1.43 Influence of tillage and residue levels on red gram equivalent yield

Conventional tillage+ Inter crop **Conventional tillage**

ZT + Inter crop **ZT**

Fig 1.44 Performance of pigeonpea + setaria intercrop under different tillage and residue treatments.

Adapting and mainstreaming available best bet location Specific conservation agriculture practices

Table 1.29 Effect of Different Moisture Conservation Methods on yield and returns in Bengalgram

Observations	**Yield kg/ha**	**Cost of Cultivation Rs/ha**	**Gross Income Rs/ha**	**Net Income Rs/ha**	**C:B ratio**
1.FP (30x10 cm)	1637	39376	79394	40018	2.01
2.Row to row distance 30 cm. Formation of channel between two rows.	1867 (14.0%)	37875	90549	52674	2.40
3. Row to row distance 35 cm.,formation of channel after 3 rows.	1970 (20.3%)	37875	95545	57670	2.52

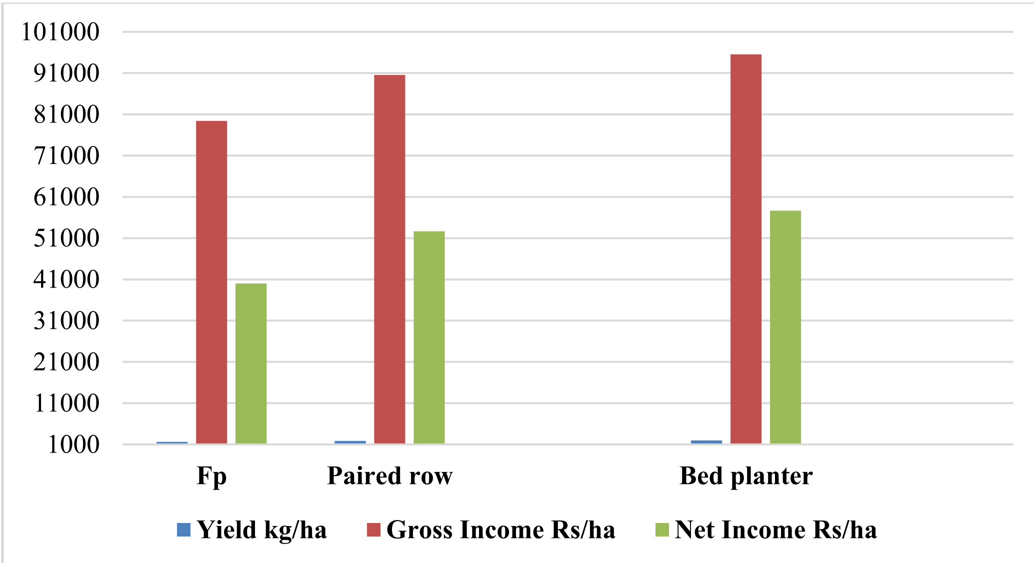


Fig 1.45 Effect of Different Moisture Conservation Methods in Bengalgram

Fig 1.46 Crop growth of bengalgram under raised bed and permanent row method

In Bengal gram higher yield was recorded in raised bed and furrow system (1970 kg/ha) followed by paired row (1867 kg/ha) and farmer practice (1637 kg/ha) (Table1.29 & Fig 1.45). Raised bed and furrow recorded higher gross income (95545 Rs/ha), net income (57670 kg/ha) and C:B ratio (2.52) whereas farmer practice recorded lower gross income (79394 kg/ha), net income (40018 kg/ha) and C:B ratio (2.01)

Table 1.30 Cultivation of Bengal gram with minimum tillage after Redgram+setaria intercrop

Particulars	yield kg/ha	Cost of cultivation Rs/ha	Gross income Rs/ha	Net income Rs/ha	Additional income Rs/ha
Redgram+setaria -Bengalgram	712 (Bengal gram equivalent yield)	40370	101319	60949	20579
Redgram+Setaria	394.8 (setaria equivalent yield)	33450	73820	40370	

New cropping system was introduced in Kurnool district. In setaria + redgram system (8:2) row ratio after harvest of setaria bengalgram was sown in zero tillage. This system recorded higher equivalent yield, and an additional returns of Rs 20,759 /ha. (Table 1.30).

Fig 1.47 Crop growth under Redgram setaria inter crop

Table 1.31 Setaria-Bengalgram cultivation with minimum tillage

Particulars	**Equivalent yield kg/ha**	**Cost of cultivation Rs/ha**	**Gross income rs/ha**	**Net income Rs/ha**	**Additional income Rs/ha**
Bengal gram	1623	48170	98969	50799	9216
Bengalgram (sole)	1531	32670	74253	41583	

The traditional cropping system of the region was fallow- Bengal gram in black soil of Kurnool. Hence setaria was introduced in Kharif season with minimum tillage. The bengalgram equivalent yields and net monetary returns were higher in setaria-bengalgram system as compared to fallow-bengalgram system (Table 1.31)

Fig 1.48 Setaria-Bengalgram cultivation with minimum tillage

Table 1.32 Cultivation of Setaria-Blackgram with minimum tillage

Particulars	**Eqivalent Yield kg/ha**	**Cost of cultivation Rs/ha**	**Gross Income Rs/ha**	**Net income Rs/ha**	**Additional Income Rs/ha**
Blackgram	1397	48580	139730	91150	14240
Blackgram (sole)	1732	35670	112580	76910	

Minimum tillage treatment recorded higher blackgram equivalent yields over farmers practice after harvest of Setaria-Blackgram intercrop (Table 1.32). This practice recorded an additional return of Rs 14240/-.

Fig 1.49 Cultivation of Setaria-Blackgram with minimum tillage

2. Pigeonpea - finger millet

CRIDA

Studies were initiated in fingermillet + pigeonpea (8:2) in rainfed ecosystem at Bangalore in 2016 with different tillage systems and cover crops. This year field bean was replaced by sunhemp. The cropping system was changed to pigeonpea-fingermillet sequence instead of pigeonpea + fingermillet intercropping system. Horsegram and sunhemp were sown as cover crops before the onset of monsoon in April to utilize the pre monsoon rainfall and increase the residues retention. The performance of both the cover crops was good as the rainfall in May was good and above normal.

The seed yields of pigeon pea were significantly influenced by the tillage and cover crops. The conventional tillage and reduced tillage recorded significantly higher yield over ZT but the CT and RT were on par with each other. The net monetary returns, benefit cost ratio were higher in RT as compared to ZT. The pigeonpea yields after cover crops were higher as compared to no cover crops. Among the cover crops pigeonpea yields after horse gram recorded higher seed yield, NMR and B: C ratio (Table1.33). The interaction between tillage and residue levels was non-significant.

Table 1.33 Yield and economics of Pigeonpea as influenced by conservation agriculture in pigeonpea - finger millet sequence cropping

Treatments	Seed yield (kg ha^{-1})	CC (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B: C	RWUE (kg ha-mm^{-1})
Tillage practice						
M_1: Conventional tillage	974	30363	58413	28050	1.92	0.82
M_2: Reduced tillage	941	27533	56448	28915	2.05	0.79

M_3:Zero tillage	813	26073	48779	22706	1.87	0.68
S. Em. ±	**31.2**					
CD (p=0.05)	**122.6**					
Cover crops						
C_1: Control	752	27190	45129	17939	1.66	0.63
C_2: Sun hemp	921	28090	55243	27153	1.97	0.77
C_3: Horsegram	1054	28690	63268	34578	2.20	0.88
S. Em. ±	**24.8**					
CD (p=0.05)	**76.3**					
Interaction						
M_1C_1	788	29563	47278	17715	1.60	0.66
M_1C_2	942	30463	56509	26046	1.86	0.79
M_1C_3	1191	31063	71451	40388	2.30	1.00
M_2C_1	815	26733	48885	22152	1.83	0.68
M_2C_2	984	27633	59060	31427	2.14	0.83
M_2C_3	1023	28233	61399	33166	2.17	0.86
M_3C_1	654	25273	39224	13951	1.55	0.55
M_3C_2	836	26173	50160	23987	1.92	0.70
M_3C_3	949	26773	56954	30181	2.13	0.80
S. Em. ±	**42.9**					
CD (p=0.05)	**NS**					

Cover crop- Sunhemp

Cover crop- Horsegram

Pigeonpea under Reduced tillage

Pigeonpea under conventional tillage

Fig 1.50 Performance sunhemp, horse gram and pigeon pea under different tillage treatments.

3. Maize-Horsegram – Pigeonpea

A field experiment was initiated with the integration of in-situ moisture conservation with CA practice in maize-Horsegram – pigeonpea sequence cropping system in 2013 at Gunegal Research Farm of ICAR-

CRIDA, Hyderabad. The experiment was laid out in split plot design with four tillage treatments: T_1- conventional tillage (CT) and T_2- minimum tillage (MT), T_3- zero tillage (ZT) and T_4- zero tillage with soil and moisture conservation practices and three residue retention treatments viz; farmers' practice of harvesting close to the ground without any retention of residues (S_1), harvesting kharif crop at 30 cm height (S_2), harvesting only cobs/pods and retaining the entire residue as such (S_3). Without disturbing the treatments this year the cropping system is changed to greengram- setaria cropping system in a year. Green gram crop was sown on 28th June, 2021 and the crop was harvested 28th August, 2021. Setaria was sown on 9th September, 2021 and the crop was harvested 15th November, 2021. Green gram variety WGG 42 and Setaria variety Sia 3222 was used for the study. An amount of 70.9 mm, 301.8 mm, 117.5 mm, 209.3 mm, 50.2 mm, 69.2 mm and 21.4 mm of rainfall was received in the month of June, July, August, September, October, November and December respectively.

Among the tillage practices, ZT with soil and moisture conservation practices (T_4) recorded significantly higher green gram yield and lower yield was recorded in ZT. ZT with in situ moisture conservation practices (T_4) recoded 11% higher green gram yield over CT (T_1). Among the residue retention levels, harvesting only pods/panicles and retaining the entire residue as such (S_3) treatment recorded significantly higher grain yields which was on par with harvesting crop at 30 cm height (S_2) treatment and significantly superior over S_1 (Fig 1.51). Similar trend was observed with biomass yields.

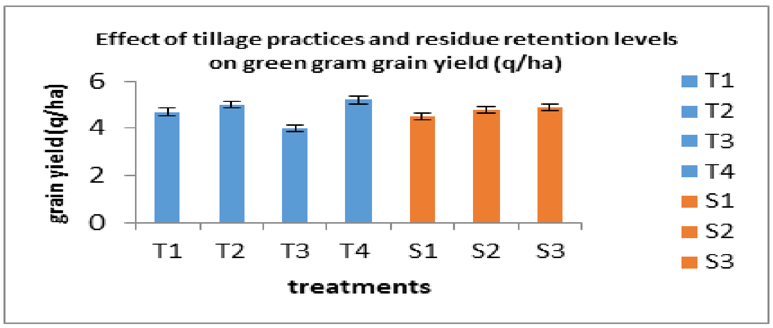


Fig 1.51 Effect of different tillage practices and residue retention levels on green gram grain yield (q/ha)

Minimum tillage with complete residue

Zero tillage with complete residue

Zero tillage with complete residue

Zero tillage with no residue

Fig 1.52 Setaria growth in various treatments during the 2021

4. Cotton- Pigeonpea

CRIDA

A field experiment was conducted every year since 2016 in sandy loam soil of Gunegal Research Farm at ICAR-Central Research Institute for Dry land Agriculture with cotton (Ujwal BG II-243) - Pigeon pea (PRG-176) rotation. For Bt Cotton RDF of 120-60-60 kg N, P_2O_5, K_2O ha^{-1} was followed.75 × 20 cm for pigeonpea, 90 × 60 cm for Bt Cotton were followed.

Yield increase in MT was 14.6% over ZT and 13% over CT. Pooled data of 5 years (2016-2020) revealed that significantly higher cotton equivalent yield (CEY) was obtained with MT with 125% RDF as compared to ZT (12% increase) but at par with CT **(Fig. 1.53)**.

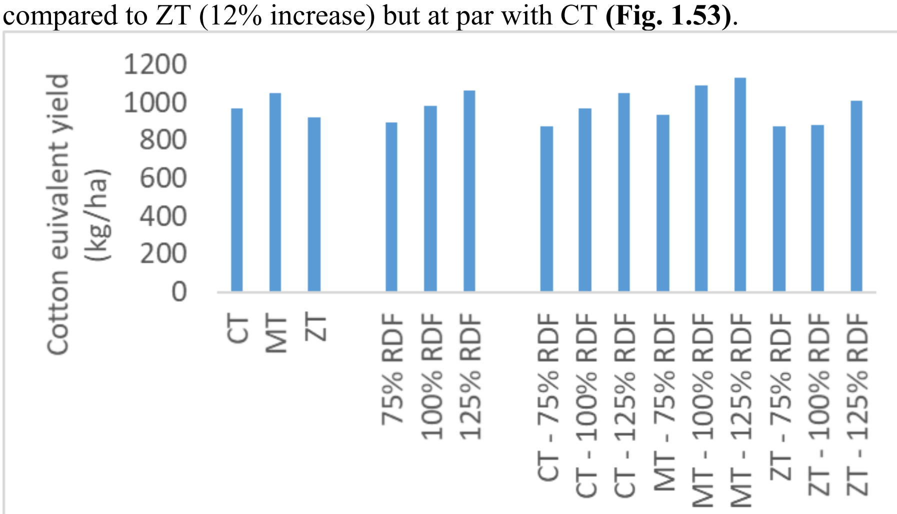


Fig 1.53 Effect of tillage and different fertilizer doses on cotton equivalent yield (kg/ha) in cotton-based systems

Fig 1.54 Pigeonpea crop under different tillage treatments

5. Sorghum-Black gram system

A long-term experiment was initiated during 2013 with sorghum and black gram as test crops in yearly rotation at Hayath nagar Research Farm of ICAR-CRIDA, Hyderabad. The experiment was laid out in a strip plot design with two tillage 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 (S_3) in sorghum. In black gram, the residue retention treatments were: No residue (S0), 50% of the residue retention (S1) (Clearing of residue from alternate rows), 100% retention (S2).

Sorghum (variety CSV 20) was sown this year (2021). In the 9th year of the study, the grain yield of sorghum in sorghum-blackgram rotation was significantly higher with residue retention. The treatments with higher residue retention (S2) recorded 27.5% higher sorghum grain yield (Table 1.34, Fig 1.55). Grain yield in both minimum tillage and conventional tillage significantly on par with each other.

Table 1.34 Effect of tillage and residue management on grain yield of sorghum

Tillage	Residue	Grain yield (kg/ha)
Minimum tillage	S0: No residue application	1512
	S1: Cutting at 35 cm height (1/3 rd height)	1714
	S2: Cutting at 60 cm height	1988
Conventional tillage	S0: No residue application	1616
	S1: Cutting at 35 cm height (1/3 rd height)	1799
	S2: Cutting at 60 cm height	2001
CD (P=0.05)		
Tillage		NS
Residues		155.9*
T X R		NS

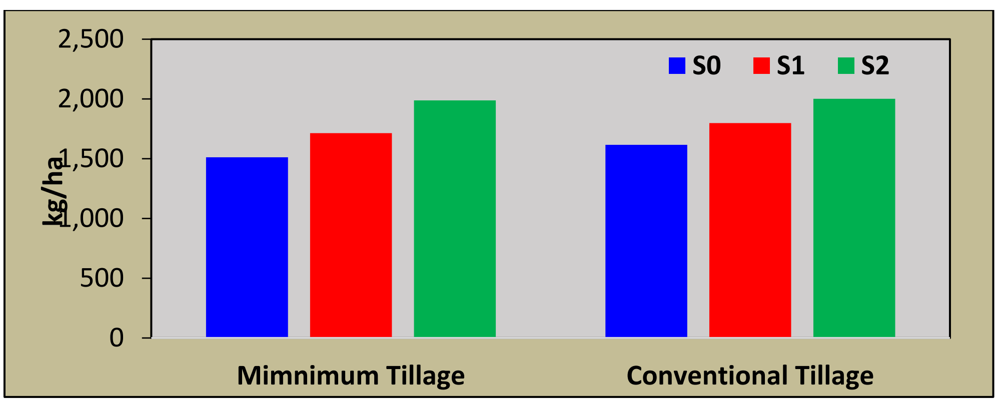


Fig 1.55 Sorghum grain yield with tillage and residue management practices

6. Soybean - Wheat cropping system

IISS

Impact of crop residue levels on crop productivity and soil health in soybean–wheat cropping system under conservation agriculture

A field experiment was conducted to study the impact of different residue levels and nutrient doses on crop establishment, soil health, ease of operation of machinery (happy seeder), 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 in the main plot and four nutrient levels viz., 100% NPK or recommended dose of fertilizer (RDF), 75% N with 100%

PK, 75% P with 100%NK and 75% K with 100% NP were compared. In soybean 100% NPK were 25:60:40 kg ha^{-1} N, P_2O_5, K_2O and in wheat 100% NPK 120:60:40 kg ha^{-1} N, P_2O_5, K_2O.

Response of different residue and nutrient levels on Soybean crop

(1) Plant height

The data pertaining to plant height (Table 1.35) shows significant differences in plant height as a result of different levels of crop residue retention. The maximum plant height (58.58 cm) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 55.25 cm, 52.25 cm, 45.17 cm respectively. In case of various levels of nutrient applications there was non significant effect of nutrient doses on plant height and the plant height varied between (52.25 to 53.83). The interaction effect between residue levels and nutrient doses not show any significant difference on plant height as a result of different residue levels and nutrient doses (Table 1.35) shown highest plant height (59 cm) recorded with 90% residue and 100% RDF and the lowest plant height (44.0 cm) was observed in without residue with 75% N, 100% P, K doses.

Table 1.35 Effect of different levels of crop residue retention and nutrient doses on plant height (cm) in soybean crop

	100% RDF (25:60:40)	75% N, 100% P, K	75% P, 100% N, K	75% K, 100% N, P	Mean
90% R	59.0	59.0	57.3	59.0	58.58
60% R	55.7	54.3	57.7	53.3	55.25
30% R	54.0	51.7	51.0	52.3	52.25
WR	46.7	44.0	44.0	46.0	45.17
Mean	53.83	52.25	52.50	52.67	
	CD 0.05				
Residue	1.589	** 1%			
Nutrient	1.589	NS			
Residue x Nutrient	3.178	NS			

(2) Number of branches

The data pertaining to number of branches (Table 1.36) shows significant differences in number of branches as a result of different levels of crop residue retention. The maximum number of tillers (5.58) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 4.58, 4.17, 3.0 respectively. In case of various levels of nutrient applications there was non-significant effect of nutrient doses on number of branches and the number of branches varied between (4.17 to 4.58). The interaction effect between residue levels and nutrient doses not show any significant difference effect on number of tillers as a result of different residue levels and nutrient doses (Table 1.36) shown highest number of branches (5.67) with 90% crop residue with 100% RDF which was statistically at par with other residue levels. The lowest number of tillers (2.67) was observed in without residue with 75% N, 100% P, K doses.

Table 1.36 Effect of different levels of crop residue retention and nutrient doses on number of branches plant^{-1} on soybean crop

	100% RDF (25:60:40)	75% N, 100% P, K	75% P, 100% N, K	75% K, 100% N, P	Mean
90% R	5.67	5.33	5.67	5.67	5.58
60% R	4.67	5.00	4.33	4.33	4.58
30% R	4.67	3.67	4.00	4.33	4.17
WR	3.33	2.67	3.00	3.00	3.00
Mean	4.58	4.17	4.25	4.33	
	CD 0.05				
Residue	0.429	** 1%			
Nutrient	0.429	NS			
Residue x Nutrient	0.859	NS			

(3) Biological yield

The data obtain from biological yield of soybean (Table 1.37) shows significant differences in biological yield as a result of different levels of crop residue retention. The maximum biological yield (4347 kg ha^{-1}) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 3619, 3329, 3223 kg ha^{-1} respectively. In case of various levels of nutrient applications there was non significant effect of nutrient doses on biological yield and biological varied between (3404 to 3920 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on biological yield as a result of different residue levels and nutrient doses (Table 1.37). The highest biological yield (5013 kg ha^{-1}) acquire from 90% crop residue with 100% RDF which was statistically at par with other residue levels. The lowest biological yield (2882 kg ha^{-1}) was observed in 60% crop residue retention with 75% N, 100% P, K doses.

Table 1.37 Effect of different levels of crop residue retention and nutrient doses on biological yield kg ha^{-1} in soybean crop

	100% RDF (25:60:40)	75% N, 100% P, K	75% P, 100% N, K	75% K, 100% N, P	Mean
90% R	5013	4084	4550	3742	4347.08
60% R	4385	2882	3958	3253	3619.17
30% R	3028	3479	3107	3706	3329.67
WR	3257	3175	3309	3152	3223.21
Mean	3920.50	3404.88	3730.83	3462.92	
	CD 0.05				
Residue	531.556	** 1%			

Nutrient	531.556	NS			
Residue x Nutrient	1063.112	NS			

(4) Grain yield

The data obtain from grain yield of soybean crop (Table 1.38) shows significant differences in grain yield as a result of different levels of crop residue retention. The maximum yield (1175 kg ha^{-1}) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 843, 676, 591 kg ha^{-1} respectively and he lowest grain yield (591 kg ha^{-1}) was observed in without residue. In case of various levels of nutrient applications there was non significant effect of nutrient doses on grain yield and the grain yield varied between (781 to 870 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on grain yield as a result of different residue levels and nutrient doses (Table 1.38). The highest grain yield (1225 kg ha^{-1}) obtains from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (580 kg ha^{-1}) was observed in without residue with 75% P, 100% N, K doses.

Table 1.38 Effect of different levels of crop residue retention and nutrient doses on grain yield kg ha^{-1} on soybean crop

	100% RDF (25:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	1225	1059	1212	1208	1175.83
60% R	963	803	848	768	845.42
30% R	691	672	658	688	676.96
WR	603	590	580	593	591.75
Mean	870.42	781.04	824.25	814.25	
	CD 0.05				
Residue	113.164	** 1%			
Nutrient	113.164	NS			
Residue x Nutrient	226.327	NS			

(5) Stover yield

The data pertaining from stover yield of soybean crop (Table 1.39) shows no significant differences in stover yield as a result of different levels of crop residue retention. The maximum stover yield (3171 kg ha^{-1}) was recorded in 90 % residue retention treatment which was at par with rest of the residue levels and he lowest stover yield (2331 kg ha^{-1}) was observed in without residue. In case of various levels of nutrient applications there was also non significant effect of nutrient doses on stover yield and the stover yield varied between (2590 to 3096 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on stover yield as a result of different residue levels and nutrient doses (Table 1.39). The highest stover yield (3801kg ha^{-1}) recorded from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (2113kg ha^{-1}) was observed in 60% crop residue retention with 75% N, 100% P, K doses.

Table 1.39 Effect of different levels of crop residue retention and nutrient doses on stover yield kg ha^{-1} on soybean crop

	100%RDF (25:60:40)	**75% N, 100% P, K**	**75%P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	3801	2877	3325	2683	3171.25
60% R	3538	2113	2995	2449	2773.75
30% R	2370	2791	2416	3034	2652.71
WR	2677	2582	2706	2562	2631.46
Mean	3096.25	2590.63	2860.42	2681.88	
	CD 0.05				
Residue	499.134	NS			
Nutrient	499.134	NS			
Residue x Nutrient	998.267	NS			

(6) Harvest index

The data obtain from harvest index (Table 1.40) shows significant differences in harvest index (HI) as a result of different levels of crop residue retention. The maximum HI (27.40%) was recorded in 90 % residue retention treatment and the lowest HI (18.87%) was observed in without residue. In case of various levels of nutrient applications there was non significant effect of nutrient doses on HI and the HI varied between (21.34 to 23.07%). The interaction effect between residue levels and nutrient doses not show any significant difference effect on stover yield as a result of different residue levels and nutrient doses (Table 1.40).

Table 1.40 Effect of different levels of crop residue and nutrient on harvest index on soybean crop

	100% RDF (25:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	26.97	24.17	28.57	29.91	27.40
60% R	24.66	19.17	25.80	27.09	24.18
30% R	21.50	23.71	18.39	19.82	20.86
WR	19.16	18.34	18.88	19.10	18.87
Mean	23.07	21.34	22.91	23.98	
	CD 0.05				
Residue	4.047	** 1%			
Nutrient	4.047	NS			
Residue x Nutrient	8.094	NS			

Fig 1.56 Response of different residue and nutrient levels on wheat crop

(1) Plant height

The data pertaining to plant height (Table1.41) shows significant differences in plant height as a result of different levels of crop residue retention. The maximum plant height (112.44 cm) was recorded in 90% residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 110.06 cm, 106.69 cm, 98.64 cm respectively. In case of various levels of nutrient applications there was non-significant effect of nutrient doses on plant height and the plant height varied between (106.28 to 107.67). The interaction effect between residue levels and nutrient doses not show any significant difference on plant height as a result of different residue levels and nutrient doses (Table 1.41) shown highest plant height (113.7 cm) recorded with 90% residue and 100% RDF and the lowest plant height (97.78 cm) was observed in without residue with 75% N, 100% P, K doses.

Table 1.41 Effect of different levels of crop residue retention and nutrient doses on plant height (cm) on wheat crop at harvest

	100% RDF (120:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	113.7	111.1	112.1	112.9	112.44
60% R	110.1	110.7	110.0	109.4	110.06
30% R	107.8	105.6	106.4	107.0	106.69
WR	99.1	97.8	98.7	99.0	98.64
Mean	107.67	106.28	106.81	107.08	
	CD 0.05				
Residue	1.554	** 1%			
Nutrient	1.554	NS			
Residue x Nutrient	3.109	NS			

(2) Number of tillers

The data pertaining to tillers (Table 1.42) shows significant differences in number of tillers as a result of different levels of crop residue retention. The maximum number of tillers (101.69) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 95.67, 91.31, 80.19 respectively. In case of various levels of nutrient applications there was non significant effect of nutrient doses on number of tillers and the number of tillers varied between (90.97 to 93.81). The interaction effect between residue levels and nutrient doses not show any significant difference effect on number of tillers as a result of different residue levels and nutrient doses (Table 1.42) shown highest number of tillers (102.9) with 90% crop residue with 100% RDF which was statistically at par with other residue levels. The lowest number of tillers (74.8) was observed in without residue with 75% N, 100% P, K doses.

Table 1.42 Effect of different levels of crop residue retention and nutrient doses on number of tillers m^{-1} row length on wheat crop at harvest

	100% NPK	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	102.9	99.9	101.6	102.4	101.69
60% R	97.4	99.1	97.2	88.9	95.67
30% R	92.7	90.1	90.9	91.6	91.31
WR	82.2	74.8	81.8	82.0	80.19
Mean	93.81	90.97	92.86	91.22	
	CD 0.05				
Residue	4.832	** 1%			
Nutrient	4.832	NS			
Residue x Nutrient	9.664	NS			

(3) Biological yield

The data obtain from biological yield of wheat (Table 1.43) shows significant differences in biological yield as a result of different levels of crop residue retention. The maximum biological yield (16915.11 kg ha^{-1}) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 16235, 15970, 14787 kg ha^{-1} respectively. In case of various levels of nutrient applications there was non significant effect of nutrient doses on biological yield and biological varied between (15103 to 17026kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on biological yield as a result of different residue levels and nutrient doses (Table 1.43). The highest biological yield (18608kh ha^{-1}) acquire with 90% crop residue with 100% RDF which was statistically at par with other residue levels. The lowest biological yield (13226 kg ha^{-1}) was observed in without residue with 75% N, 100% P, K doses.

Table 1.43 Effect of different levels of crop residue retention and nutrient doses on biological yield (kg ha^{-1}) on wheat crop at harvest

	100% RDF (120:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**

90% R	18608	15209	16578	17266	16915.11
60% R	16798	15675	15995	16472	16235.00
30% R	15979	16304	15830	15769	15970.67
WR	16722	13226	14529	14674	14787.78
Mean	17026.89	15103.44	15732.89	16045.33	
	CD 0.05				
Residue	1388.308	* 5%			
Nutrient	1388.308	NS			
Residue x Nutrient	2776.617	NS			

(4) Grain yield

The data pertaining from grain yield of wheat crop (Table 1.44) shows significant differences in grain yield as a result of different levels of crop residue retention. The maximum yield (6775 kg ha^{-1}) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 6366, 5811, 5727 kg ha^{-1} respectively and he lowest grain yield (5727kg ha^{-1}) was observed in without residue. In case of various levels of nutrient applications there was non significant effect of nutrient doses on grain yield and the grain yield varied between (6088 to 6338 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on grain yield as a result of different residue levels and nutrient doses (Table 1.44). The highest grain yield (7022 kg ha^{-1}) obtains from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (5578 kg ha^{-1}) was observed in without residue with 75% N, 100% P, K doses.

Table 1.44 Effect of different levels of crop residue retention and nutrient doses on grain yield (kg ha^{-1}) on wheat crop

	100% RDF (120:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	7022	6667	6667	6744	6775.00
60% R	6411	6544	6278	6233	6366.67
30% R	6000	5689	5778	5778	5811.11
WR	5922	5578	5633	5728	5727.78
Mean	6338	6119	6088	6133	
	CD 0.05				
Residue	357.984	** 1%			
Nutrient	357.984	NS			
Residue x Nutrient	715.968	NS			

(5) Stover yield

The data pertaining from stover yield of wheat crop (Table 1.45) shows significant differences in stover yield as a result of different levels of crop residue retention. The maximum stover yield (11104 kg ha^{-1}) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 9604, 9460, 9060 kg ha^{-1} respectively and he lowest stover yield (9060 kg ha^{-1}) was observed in without residue. In case of various levels of nutrient applications there was non significant effect of nutrient doses on stover yield and the stover yield varied between (8984 to 10688 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on stover yield as a result of different residue levels and nutrient doses (Table 1.45). The highest stover yield (12608 kg ha^{-1}) recorded from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (7648 kg ha^{-1}) was observed in without residue with 75% N, 100% P, K doses.

Table 1.45 Effect of different levels of crop residue and nutrient doses on stover yield (kg ha^{-1}) on wheat crop

	100% RDF (120:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	12608	9520	10800	11488	11104.00
60% R	9568	9760	9552	9536	9604.00
30% R	9776	9008	9328	9728	9460.00
WR	10800	7648	8896	8896	9060.00
Mean	10688	8984	9644	9912	
	CD 0.05				
Residue	1348.722	* 5%			
Nutrient	1348.722	NS			
Residue x Nutrient	2697.445	NS			

(6) Harvest index

The data obtain from harvest index (Table 1.46) shows significant differences in harvest index (HI) as a result of different levels of crop residue retention. The maximum HI (41.97%) was recorded in 90 % residue retention treatment and the lowest HI(35.25%) was observed in without residue. In case of various levels of nutrient applications there was non significant effect of nutrient doses on HI and the HI varied between (37.72 to 40.98 %). The interaction effect between residue levels and nutrient doses not show any significant difference effect on stover yield as a result of different residue levels and nutrient doses (Table1.46).

Table 1.46 Effect of different levels of crop residue and nutrient on harvest index on wheat crop

	100% RDF (120:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	41.79	43.20	41.93	40.95	41.97
60% R	41.08	40.29	40.76	39.55	40.42

30% R	35.76	42.25	39.08	39.60	39.17
WR	32.28	38.19	36.82	33.70	35.25
Mean	37.72	40.98	39.65	38.45	
	CD 0.05				
Residue	3.298	** 1%			
Nutrient	3.298	NS			
Residue x Nutrient	6.595	NS			

9. Horsegram- Pearlmillet

CRIDA

A field experiment was conducted every year since 2016 in sandy loam soil of Gunegal Research Farm at ICAR-Central Research Institute for Dryland Agriculture (ICAR-CRIDA), Hyderabad to study the impact of different fertilizer levels with CA as complimentary practice CA (ZT- no till, direct seeded with residue retention), minimum tillage (MT- One ploughing, sowing with residue retention) and conventional tillage (CT- two ploughing with disk plough, one harrowing and sowing) as main plots and 75% RDF, 100% RDF (Pearl millet: 80-40-30 kg N, P_2O_5, K_2O ha^{-1}, on residual fertility, Pigeon pea: 20-50-0 kg N, P2O5, K2O ha-1) and 125% RDF as subplots, to study the effect of tillage practices and different doses of fertilizers on performance of pearlmillet (MP MH21) and horsegram (CRHG 4). Short duration (75-80 days) pearlmillet (MP MH21) was selected to take the advantage of early sowing of horsegram. Pearl millet was sown at a spacing of 45 × 12 cm, and horsegram at 30x10cm.

Significantly higher pearlmillet grain yield was observed in MT (2361 kg/ha) compared to ZT and CT. Higher yield was observed in 125% RDF (2348 kg/ha). Pooled data of 5 years (2016-2020) revealed that significantly higher pearlmillet equivalent yields were obtained in minimum tillage (MT) with 125% RDF compared to zero tillage (ZT) and conventional tillage (CT) (Fig 1.57).

The percent residue cover was recorded. In general residue cover decreased gradually with increased number of days after harvesting of pigeonpea (Fig 1.58). Among the various tillage treatments significantly higher percent residue cover was observed in MT over ZT and CT at all DAH of pigeonpea except at 45 DAH where higher per cent of residue cover was observed in MT which was on a par with ZT and significantly superior to CT. At 45 DAH the residue cover percentage was significantly higher with 125 % RDF over 75 % RDF and it was statistically on par with 100 % RDF. At 60 DAH significantly higher residue cover percentage was recorded with 75 % RDF over 100 and 125 % RDF. At 75 and 90 DAH higher residue cover percentage was observed in 125 % RDF over 100 and 75 % RDF.

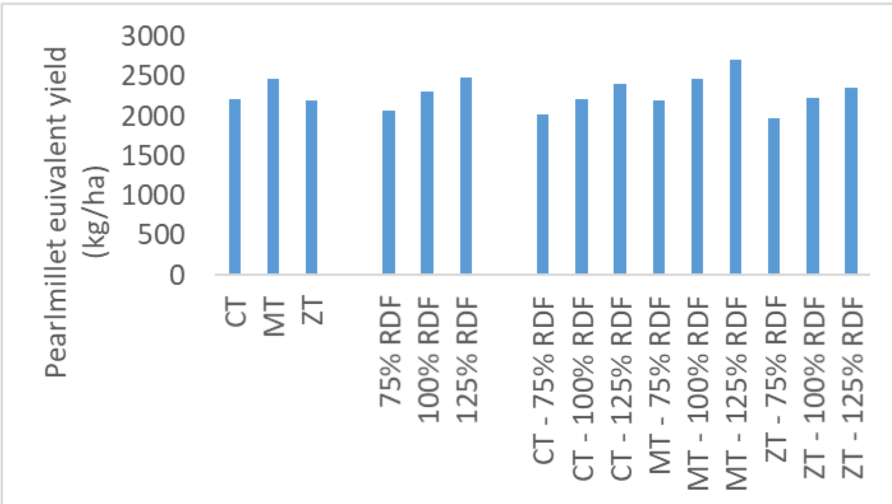


Fig 1.57 Effect of tillage and different fertilizer doses on pearlmillet equivalent yield

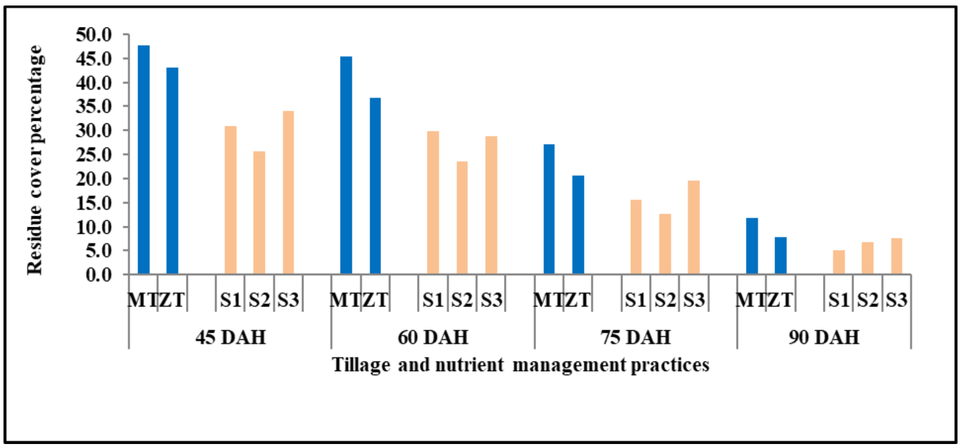


Fig 1.58 Effect of tillage and nutrient management practices on residue cover percentage at different days

Fig 1.59 Pearl millet crop growth in various treatments

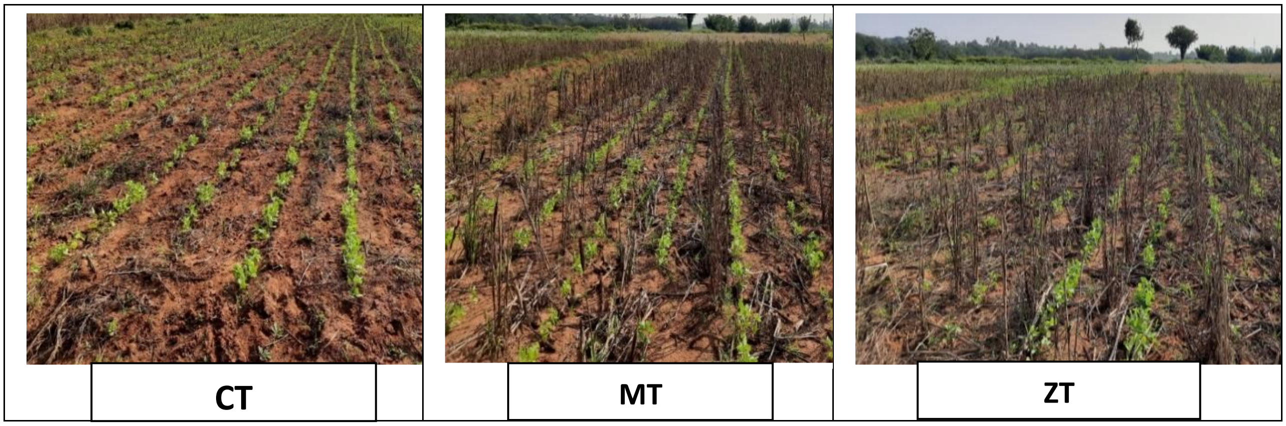


Fig 1.60 Horsegram under different tillage and residue cover

2. Weed Management

1. Maize-Chickpea cropping system

IISS

Table 1.47 Treatment details

Factor. A↓/ Factor B→ Residue levels	**Herbicide treatment**	
A_1(90%)Crop residue	B_1. Imazethapyr @ 50 g a.i. ha^{-1} (as pre-em)	B_1.Tembotrione@120g a.i. ha^{-1}+Atrazin @ 1 kg a.i. ha^{-1} (as pre-em)
A_2(60%)Crop residue	B_2. Imazethapyr @ 50 g a.i. ha^{-1} (as pre-em) fb HW (50 DAS)	B_2.Tembotrione@120g a.i. ha^{-1}+Atrazin @ 625 g a.i. ha^{-1} (30 DAS)
A_3(30%)Crop residue	B_3. Imazethapyr @ 25 g a.i. ha^{-1}+Clodinafop @ 60 g a.i. ha^{-1} (30 DAS)	B_3.Tembotrione@180g a.i. ha^{-1}+Atrazin @1kg a.i. ha^{-1} (30 DAS)
A_4(0%)Crop residue	B_4. Imazethapyr @ 25g a.i. ha^{-1}+ Clodinafop @ 60g a.i. ha^{-1} (30 DAS) fb HW (50 DAS)	B_4.Tembotrione@120g a.i. ha^{1}+Atrazin @ 625g a.i. ha^{-1} (30 DAS) fb HW (50 DAS)

Maize Crop

Table 1.48 Effect of different levels of crop residue retention and herbicidal weed control treatments on plant height (cm) on maize crop at harvest

	B1	B2	B3	B4	Mean of A
A1	171.0	168.2	174.1	175.2	172.14
A2	168.0	166.6	168.9	169.0	168.11
A3	162.0	162.3	158.8	158.9	160.50
A4	137.2	145.0	148.2	147.6	144.50
MEAN OF B	159.56	160.53	162.50	162.67	
	CD 0.05				

A	3.979	** 1%			
B	3.979	NS			
AB	7.957	NS			

The data pertaining to plant height presented in table1.48 depicts significant effect on plant height as a result of different levels of crop residue retention. The maximum plant height (172.14cm) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (168.11cm) and significantly superior over 30% crop residue retention (160.50cm) and without residue retention treatment (144.50cm). In case of different herbicidal weed control treatments shows non-significant effect on the plant height. The plant height as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.49 Effect of different levels of crop residue retention and herbicidal weed control treatments on fresh weight (gm plant^{-1}) on maize crop at harvest

	B1	B2	B3	B4	Mean of A
A1	451.6	517.0	518.8	559.1	511.61
A2	495.8	475.7	500.8	506.0	494.56
A3	476.6	446.9	491.7	500.6	478.92
A4	357.7	380.4	381.1	392.6	377.94
MEAN OF B	445.39	455.00	473.08	489.56	
	CD 0.05				
A	39.251	** 1%			
B	39.251	NS			
AB	78.503	NS			

The data pertaining to fresh weight presented in Table 1.49 depicts significant effect on fresh weight as a result of different levels of crop residue retention. The maximum fresh weight (511.61gm plant^{-1}) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (494.56gm plant^{-1}) and 30% crop residue retention (478.92gm plant^{-1}) and significantly superior over without residue retention treatment (377.94gm plant^{-1}). In case of different herbicidal weed control treatments shows non-significant effect on the fresh weight. The fresh weight as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.50 Effect of different levels of crop residue retention and herbicidal weed control treatments on dry weight (gm plant-1) on maize crop at harvest

	B1	B2	B3	B4	Mean of A
A1	387.8	338.7	389.1	419.3	383.71
A2	371.8	356.8	375.6	379.5	370.92
A3	357.4	335.2	368.8	375.4	359.19
A4	268.3	285.3	285.8	294.4	283.46
MEAN OF B	346.31	328.98	354.81	367.17	
	CD 0.05				
A	29.439	** 1%			
B	29.439	NS			
AB	58.877	NS			

The data pertaining to dry weight presented in Table 1.50 depicts significant effect on dry weight as a result of different levels of crop residue retention. The maximum dry weight (383.71gm plant^{-1}) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (370.92gm plant^{-1}) and 30% crop residue retention (359.19gm plant^{-1}) and significantly superior over without residue retention treatment (283.46gm plant^{-1}). In case of different herbicidal weed control treatments shows non-significant effect on the dry weight. The dry weight as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.51 Effect of different levels of crop residue retention and herbicidal weed control treatments on row cob^{-1} in maize crop

	B1	B2	B3	B4	Mean of A
A1	12.7	12.4	13.1	13.3	12.89
A2	11.6	11.3	12.0	12.2	11.78
A3	11.1	11.1	11.3	11.6	11.28
A4	10.9	10.9	11.1	11.1	11.00
MEAN OF B	11.56	11.44	11.89	12.06	
	CD 0.05				
A	0.746	** 1%			
B	0.746	NS			
AB	1.492	NS			

The data pertaining to row cob^{-1} presented in Table1.51 depicts significant effect on row cob^{-1}as a result of different levels of crop residue retention. The maximum row cob^{-1} (12.89) was recorded in 90% crop residue retention level and significantly superior over 60% crop residue retention (11.78), 30% crop residue retention (11.28) and without residue retention treatment (11.00). In case of different herbicidal weed control treatments shows non-significant effect on the row cob^{-1}. The row cob^{-1}as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.52 Effect of different levels of crop residue retention and herbicidal weed control treatments on grain row^{-1} in maize crop

	B1	B2	B3	B4	Mean of A
A1	36.7	36.3	38.7	40.0	37.92
A2	35.0	34.7	35.7	36.3	35.42
A3	30.0	27.3	30.7	32.3	30.08
A4	25.7	24.7	28.7	30.0	27.25
MEAN OF B	31.83	30.75	33.42	34.67	
	CD 0.05				
A	2.623	** 1%			
B	2.623	* 5%			
AB	5.245	NS			

The data pertaining to grain row^{-1}presented in table 1.52 depicts significant effect on grain row^{-1}as a result of different levels of crop residue retention. The maximum grain row^{-1} (37.92) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (35.42) and significantly superior over 30% crop residue retention (30.08) and without residue retention treatment (27.25). The different herbicidal weed control treatments has significant influence on grain row^{-1}and maximum grain row^{-1} (34.67) was recorded under treatment post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing which was at par with post-emergence application of Tembotrione@180g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} (33.42) and significantly superior over Tembotrione@120g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} as a pre-emergence (31.83) and Tembotrione @ 120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} without hand weeding (30.75). The grain row^{-1}as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.53 Effect of different levels of crop residue retention and herbicidal weed control treatments on grain cob^{-1}in maize crop

	B1	B2	B3	B4	Mean of A
A1	447.8	442.3	505.3	521.7	479.28
A2	439.3	414.0	444.2	448.9	436.61
A3	403.9	393.1	348.4	373.6	379.75
A4	279.1	266.9	317.6	335.1	299.67
MEAN of B	392.53	379.08	403.89	419.81	
	CD 0.05				
A	39.056	** 1%			
B	39.056	NS			
AB	78.113	NS			

The data pertaining to grain cob^{-1} presented in table 1.53 depicts significant effect on grain cob^{-1}as a result of different levels of crop residue retention. The maximum grain cob^{-1} (479.28) was recorded in 90% crop residue retention level and significantly superior over 60% crop residue retention (436.61), 30% crop residue retention (379.75) and without residue retention treatment (299.67). In case of different herbicidal weed control treatments shows non-significant effect on the grain cob^{-1}. The grain cob^{-1}as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.54 Effect of different levels of crop residue retention and herbicidal weed control treatments on length of cob in maize crop

	B1	B2	B3	B4	Mean of A
A1	17.1	17.0	17.3	18.8	17.56
A2	16.9	16.1	17.2	17.8	17.00
A3	16.6	16.4	16.4	16.9	16.58
A4	15.3	15.1	15.8	16.0	15.56
MEAN OF B	16.47	16.17	16.69	17.36	
	CD 0.05				
A	0.932	** 1%			
B	0.932	NS			
AB	1.864	NS			

The data pertaining to length of cob presented in table 1.54 depicts significant effect on length of cob as a result of different levels of crop residue retention. The maximum length of cob (17.56cm) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (17.00cm) and significantly superior over 30% crop residue retention (16.58cm) and without residue retention treatment (15.56). In case of different herbicidal weed control treatments shows non-significant effect on the length of cob. The length of cob as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.55 Effect of different levels of crop residue retention and herbicidal weed control treatments on test weight (g) in maize crop

	B1	B2	B3	B4	Mean of A
A1	279.8	279.5	279.8	280.2	279.83
A2	278.9	279.0	279.2	279.9	279.27
A3	279.4	278.6	278.9	279.1	278.98
A4	277.7	277.6	278.2	278.6	278.03
MEAN of B	278.94	278.66	279.03	279.47	
	CD 0.05				
A	0.843	** 1%			
B	0.843	NS			
AB	1.686	NS			

The data pertaining to test weight presented in table 1.55 depicts significant effect on test weight as a result of different levels of crop residue retention. The maximum test weight (279.83g) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (279.27g) and significantly superior over 30% crop residue retention (278.98g) and without residue retention treatment (278.03g). In case of different herbicidal weed control treatments shows non-significant effect on the test weight. The test weight as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.56 Effect of different levels of crop residue retention and herbicidal weed control treatments on grain yield in maize crop (kg ha^{-1})

	B1	B2	B3	B4	Mean of A
A1	6996.7	6916.3	7096.0	7103.3	7028.08
A2	6421.3	6318.7	6446.3	6693.0	6469.83
A3	5494.7	5479.3	6215.3	6215.7	5851.25
A4	5150.0	5091.7	5237.7	5403.7	5220.75
MEAN OF B	6015.67	5951.50	6248.83	6353.92	
	CD 0.05				
A	300.428	** 1%			
B	300.428	* 5%			
AB	600.856	NS			

The data pertaining to grain yield presented in table 1.56 depicts significant effect on grain yield as a result of different levels of crop residue retention. The maximum grain yield (7028.08 kg ha^{-1}) was recorded in 90% crop residue retention level and significantly superior over 60% crop residue retention (6469.83 kg ha^{-1}), 30% crop residue retention (5851.25kg ha^{-1}) and without residue retention treatment (5220.75qt ha^{-1}). The different herbicidal weed control treatments has significant influence on grain yield and maximum grain yield (6353 kg ha^{-1}) was recorded under treatment post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing which was at par with post-emergence application of Tembotrione@180g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} (6249 kg ha^{-1}) and significantly superior over Tembotrione@120g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} as a pre-emergence (6016 kg ha^{-1}) andTembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} without hand weeding (5952 kg ha^{-1}). The grain yield as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.57 Effect of different levels of crop residue retention and herbicidal weed control treatments on stover yield in maize crop (kg ha^{-1})

	B1	B2	B3	B4	Mean of A
A1	10189.7	10187.3	10213.3	10418.7	10252.25
A2	9562.0	9527.3	10117.0	10139.3	9836.42
A3	8896.3	9025.0	9338.7	9630.0	9222.50
A4	8746.0	8664.7	8610.7	8785.0	8701.58
MEAN of B	9348.50	9351.08	9569.92	9743.25	
	CD 0.05				
A	308.854	** 1%			
B	308.854	* 5%			
AB	617.708	NS			

The data pertaining to stover yield presented in Table1.57 depicts significant effect on stover yield as a result of different levels of crop residue retention. The maximum stover yield (10252 kg ha^{-1}) was recorded in 90% crop residue retention level and significantly superior over 60% crop residue retention (9836 kg ha^{-1}), 30% crop residue retention (9223 kg ha^{-1}) and without residue retention treatment (8702 kg ha^{-1}). The different herbicidal weed control treatments has significant influence on stover yield and maximum stover yield (9743 kg ha^{-1}) was recorded under treatment post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing which was at par with post-emergence application of Tembotrione@180g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} (9570 kg ha^{-1}) and significantly superior over Tembotrione@120g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} as a pre-emergence (9349 kg ha^{-1}) andTembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} without hand weeding (9351 kg ha^{-1}). The stover yield as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.58 Effect of different levels of crop residue retention and herbicidal weed control treatments on total biomass yield in maize crop (kg ha^{-1})

	B1	B2	B3	B4	Mean of A
A1	17190	17100	17310	17520	17280
A2	15980	15850	16560	16830	16306
A3	14390	14500	15550	15850	15074
A4	13900	13760	13850	14190	13922
MEAN of B	15364	15303	15819	16097	
	CD 0.05				
A	425.3	** 1%			
B	425.3	** 1%			
AB	NS	NS			

The data pertaining to total biomass yield presented in table1.58 depicts significant effect on stover yield as a result of different levels of crop residue retention. The maximum stover yield (17280 kg ha^{-1}) was recorded in 90% crop residue retention level and significantly superior over 60% crop residue retention (16306 kg ha^{-1}), 30% crop residue retention (15074 kg ha^{-1}) and without residue retention treatment (13922 kg ha^{-1}). The different herbicidal weed control treatments has significant influence on stover yield and maximum stover yield (16097 kg ha^{-1}) was recorded under treatment post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing which was at par with post-emergence application of Tembotrione@180g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} (15819 kg ha^{-1}) and significantly superior over Tembotrione@120g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} as a pre-emergence (15364 kg ha^{-1}) andTembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} without hand weeding (15303 kg ha^{-1}). The stover yield as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.59 Effect of different levels of crop residue retention and herbicidal weed control treatments on harvest index (%) in maize crop

	B1	B2	B3	B4	Mean of A
A1	40.7	40.4	41.0	41.1	40.81
A2	40.2	39.8	38.9	39.8	39.66
A3	38.2	37.8	39.9	39.2	38.78
A4	37.1	37.0	37.8	38.1	37.48
MEAN of B	39.03	38.76	39.41	39.53	
	CD 0.05				
A	1.422	** 1%			
B	1.422	NS			
AB	2.844	NS			

The data pertaining to harvest index presented in table1.59 depicts significant effect on harvest index as a result of different levels of crop residue retention. The maximum harvest index (40.81%) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (39.66%) and significantly superior over 30% crop residue retention (38.78%) and without residue retention treatment (37.48%). In case of different herbicidal weed control treatments shows non-significant effect on the harvest index. The harvest index as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.60 Effect of different levels of crop residue retention and herbicidal weed control treatments on weed index (%) of maize crop

	B1	B2	B3	B4	Mean of A
A1	10.5	11.5	9.2	9.1	10.09
A2	17.9	19.2	17.5	14.4	17.23
A3	29.7	29.9	20.5	20.5	25.15
A4	34.1	34.9	33.0	30.9	33.21
MEAN OF B	23.04	23.86	20.06	18.72	
	CD 0.05				
A	3.843	** 1%			
B	3.843	* 5%			
AB	7.687	NS			

The data pertaining to weed index presented in table1.60 depicts significant effect on weed index as a result of different levels of crop residue retention. The maximum weed index (33.21) was recorded in without crop residue retention level and significantly higher over 30% crop residue retention (25.15), 60% crop residue retention (17.23) and 90% crop residue retention treatment (10.09). The different herbicidal weed control treatments have significant influence on weed index and the maximum weed index (23.86) was recorded under treatment Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} without hand weeding which was at par with Tembotrione@120g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} as a pre-emergence (23.04) and tembotrione@180g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} (20.06) and significantly higher over post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing (18.72). The weed index as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.61 Effect of different levels of crop residue retention and herbicidal weed control treatments on total weed biomass (kgha^{-1}) in maize crop

	B1	**B2**	**B3**	**B4**	**Mean of A**
A1	547	487	373	113	380.0
A2	600	580	380	173	433.3
A3	820	700	600	260	595.0
A4	1053	777	640	333	700.8
MEAN OF B	755.0	635.8	498.3	220.0	
	CD 0.05				
A	92.78	** 1%			
B	92.78	** 1%			
AB	185.57	NS			

The data pertaining to weed biomass presented in Table1.61 depicts significant effect on weed biomass as a result of different levels of crop residue retention. The maximum weed biomass (700.8 kg ha^{-1}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (595.0 kgha^{-1}), 60% crop residue retention (433.3kgha^{-1}) and 90% crop residue retention treatment (380.0kgha^{-1}). The different herbicidal weed control treatments has significant influence on weed biomass and maximum weed biomass (755.0kgha^{-1}) was recorded under treatment Tembotrione@120g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} as a pre-emergence and significantly higher weed biomass over post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} without hand weeding (635.8kgha^{-1}), post-emergence application of Tembotrione@180g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} (498.3kgha^{-1}) and post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing has lowest weed biomass(220.0kgha^{-1}). The weed biomass as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.62 Effect of different levels of crop residue retention and herbicidal weed control treatments on weed density at 30 DAS in maize (m^{-2}) in maize crop

	B1	**B2**	**B3**	**B4**	**Mean of A**
A1	16.7	68.0	70.7	70.7	56.50
A2	24.0	80.0	66.0	78.0	62.00
A3	47.3	99.3	98.7	98.0	85.83
A4	45.3	120.7	117.3	129.3	103.17
MEAN OF B	33.33	92.00	88.17	94.00	
	CD 0.05				
A	10.661	** 1%			
B	10.661	** 1%			
AB	21.321	NS			

The data pertaining to weed density at 30 DAS presented in table15 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (103.17 m^{-2}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (85.83 m^{-2}), 60% crop residue retention (62.00 m^{-2}) and 90% crop residue retention treatment (56.50 m^{-2}). The different herbicidal weed control treatments has significant influence on weed density and maximum weed density (94.00 m^{-2}) was recorded under treatment post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing which was at par with post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@ 625g a.i.ha^{-1} without hand weeding (92.00 m^{-2}), post-emergence application of Tembotrione@180g a.i.ha^{-1}+Atrazin @1000g a.i.ha^{-1} (88.17 m^{-2}).The lowest weed density has Tembotrione@120g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} as a pre-emergence (33.33 m^{-2}). The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.63 Effect of different levels of crop residue retention and herbicidal weed control treatments on weed density at harvest in maize (m^{-2}) in maize crop

	B1	B2	B3	B4	Mean of A
A1	64.0	42.7	30.7	13.3	37.67
A2	73.3	48.7	39.3	20.7	45.50
A3	100.0	62.0	54.0	30.7	61.67
A4	106.7	70.0	52.0	38.0	66.67
MEAN OF B	86.00	55.83	44.00	25.67	
	CD 0.05				
A	8.592	** 1%			
B	8.592	** 1%			
AB	17.184	NS			

The data pertaining to weed density at harvest presented in Table1.63 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (66.67 m^{-2}) was recorded in without residue retention level and which was at par with 30% crop residue retention (61.67 m^{-2}) and significantly higher over 60% crop residue retention (45.50 m^{-2}) and 90% crop residue retention treatment (37.67 m^{-2}). The different herbicidal weed control treatments has significant influence on weed biomass and maximum weed density (86.00 m^{-2}) was recorded under treatment Tembotrione@120g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} as a pre-emergence and significantly higher weed density over post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} without hand weeding (55.83 m^{-2}), post-emergence application of Tembotrione@180g a.i.ha^{-1}+Atrazin@1000g a.i.ha^{-1} (44.00 m^{-2}) and post-emergence application of Tembotrione@120g a.i.ha^{-1}+Atrazin@625g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing has lowest weed density (25.67 m^{-2}). The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Chickpea crop

Table 1.64 Effect of different levels of crop residue retention and herbicidal weed control treatments on plant height (cm) on chickpea crop at harvest

	B1	B2	B3	B4	Mean of A
A1	56.4	57.9	52.3	53.6	55.07
A2	56.3	58.3	50.9	52.3	54.47
A3	53.8	54.8	50.6	52.3	52.86
A4	51.8	52.8	48.8	49.4	50.69
Mean of B	54.58	55.94	50.64	51.93	
	CD 0.05				
A	0.921	** 1%			
B	0.921	** 1%			
AB	1.843	NS			

The data pertaining to plant height presented in table1.64 depicts significant differences in plant height as a result of different levels of crop residue retention. The maximum plant height (55.07cm) was recorded in A_1(90% crop residue retention) which was at par with A_2 (60% crop residue retention) and significantly superior over 30% residue level (52.86 cm) and without residue retention treatment (50.69 cm). The different herbicidal weed control treatments has significant influence on plant height and maximum plant height (55.94cm) was recorded under treatment B_2(pre-emergence application of Imazethapyr@ 50g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing) which was at par with treatment B_1 (54.58cm) with pre-emergence application of Imazethapyr @ 50g a.i. ha^{-1} alone. The minimum plant height (50.69 cm) was observed in treatment B_3 (post-emergence application of Imazethapyr@ 25g a.i. ha^{-1} +Clodinafop@60g a.i.ha^{-1}).The plant height as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.65 Effect of different levels of crop residue retention and herbicidal weed control treatments on Branches plant $^{-1}$ on chickpea crop at harvest

	B1	**B2**	**B3**	**B4**	**Mean of A**
A1	7.0	7.7	13.1	14.0	10.44
A2	6.6	7.1	12.7	13.3	9.92
A3	6.0	6.8	11.2	11.7	8.92
A4	5.6	6.6	10.7	11.2	8.50
Mean of B	6.28	7.03	11.92	12.56	
	CD 0.05				
A	0.422	** 1%			
B	0.422	** 1%			
AB	0.843	NS			

The data pertaining to branches plant^{-1}presented in Table1.65 shows significant difference in branches plant^{-1}as a result of different levels of crop residue retention. The maximum branches plant^{-1} (10.44) was recorded in 90% crop residue retention level and significantly superior over 60% crop residue retention (9.92),30% crop residue retention (8.92) and without residue retention treatment (8.50). In case of different herbicidal weed control treatments shows significant effect on the branches plant^{-1}. The maximum branches plant^{-1}(12.56) was recorded in B_4(Imazethapyr@25g a.i.ha^{-1} +Clodinafop@60g a.i.ha^{-1} as post-emergence followed by one hand weeding at 50 days after sowing) which was at par with B_3 (Imazethapy r@ 25g a.i. ha^{-1} +Clodinafop @ 60g a.i.ha^{-1} as post-emergence). The minimum branches plant^{-1} (6.28) was observed in B_1(Imazethapyr@50g a.i. ha^{-1}as pre-emergence). The branches plant^{-1} as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.66 Effect of different levels of crop residue retention and herbicidal weed control treatments on fresh weight (gm plant^{-1}) on chickpea crop at harvest

	B1	**B2**	**B3**	**B4**	**Mean of A**
A1	31.2	31.6	27.1	28.3	29.56
A2	30.7	30.7	26.7	27.0	28.75
A3	28.3	29.4	26.0	26.6	27.58
A4	25.7	25.0	23.0	23.6	24.31
Mean of B	28.97	29.17	25.69	26.36	
	CD 0.05				
A	3.409	* 5%			
B	3.409	NS			
AB	6.818	NS			

The data pertaining to fresh weight presented in Table 1.66 depicts significant effect on fresh weight as a result of different levels of crop residue retention. The maximum fresh weight (29.56 gm plant^{-1}) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (28.75 gm plant^{-1}) and 30% crop residue retention (27.58 gm plant^{-1}) and significantly superior over without residue retention treatment (24.31 gm plant^{-1}). In case of different herbicidal weed control treatments shows non-significant effect on the fresh weight. The fresh weight as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.67 Effect of different levels of crop residue retention and herbicidal weed control treatments on Dry weight (gm plant^{-1}) on chickpea crop at harvest

	B1	B2	B3	B4	Mean of A
A1	12.6	14.0	12.1	13.9	13.15
A2	12.0	13.7	11.9	13.7	12.81
A3	11.8	13.1	11.6	12.6	12.28
A4	10.5	11.1	10.3	11.4	10.83
MEAN of B	11.74	12.99	11.45	12.89	
	CD 0.05				
A	1.525	* 5%			
B	1.525	NS			
AB	3.050	NS			

The data pertaining to dry weight presented in Table 1.67 depicts significant effect on dry weight as a result of different levels of crop residue retention. The maximum dry weight (29.56 gm plant^{-1}) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (12.81gm plant^{-1}) and 30% crop residue retention (12.28 gm plant^{-1}) and significantly superior over without residue retention treatment (10.83 gm plant^{-1}). In case of different herbicidal weed control treatments has non-significant effect on the dry weight. The fresh weight as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.68 Effect of different levels of crop residue retention and herbicidal weed control treatments on No. of pod plant^{-1}on chickpea crop

	B1	B2	B3	B4	Mean of A
A1	48.4	52.3	48.0	48.3	49.28
A2	48.2	52.1	47.8	48.1	49.06
A3	42.9	47.7	41.1	46.4	44.53
A4	40.8	40.9	40.4	40.7	40.69
MEAN of B	32.19	35.29	31.19	35.01	
	CD 0.05				
A	1.475	** 1%			
B	1.475	** 1%			
AB	2.949	NS			

The data pertaining to pods plant^{-1}presented in Table 1.68 shows significant differences in pods plant^{-1}as a result of different levels of crop residue retention. The maximum pods plant^{-1} (49.28) was recorded in 90% crop residue retention which was at par with 60% crop residue retention and significantly superior over 30% residue level (44.53) and without residue retention treatment (40.69). The different herbicidal weed control treatments has significant influence on pods plant^{-1} and maximum pods plant^{-1} (35.29) was recorded under treatment pre-emergence application of Imazethapyr @ 50g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing which was at par with treatment Imazethapyr @ 25g a.i.ha^{-1} + Clodinafop @ 60g a.i.ha^{-1} as post-emergence followed by one hand weeding at 50 days after sowing (35.01). The minimum pods plant^{-1} (31.19) was observed in treatment post-emergence application of

Imazethapyr@25g a.i.ha^{-1}+Clodinafop @ 60g a.i.ha^{-1}at 30 DAS. The number of pod plant^{-1}as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.69 Effect of different levels of crop residue retention and herbicidal weed control treatments on Seed index on chickpea crop

	B1	B2	B3	B4	Mean of A
A1	15.1	15.2	15.0	15.0	15.08
A2	15.0	15.0	15.0	15.1	15.01
A3	14.9	14.9	14.9	15.0	14.92
A4	14.9	15.0	14.8	14.9	14.89
MEAN of B	14.96	15.02	14.93	14.97	
	CD 0.05				
A	0.246	NS			
B	0.246	NS			
AB	0.492	NS			

The data pertaining to seed index in Table 1.69 shows non-significant difference in seed index as a result of different levels of crop residue retention. In case of different herbicidal weed control treatments shows non-significant effect on seed index. The number of pod plant^{-1}as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.70 Effect of different levels of crop residue retention and herbicidal weed control treatments on Grain yield on chickpea crop

	B1	B2	B3	B4	Mean of A
A1	1124.1	1414.5	1068.7	1216.0	1112.75
A2	1118.4	1335.5	1005.2	1001.0	1108.84
A3	1000.2	1193.3	999.3	1006.4	1063.64
A4	920.1	961.1	903.4	956.8	970.01
MEAN of B	1040.69	1226.09	994.13	1045.07	
	CD 0.05				
A	181.609	* 5%			
B	181.609	NS			
AB	363.218	NS			

The data pertaining to grain yield presented in Table 1.70 depicts significant effect on grain yield as a result of different levels of crop residue retention. The maximum grain yield (1112.75kgha^{-1}) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (1108.84 kg ha^{-1}) and 30% crop residue retention (1063.64 kgha^{-1}) and significantly superior over without residue retention treatment (970.01 kgha^{-1}). In case of different herbicidal weed control treatments shows non-significant effect on the grain yield. The grain yield as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.71 Effect of different levels of crop residue retention and herbicidal weed control treatments on straw yield on chickpea crop (kgha^{-1})

	B1	B2	B3	B4	Mean of A
A1	1641.4	2023.3	1574.4	1763.8	1750.70
A2	1649.5	1914.6	1461.0	1443.2	1617.06
A3	1461.1	1707.6	1493.7	1468.7	1532.77
A4	1374.6	1410.5	1387.1	1450.4	1405.67
MEAN of B	1531.64	1763.98	1479.05	1531.54	
	CD 0.05				
A	256.785	NS			
B	256.785	NS			
AB	513.571	NS			

The data pertaining to straw yield (kgha^{-1}) in Table 1.71 shows non-significant difference in straw yield as a result of different levels of crop residue retention. In case of different herbicidal weed control treatments shows non-significant effect on straw yield. The straw yield as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.72 Effect of different levels of crop residue retention and herbicidal weed control treatments on total biomass (kgha^{-1}) on chickpea

	B1	B2	B3	B4	Mean of A
A1	2765.4	3437.8	2643.0	2979.8	2956.51
A2	2767.9	3250.0	2466.2	2444.2	2732.08
A3	2461.4	2900.9	2493.0	2475.1	2582.57
A4	2294.7	2371.6	2290.5	2407.3	2341.02
MEAN of B	2572.34	2990.07	2473.17	2576.61	
	CD 0.05				
A	436.931	* 5%			
B	436.931	NS			
AB	873.862	NS			

The data pertaining to total biomass (kgha^{-1}) presented in Table1.72 depicts significant effect on total biomass as a result of different levels of crop residue retention. The maximum total biomass (2956.51 kgha^{-1}) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (2732.08 kgha^{-1}) and 30% crop residue retention (2582.57 kgha^{-1}) and significantly superior over without residue retention treatment (2341.02 kgha^{-1}). In case of different herbicidal weed control treatments has non-significant effect on the total biomass. The total biomass as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.73 Effect of different levels of crop residue retention and herbicidal weed control treatments on harvest index (%) on chickpea crop

	B1	B2	B3	B4	Mean of A
A1	34.3	35.0	33.9	34.5	34.43
A2	34.0	34.7	34.2	34.4	34.32
A3	33.8	34.5	33.4	34.2	34.00
A4	33.3	34.0	32.6	33.0	33.22
MEAN of	33.85	34.57	33.54	34.02	

B					
	CD 0.05				
A	0.903	* 5%			
B	0.903	NS			
AB	1.806	NS			

The data pertaining to harvest index (%) presented in Table1.73 depicts significant effect on total biomass as a result of different levels of crop residue retention. The maximum harvest index (34.43%) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (34.32%) and 30% crop residue retention (34.00%) and significantly superior over without residue retention treatment (33.22%). In case of different herbicidal weed control treatments has non-significant effect on the harvest index. The harvest index as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.74 Effect of different levels of crop residue retention and herbicidal weed control treatments on weed index (%) in chickpea crop

	B1	**B2**	**B3**	**B4**	**Mean of A**
A1	39.2	23.5	42.2	34.3	34.82
A2	39.5	27.8	45.7	45.9	39.73
A3	45.9	35.5	46.0	45.6	43.25
A4	50.3	48.0	51.2	48.3	49.44
MEAN of B	43.75	33.72	46.26	43.51	
	CD 0.05				
A	9.817	* 5%			
B	9.817	NS			
AB	19.633	NS			

The data pertaining to weed index presented in table1.74 depicts significant effect on weed index as a result of different levels of crop residue retention. The maximum weed index (49.44%) was recorded in without crop residue retention level and which was at par with 30% crop residue retention (43.25%) and significantly higher over 60% crop residue retention (39.73%) and 90% crop residue retention treatment (34.82%). In case of different herbicidal weed control treatments shows non-significant effect on weed index. The weed index as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.75 Effect of different levels of crop residue retention and herbicidal weed control treatments on Weed biomass (kgha^{-1}) in chickpea crop

	B1	**B2**	**B3**	**B4**	**Mean of A**
A1	1017.8	400.0	488.0	382.2	572.00
A2	1382.2	535.1	661.8	440.0	754.78
A3	1568.9	543.1	795.1	478.7	846.44
A4	1792.9	762.2	901.8	749.8	1051.67
MEAN of B	1440.44	560.11	711.67	512.67	
	CD 0.05				
A	132.883	** 1%			
B	132.883	** 1%			
AB	265.766	NS			

The data pertaining to weed biomass presented in table1.75 depicts significant effect on weed biomass as a result of different levels of crop residue retention. The maximum weed biomass (1051.67 kg ha^{-1}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (846.44kg ha^{-1}), 60% crop residue retention (754.78kg ha^{-1}) and 90% crop residue retention treatment (572.00kg ha^{-1}). The different herbicidal weed control treatments have significant influence on weed biomass and maximum weed biomass (1440.44kg ha^{-1}) was recorded under treatment Imazethapyr @ 50 g a. i. ha^{-1} (as pre-em) and significantly higher weed biomass over post-emergence application of treatment Imazethapyr @25g a.i.ha^{-1} + Clodinafop @ 60g a.i.ha^{-1} (711.67kgha^{-1}), post-emergence application of pre-emergence application of Imazethapyr@50g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing (560.11kgha^{-1}) and post-emergence application of Imazethapyr @ 25g a.i.ha^{-1} + Clodinafop @ 60g a.i. ha^{-1} as post-emergence followed by one hand weeding at 50 days after sowing has lowest weed biomass(512.67 kg ha^{-1}). The weed biomass as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.76 Effect of different levels of crop residue retention and herbicidal weed control treatments on Weed density in chickpea at 30 DAS (m^{-2})

	B1	B2	B3	B4	Mean of A
A1	18.7	20.0	64.0	62.7	41.35
A2	34.0	36.0	90.0	108.0	67.00
A3	53.3	55.3	121.3	117.3	86.83
A4	77.3	86.0	156.0	160.7	120.00
MEAN OF B	45.83	49.33	107.83	112.17	
	CD 0.05				
A	9.705	** 1%			
B	9.705	** 1%			
AB	19.410	NS			

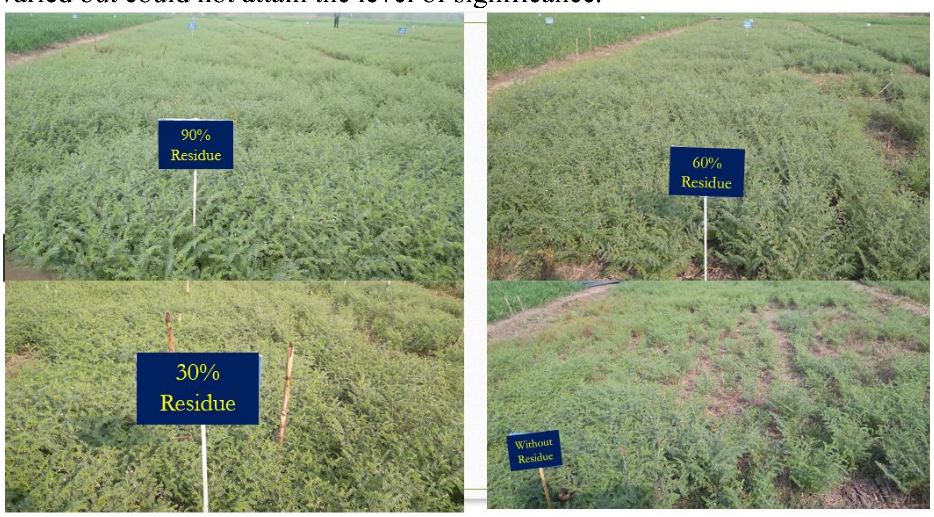
The data pertaining to weed density at 30 DAS presented in Table1.76 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (120.00m^{-2}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (86.83m^{-2}) ,60% crop residue retention (67.00m^{-2}) and 90% crop residue retention treatment (41.35m^{-2}). The different herbicidal weed control treatments have significant influence on weed density and maximum weed density (112.17 m^{-2}) was recorded under treatment pre-emergence application of Imazethapyr @ 50g a.i. ha^{-1} followed by one hand weeding at 50 days after sowing and which was at par with post-emergence application of treatment Imazethapyr @ 25g a.i. ha^{-1} + Clodinafop @ 60g a.i. ha^{-1}(107.83 m^{-2}) and significantly higher weed density over Imazethapyr @ 50 g a.i. ha^{-1} (as pre-em) followed by one hand weeding at 50 days after sowing(49.33m^{-2}) and Imazethapyr @ 50 g a.i. ha^{-1} as a pre-emergence (45.83m^{-2}). The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.

Table 1.77 Effect of different levels of crop residue retention and herbicidal weed control treatments on Weed density in chickpea at harvest (m^{-2})

	B1	B2	B3	B4	Mean of A
A1	66.7	15.3	27.3	14.0	30.83
A2	81.3	16.7	31.3	16.0	36.33
A3	100.7	25.3	50.7	26.0	50.67
A4	141.3	34.7	69.3	36.7	70.50
MEAN OF B	97.50	23.00	44.67	23.17	

	CD 0.05				
A	6.846	** 1%			
B	6.846	** 1%			
AB	13.692	** 1%			

The data pertaining to weed density at harvest presented in Table1.77 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (70.50m^{-2}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (50.67m^{-2}) ,60% crop residue retention (36.33m^{-2}) and 90% crop residue retention treatment (30.83m^{-2}).The different herbicidal weed control treatments have significant influence on weed density and maximum weed density (97.50 m^{-2}) was recorded under treatment Imazethapyr @ 50 g a.i. ha^{-1} (as pre-em) and significantly higher weed density over post-emergence application of treatment Imazethapyr@25g a.i.ha^{-1} +Clodinafop@60g a.i.ha^{-1}(44.67 m^{-2}), pre-emergence application of Imazethapyr@50g a.i.ha^{-1} followed by one hand weeding at 50 days after sowing (23.00 m^{-2}) and post-emergence application of Imazethapyr@25g a.i.ha^{-1} +Clodinafop@60g a.i.ha^{-1} as post-emergence followed by one hand weeding at 50 days after sowing has lowest weed density (23.17 m^{-2}). The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments varied but could not attain the level of significance.



3. Nutrient Management
CRIDA
Nutrient Management as complementary practice in rainfed Conservation agriculture systems

Nutrient management as complimentary practice along with CA on various rainfed cropping systems was evaluated in different cropping systems.

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. In Initial two years there was no significant difference among the tillage treatments in maize and pigeonpea system. After 9 years ZT recorded significantly higher yield as compared to CT and RT in both pigeonpea and maize crops.

This year pigeonpea crop was sown. Both tillage practices and nitrogen management did not influence the seed germination of pigeonpea crop. An increase of 24.1 and 12.8 % higher pigeonpea seed yield was recorded in ZT and RT over CT, respectively and about 10.1% higher seed yield was recorded in ZT as compared to RT. The nitrogen levels enhanced the seed yield significantly. The % increase in yields with 75,100 and 125 % RDF was 163.0, 204.8 and 231.6% over 0 levels respectively (Fig1.61). The interaction of tillage and nitrogen levels was found to be significant. Significantly higher pigeonpea seed yield recorded in NT-N125% treatment as compared to the other treatment combinations (Fig 1.62).

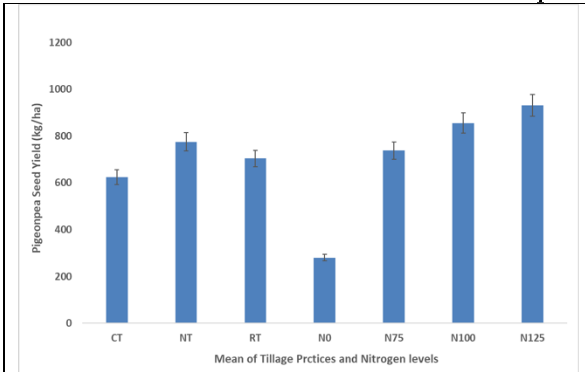


Fig1.61 Mean effect of tillage practices and nitrogen levels on pigeonpea seed yield (kg/ha).

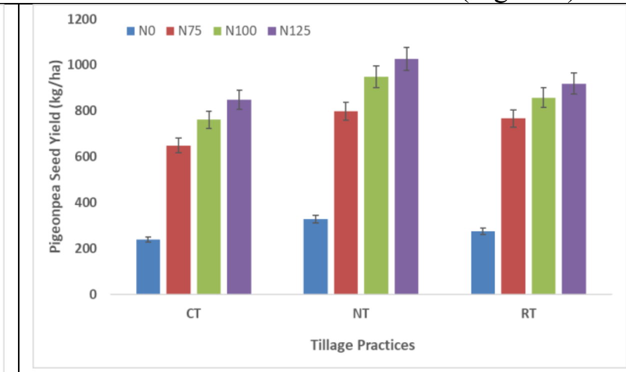


Fig1.62 Interactive effect of tillage practices and nitrogen levels on pigeonpea seed yield (kg/ha).

1. Horsegram- pearlmillet

A field experiment was conducted every year since 2016 in sandy loam soil of Gunegal Research Farm at ICAR-Central Research Institute for Dryland Agriculture (ICAR-CRIDA), Hyderabad to study the impact of different fertilizer levels with CA as complimentary practice CA (ZT- no till, direct seeded with residue retention), minimum tillage (MT- One ploughing, sowing with residue retention) and conventional tillage (CT- two ploughing with disk plough, one harrowing and sowing) as main plots and 75% RDF, 100% RDF (Pearl millet: 80-40-30 kg N, P_2O_5, K_2O ha^{-1}, on residual fertility, Pigeon pea: 20-50-0 kg N, P2O5, K2O ha-1) and 125% RDF as subplots, to study the effect of tillage practices and different doses of fertilizers on performance of pearlmillet (MP MH21) and horsegram (CRHG 4). Short duration (75-80 days) pearlmillet (MP MH21) was selected to take the advantage of early sowing of horsegram. Pearl millet was sown at a spacing of 45 × 12 cm, and horsegram at 30x10cm.

Significantly higher pearlmillet grain yield was observed in MT (2361 kg/ha) compared to ZT and CT. Higher yield was observed in 125% RDF (2348 kg/ha). Pooled data of 5 years (2016-2020) revealed that significantly higher pearlmillet equivalent yields were obtained in minimum tillage (MT) with 125% RDF compared to zero tillage (ZT) and conventional tillage (CT) (Fig. 1.63).

The percent residue cover was recorded. In general residue cover decreased gradually with increased number of days after harvesting of pigeonpea (Fig. 1.64). Among the various tillage treatments significantly higher percent residue cover was observed in MT over ZT and CT at all DAH of pigeonpea except at 45 DAH where higher per cent of residue cover was observed in MT which was on a par with ZT and significantly superior to CT. At 45 DAH the residue cover percentage was significantly higher with 125 % RDF over 75 % RDF and it was statistically on par with 100 % RDF. At 60 DAH significantly higher residue cover percentage was recorded with 75 % RDF over 100 and 125 % RDF. At 75 and 90 DAH higher residue cover percentage was observed in 125 % RDF over 100 and 75 % RDF.

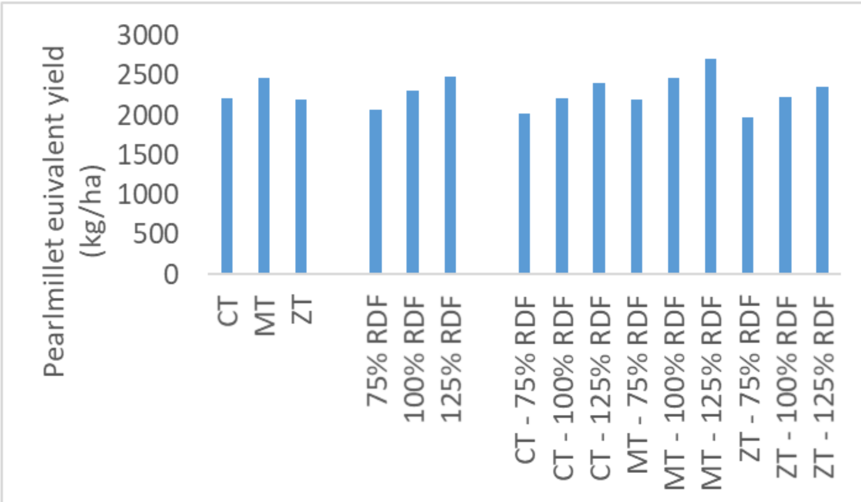


Fig 1.63 Effect of tillage and different fertilizer doses on pearlmillet equivalent yield

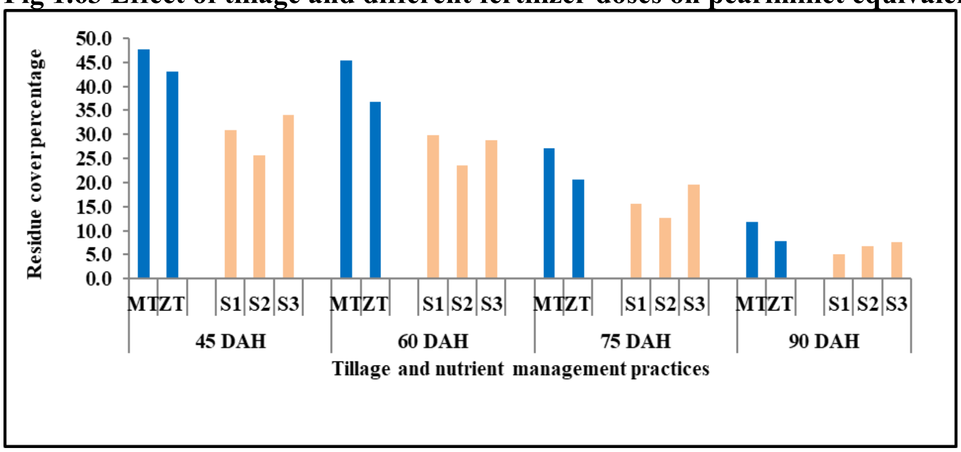


Fig 1.64 Effect of tillage and nutrient management practices on residue cover percentage at different days

Fig 1.65 Pearl millet crop growth in various treatments

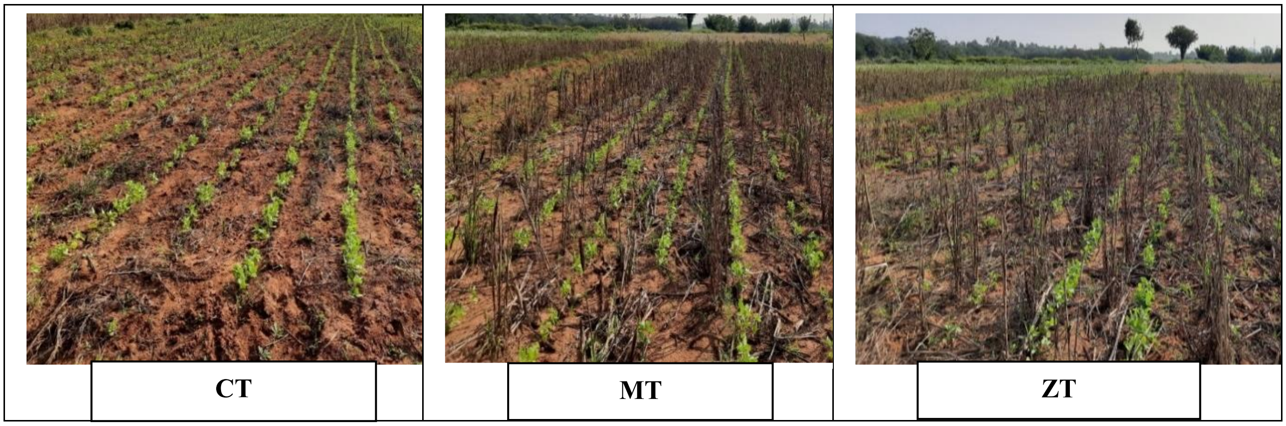


Fig 1.66 Horsegram under different tillage and residue cover

4. Water Management

1. Setaria-Blackgram Crooping System

Table 1.78 Effect of Different Moisture Conservation Methods on yield and returns in Bengalgram

Observations	Yield kg/ha	Cost of Cultivation Rs/ha	Gross Income Rs/ha	Net Income Rs/ha	C:B ratio
1.FP (30x10 cm)	1637	39376	79394	40018	2.01
2.Row to row distance 30 cm. Formation of channel between two rows.	1867 (14.0%)	37875	90549	52674	2.40
3. Row to row distance 35 cm.,formation of channel after 3 rows.	1970 (20.3%)	37875	95545	57670	2.52

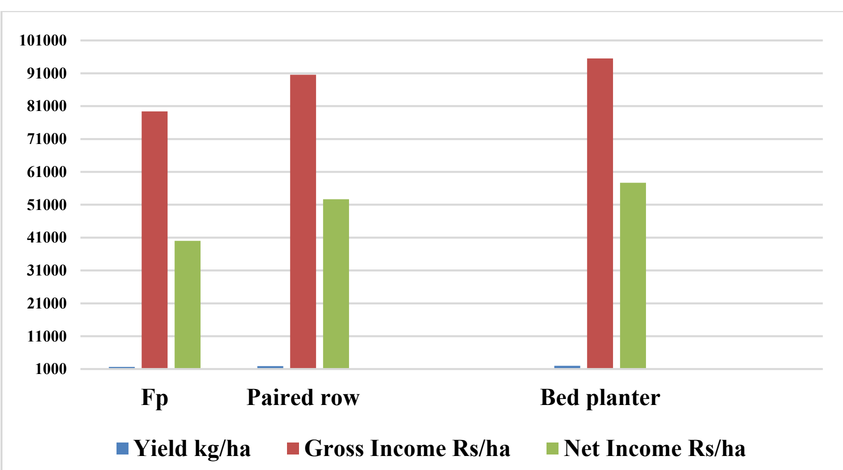


Fig 1.67 Effects of Different Moisture Conservation Methods in Bengalgram

Fig 1.68 Crop growth of bengalgram under raised bed and permanent row method

In Bengal gram higher yield was recorded in raised bed and furrow system (1970 kg/ha) followed by paired row (1867 kg/ha) and farmer practice (1637 kg/ha) (Table.1.78 & **Fig 1.67**). Raised bed and furrow recorded higher gross income (95545 Rs/ha), net income (57670 kg/ha) and C:B ratio (2.52) whereas farmer practice recorded lower gross income (79394 kg/ha), net income (40018 kg/ha) and C:B ratio (2.01)

Table 1.79 Cultivation of Bengal gram with minimum tillage after Redgram+setaria intercrop

Particulars	**Yield kg/ha**	**Cost of cultivation Rs/ha**	**Gross income Rs/ha**	**Net income Rs/ha**	**Additional income Rs/ha**
Redgram+setaria - Bengalgram	712 (Bengal gram equivalent yield)	40370	101319	60949	20579
Redgram+Setaria	394.8 (setaria equivalent yield)	33450	73820	40370	

New cropping system was introduced in Kurnool district. In setaria + redgram system (8:2) row ratio after harvest of setaria bengalgram was sown in zero tillage. This system recorded higher equivalent yield, and an additional returns of Rs 20,759 /ha. (Table 1.79).

Fig 1.69 Crop growth under Redgram setaria inter crop

2. Maize- Pigeonpea system

CRIDA

An experiment was initiated with the integration of in-situ moisture conservation with CA practice in maize-pigeonpea system in 2014. In first year 2014 maize crop was sown as test crop whereas pigeon pea was taken as test crop in 2015. These two crops were rotated. The experiment was laid out in RBD with different treatments (Conventional tillage without residues (CT), conventional tillage with residues (CTR), conventional tillage formation of raised bed every year CTRB), conventional planting with conservation furrow (CTCF), CA, permanent raised bed reshaping every year with residues (PRB), CA+ conservation furrows (CACF) reshaped every year). The bed and furrows and conservation furrow were reshaped at the time of sowing in zero tillage, whereas in conventional method, furrows and beds were prepared every year before sowing with the implements. CT recorded lowest yields. Integration of in-situ moisture conservation practices either through conservation furrow or bed and furrow method in both CA and CT has recorded higher yield as compared to no moisture conservation treatments in both the crops. Among the in situ moisture conservation treatments CACF recorded higher yields (Fig 1.70). The higher yields in moisture conservation treatments were due to higher retention of soil moisture as compared to no moisture conservation.

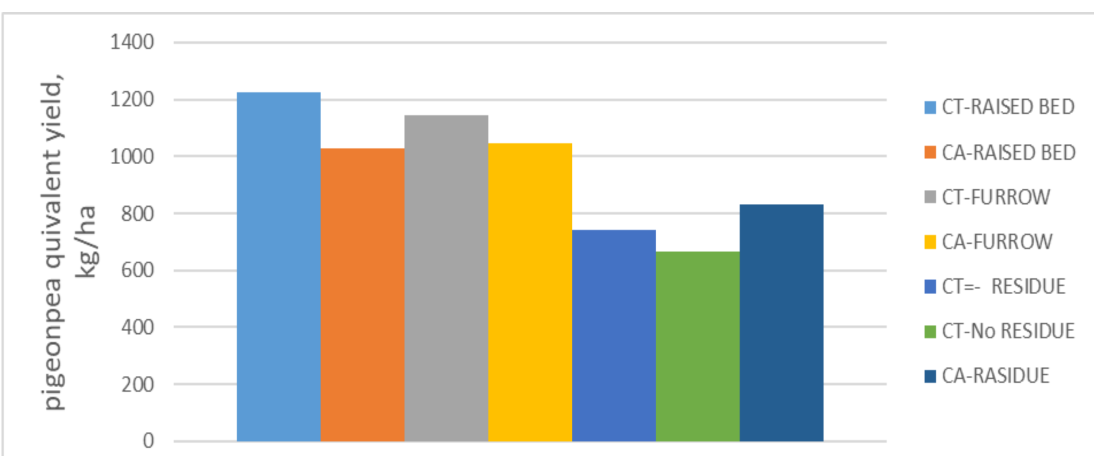


Fig 1.70 Impact of different in situ moisture conservation on pigeonpea seed yield

3. Soyabean - Wheat Cropping System

IISS

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

A field experiment on soybean-wheat cropping system was initiated in 2018 to evaluate the performance of different irrigation, tillage and nutrient management packages and to identify the most suitable irrigation and nutrient management package for conservation agriculture in Vertisols of central India. During the *kharif* season soybean (cv. RVS 2001-4) was grown with three fertilizer management treatments viz. 100% RDF (Recommended dose of fertilizer), 75% RDF, STCR (Soil test crop response) and three tillage treatments viz. CT-Conventional tillage, RT-Reduced tillage and NT- No tillage. During the *rabi* season wheat (cv. HI 1544) was grown with three irrigation methods (Flood, Sprinkler and Drip irrigation), three tillage management treatments (CT, RT and NT) and four levels of fertilizer treatments (100% RDF, 75% RDF, STCR and Leaf colour chart based fertilizer management, LCC). Measured amount of irrigation water was applied in each of the irrigation treatment plots. Temporal variations of soil water content in the profile and soil temperature at 5 and 15-cm soil depth were monitored. Experiment was laid on a split-split plot design where, irrigation method was kept in the main plot; tillage management was in the sub-plot and fertilizer dose treatment was put in the sub-sub plot level. Observations on crop growth parameters, seed yield and yield parameters for both the *kharif* and *rabi* season crops were monitored at regular interval to evaluate the impact of different treatments on crop performance.

Performance of wheat grown during the *rabi* season of 2020-21 and soybean grown during the *kharif* season of 2021 are presented below:

Wheat (2020-2021)

Wheat was sown during the first week of November, 2020 and harvested during the 3rd week of March, 2021. Among the irrigation treatments, flood irrigated plots received 5 post sowing irrigations and a seasonal total of 314 mm water was applied. In sprinkler irrigation plots a measured total amount of 251 mm water (about 80% of the flood irrigation) was applied through micro sprinklers at twice a week interval, while in drip irrigation treatment a seasonal total of 188 mm of irrigation water (about 60% of the flood irrigation water) was applied through drip system at alternate day interval throughout the season. Thus, in sprinkler and drip systems a better temporal distribution of irrigation water could be attained with less but more frequent irrigation water application to wheat. Plant growth parameters like, plant height, tiller numbers, root weight, leaf area index etc., crop yield attributes like, straw yield, grain yield, harvest index; and soil temperature at 5 and 15 cm soil depths were recorded. Besides this, water use efficiency was also calculated. Perusal of data showed that, the plant height, plant tiller number, root weight per tiller, grain yield, straw yield of wheat and soil temperature did not vary significantly among the irrigation, tillage and fertilizer treatments (Table 1.80, 1.81 and 1.83). However, leaf area index measured at 45 DAS was found to be significantly higher in sprinkler and drip irrigations compared to that in flood irrigation. Similarly, water use efficiency (WUE) was significantly higher under drip irrigation than the sprinkler and flood irrigation. The WUE was lowest under flood irrigation which was significantly lower than that under sprinkler irrigation (Table 1.82).

Table 1.80 Effect of irrigation methods, tillage systems and nutrients doses on temporal variation of plant height and tillers numbers per plant of wheat

Treatment	**Plant height (cm)**			**Number of tillers/plant**	
	30 DAS	**60 DAS**	**90 DAS**	**45 DAS**	**60 DAS**
Irrigation methods					
Flood	16.6	41.1	71.5	3.8	4.4
Sprinkler	17.5	40.9	75.2	4.1	4.6
Drip	17.0	41.7	76.1	3.7	4.6

LSD (0.05)	NS	NS	NS	NS	NS
Tillage systems					
CT	17.3	40.9	73.8	3.8	4.5
RT	16.6	41.7	74.1	3.9	4.6
NT	17.1	41.2	74.9	3.9	4.6
LSD (0.05)	NS	NS	NS	0.58	NS
Nutrients Doses					
100% RDF	16.9	40.4	74.4	3.5	4.7
75% RDF	17.0	41.2	74.5	4.0	4.5
STCR Dose	17.3	41.4	72.9	4.2	4.6
75% RDF +25% LCC	16.9	42.0	75.2	3.8	4.2
LSD (0.05)	NS	NS	NS	NS	NS

Table 1.81 Effect of irrigation methods, tillage systems and nutrients doses on root weight of wheat (g/m^2) at 30, 60 and 90 days after sowing (DAS) and leaf area index (LAI) of wheat at 45 DAS

Treatment	**Root weight (g/m^2)**			**LAI (45 DAS)**
	30 DAS	**60 DAS**	**90 DAS**	
Irrigation methods				
Flood	19	126	386	2.8
Sprinkler	21	142	455	3.3
Drip	19	123	407	3.2
LSD (0.05)	NS	NS	NS	0.01
Tillage systems				
CT	19	152	372	3.3
RT	19	130	471	2.9
NT	19	109	407	3.1
LSD (0.05)	NS	NS	NS	0.10
Nutrients Doses				
100% RDF	21	135	445	3.0
75% RDF	21	121	401	3.1
STCR Dose	19	133	415	3.1
75% RDF +25% LCC	19	131	400	3.1
LSD (0.05)	NS	NS	NS	NS

Table 1.82 Effect of irrigation methods, tillage systems and nutrients doses on grain yield, straw yield, harvest index and water use efficiency of wheat crop

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest Index (%)	Water Use efficiency (kg ha^{-1} cm^{-1})
Irrigation methods				
Flood	5026	5786	0.46	12.3
Sprinkler	4893	5731	0.46	13.7

Drip	4964	5849	0.47	16.8
LSD (0.05)	NS	NS	NS	0.72
Tillage systems				
CT	5054	5799	0.46	14.6
RT	4903	5720	0.45	14.1
NT	4927	5848	0.48	14.2
LSD (0.05)	NS	NS	NS	NS
Nutrients Doses				
100% RDF	5091	5628	0.47	13.9
75% RDF	4921	5857	0.49	14.3
STCR Dose	4854	5861	0.44	14.6
75% RDF +25% LCC	4977	5811	0.46	14.2
LSD (0.05)	NS	NS	NS	NS

Table 1.83 Effect of irrigation methods, tillage systems and nutrients doses on diurnal variation of soil temperature in 0-5 and 5-15 cm soil depth

Treatment	**Soil temperature (^{0}C) (30 DAS)**			
	7 am		**2 pm**	
	Surface (0-5 cm)	**Sub-Surface (5-15)**	**Surface (0-5 cm)**	**Sub-Surface (5-15)**
Irrigation methods				
Flood	17.4	18.4	24.1	23.0
Sprinkler	17.5	18.6	23.2	22.0
Drip	17.5	18.5	23.1	22.0
LSD (0.05)	NS	NS	NS	NS
Tillage systems				
CT	17.4	18.4	23.7	22.5
RT	17.3	18.4	23.5	22.5
NT	17.7	18.7	23.1	21.9
LSD (0.05)	NS	NS	NS	NS
Nutrients Doses				
100% RDF	17.5	18.4	23.4	22.4
75% RDF	17.4	18.6	23.5	22.3
STCR Dose	17.4	18.4	23.5	22.4
75% RDF +25% LCC	17.5	18.6	23.4	22.2
LSD (0.05)	NS	NS	NS	NS

Fig 1.71 Wheat crop grown under flood, sprinkler and drip irrigation system

Soybean (2021)

During the rainy season of 2021, a field experiment on soybean crop was conducted. Soybean (cv. JS-2029) was sown on June 28, 2021 and harvested on October 14, 2021. Observation on crop growth and yield parameters were recorded during the crop season. Grain and straw yield of soybean did not vary significantly among the tillage and nutrient treatments (Table 5). Soybean crop growth was good but the seed yield was low during the year due to heavy rainfall induced poor pod filling during the later stage. Plant height measured at 30 and 60 DAS, root and shoot weight and diurnal variation of soil temperature during the maximum vegetative stage are depicted through Table 6, 7 and 8. At 30 DAS the plant height in RT was significantly higher than CT and NT and was also significantly higher in STCR compared to 75% RDF. However the difference in crop height was not significant at 60 DAS.

Table 1.84 Effect of tillage systems and nutrients doses on grain and straw yield of soybean

	Soybean grain yield (kg ha^{-1})				Soybean straw yield (kg ha^{-1})			
	100% RDF	75% RDF	STCR	Mean	100% RDF	75% RDF	STCR	Mean
CT	604	643	654	634	3016	2979	2954	2983
RT	654	604	686	648	3221	3055	3599	3292
NT	620	565	587	590	2771	2615	2854	2747
Mean	626	604	642		3002	2883	3136	
	Tillage : NS, Nutrient Dose: NS, Tillage x Nutrient: NS				Tillage : NS, Nutrient Dose : NS, Tillage x Nutrient: NS			

Table 1.85 Effect of tillage systems and nutrients doses on plant height of soybean

	Plant height (cm)							
	30 DAS				60 DAS			
	100% RDF	75% RDF	STCR	Mean	100% RDF	75% RDF	STCR	Mean
CT	21.0	20.6	22.3	21.3	47.7	52.0	51.3	50.3
RT	22.7	23.0	24.3	23.3	48.3	50.0	55.3	51.2
NT	20.7	18.3	21.0	20.0	44.3	44.3	46.0	44.9
Mean	21.4	20.7	22.5		46.8	48.8	50.9	
	Tillage : 1.23, Nutrient Dose: 1.23, Tillage x Nutrient dose : NS				Tillage : NS, Nutrient Dose: NS, Tillage x Nutrient dose : NS			

Table 1.86 Effect of tillage systems and nutrients doses on shoot and root weight (g/plant) of soybean

	Shoot weight (g/plant)				Root weight (g/plant)			
	100% RDF	75% RDF	STCR	Mean	100% RDF	75% RDF	STCR	Mean
CT	9.7	11.7	11.6	11.0	2.4	2.2	2.6	2.4
RT	11.2	10.0	10.2	10.5	2.0	2.2	2.2	2.1
NT	9.7	8.6	11.0	9.7	1.8	1.6	2.2	1.9
Mean	10.2	10.1	10.9	10.2	2.1	2.0	2.3	
	Tillage : NS, Nutrient: NS, Tillage x Nutrient: NS				Tillage : 134, Nutrient: NS , Tillage x Nutrient: NS			

Table 1.87 Effect of tillage systems and nutrients doses on soil temperature at 0-5 and 5-15 cm soil depth

	Soil Temperature (^{O}C) (0-5 cm)							
	7AM				2PM			
	100% RDF	75% RDF	STCR	Mean	100% RDF	75% RDF	STCR	Mean
CT	18.2	18.9	17.9	18.3	37.8	37.3	37.9	37.7
RT	19.5	20.3	20.2	20.0	38.1	37.0	35.9	37.0
NT	19.8	20.6	19.8	20.0	36.8	33.0	36.3	35.3
Mean	19.1	19.9	19.3		37.6	35.8	36.7	
	Tillage : NS, Nutrient: NS, Tillage x Nutrient: NS				Tillage : NS, Nutrient: NS , Tillage x Nutrient: NS			
	Soil Temperature (^{O}C) (5-15 cm)							
	7AM				2PM			
	100% RDF	75% RDF	STCR	Mean	100% RDF	75% RDF	STCR	Mean

CT	19.4	20.3	21.3	20.3	27.2	27.5	27.6	27.4
RT	20.8	21.4	21.6	21.3	27.4	27.5	26.8	27.3
NT	21.2	21.3	21.1	21.2	27.0	26.5	26.8	26.8
Mean	20.4	21.0	21.3		27.2	27.2	27.1	
	Tillage : NS, Nutrient Dose: NS, Tillage x Nutrient: NS				Tillage : NS, Nutrient Dose: NS , Tillage x Nutrient: NS			

Fig 1.72 Sowing of soybean and crop growth under different tillage system

NIASM
New research initiatives:

Responses of growth regulators, crop residue and micro-irrigation for alleviating water stress in sugarcane cropping system

Water stress is most encountered abiotic stress in sugarcane owing to its longer duration and high water demand. Therefore, a new field experiment was initiated to study the interactive responses of plant growth regulators (PGRs), crop residues and micro-irrigation for alleviating water in sugarcane (Co-86032) during the year 2021 (Fig 1.73). The main treatments consisting of three water stress levels viz., I1: 50% DI; I2: 75%DI and I3: 100% (full irrigation) were applied using sub surface drip irrigation system during cropping period. Two soil surface cover management practices *viz.,* S1: Intercrop (chickpea) residue covering and S2: no residue was accommodated in subplots. Four PGRs namely thiourea (TU, 1800 ppm), irradiated chitosan (IC, 5 ml/L), nano-urea (4 ml/L), salicylic acid (SA, 25 μM) and no PGRs (control) were applied exogenously with interval of one month after crop establishment (60 DAT) as sub-sub plot treatments. The real time crop-soil-water parameters measurements are under process.

Fig 1.73 Overview of the experimental plot

Objective 2: Quantification of tangible and non tangible effects

1. Physical Property

A. Mean Weight Diameter (MWD)

Maize-Wheat Cropping System: Soil health was assessed under 11 years old conservation agriculture experiment with rice-wheat cropping system at ICAR-Indian Agricultural Research Institute (IARI) farm from six treatments at 0-5 and 5-15 cm depth. After ten year of cropping, it was observed that under CA practices there was improvement in the mean weight diameter (MWD) of soil at 0-5, 5-15 and 15-30 cm soil depth by 37.3, 31.2 and 54.2%, respectively (Table 2.1). Among the CA systems retention of crop residues could improve the MWD at 0-5 cm soil depth by 14.5. Among the CA practices i.e. zero tilled flatbed, zero tilled permanent broad bed and zero tilled permanent narrow bed system, the permanent narrow bed system with residue retention registered highest MWD at 0-5 cm soil depth.

Table 2.1 Mean weight diameter (mm) under conservation and conventional agriculture practices at 0-5, 5-15 and 15-30 cm soil depth after wheat 2020-21

Treatment	MWD (mm)			
	0-5 cm	5-15 cm	15-30 cm	Mean
Zero tillage (ZT)	0.75	0.88	0.80	0.62
ZT + Residue	0.93	0.87	0.87	0.81
Broad bed (BB)	0.78	0.70	0.77	0.89
BB + Residue	0.89	0.70	0.87	0.75
Narrow bed (NB)	0.88	0.93	0.77	0.82
NB + Residue	0.94	0.91	0.85	0.86
Flat Bed	0.67	0.63	0.56	0.90
Mean	0.83	0.80	0.78	0.81

To quantifies soil aggregation among different tillage and cropping system, soil samples at different depths were analysed for MWD (Fig 2.1) at ICAR-IISS, Bhopal under soybean-wheat cropping system. The statistical analysis shows that tillage system had a significant impact on MWD after crop cycles. The mean value varied from 1.34 to 1.48 mm for 0-10 and 10-20 cm soil depth. General trends showed that MWD decreases with increases in soil depth under different tillage system and nutrient doses. The highest value of MWD (1.56 mm) was observed under T2 (No Tillage with 60 cm residue height) at 0-10 and T3 and T4 (RT with 30 and 60 cm residue height) at 10-20 cm soil depth. Minimum value of MWD was observed under T5 (Conventional tillage) at 0-10 and 10-20 cm soil depths (1.13 and 1.20 mm). The effect of nutrient management treatment on MWD was non-significant at different depth of soil. The highest value of MWD was obtained under N3 (STCR) at 0-10 cm depth (1.43 mm) and under N2 (N 100% RDF) at 10-20 cm soil depth (1.36 mm). Minimum value was found (1.33 mm) under N2 at 0-10 cm depth. Further, the interaction effect of tillage system x nutrient dose, tillage system x depth, nutrient dose x depth and tillage system x nutrient dose x depth were not shown significant effect on MWD.

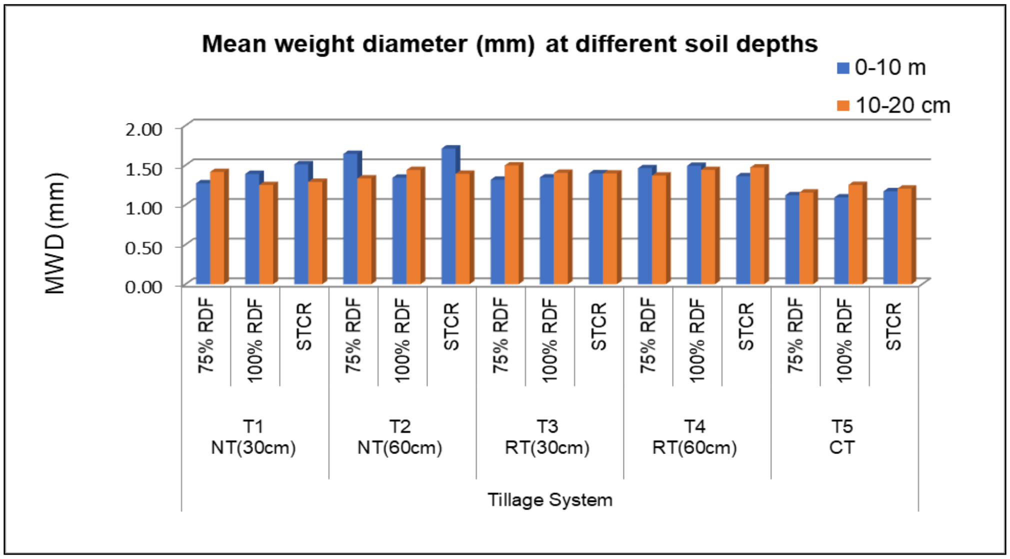


Fig 2.1 Effect of conservation agriculture on Mean weight diameter (mm) under different tillage and nutrient management practices at different soil depths

B. Aggregate Size distribution

The relative percentage of soil aggregates as affected by different levels of residue under soybean-wheat cropping sequence at ICAR-IISS, Bhopal obtained by wet sieving is shown in the Fig 2.13 and 2.14. Results indicated that only tillage system had significant impact on aggregate size large macroaggregate (LM) and micro aggregate (M) at different soil depths. On an average amount of small macro aggregate fractions was determined to be highest followed by large macroaggregate, microaggregate and silt + clay under different soil depths. Significantly higher amount large macroaggregate fraction of 25.09 % and 14.52 % was recorded under T2 (No Tillage with 60 cm residue height) at 0-10 and 10-20 cm soil depths, respectively. While minimum amount of large macroaggregate fractions (13.64 and 10.63%) were obtained under T5 (Conventional Tillage) at 0-10 and 10-20 cm soil depths. The mean value of large macroaggregate decreased with increased soil depth.

The highest amount (48.44%) of small macro aggregate frictions (0.25-2 mm) was obtained in T2 (NT with 60 cm residue height) at 0-10cm soil depth which was significantly higher than RT and CT. While minimum small macroaggregate frictions found under RT with 30 cm crop residue height in the surface layer. Microaggregate fractions were observed higher value (22.19%) under CT at 0-10 cm soil depth and under NT with 30 cm residue height (23.39%) at 10-20 cm soil depth. However, the minimum amount of microaggregate fractions of 14.52 and 16.77% were obtained under RT with 60 cm residue height at 0-10 and 10-20cm soil depth. Higher amount of silt+clay fraction was found also under CT than other treatment of RT and NT at 0-10 and 10-20 cm soil depth. Depth had significant impact on large macroaggregate, small macroaggregate and silt+clay frictions. On an average the mean value of small macroaggregate, microaggregate increased with soil depth. However, large macroaggregate and silt+clay fraction decreased with increased depth. Nutrient management treatment did not have significant effect on aggregate size distribution (i.e. large macroaggregate, small macroaggregate, microaggregate and silt + clay aggregate frictions). Maximum amount of large macroaggregate frictions (20.58% and 13.12%) and small macroaggregate frictions (47.44 and 56.18%) found under N3 (STCR) at 0-10 and 10-20 cm soil depth, respectively. However, minimum value of large macroaggregate (17.54% and 12.05%) and small macroaggregate frictions of 45.98% and 53.68% recorded under N2 (N 100% RDF) at surface and subsurface layer. At surface layer (0-10 cm) highest amount of microaggregate fractions of 20.26% and

51.28% silt+clay frictions of 16.23% were observed under N2 (N100% RDF) treatments. Higher value of microaggregate fraction of 19.94% and silt+clay frictions 14.22% found under N3 (STCR) at 10-20 cm depth of soil. However, minimum value of microaggregate and silt+clay friction was observed under N1 (N 75% RDF).

Further, interaction of tillage system X nutrient dose X depth, tillage system X nutrient dose, tillage system X depth and nutrient dose X depth effect on large macroaggregate, microaggregate and silt+clay fractions was non-significant but effect of tillage system X nutrient dose was significant on silt+clay fractions.

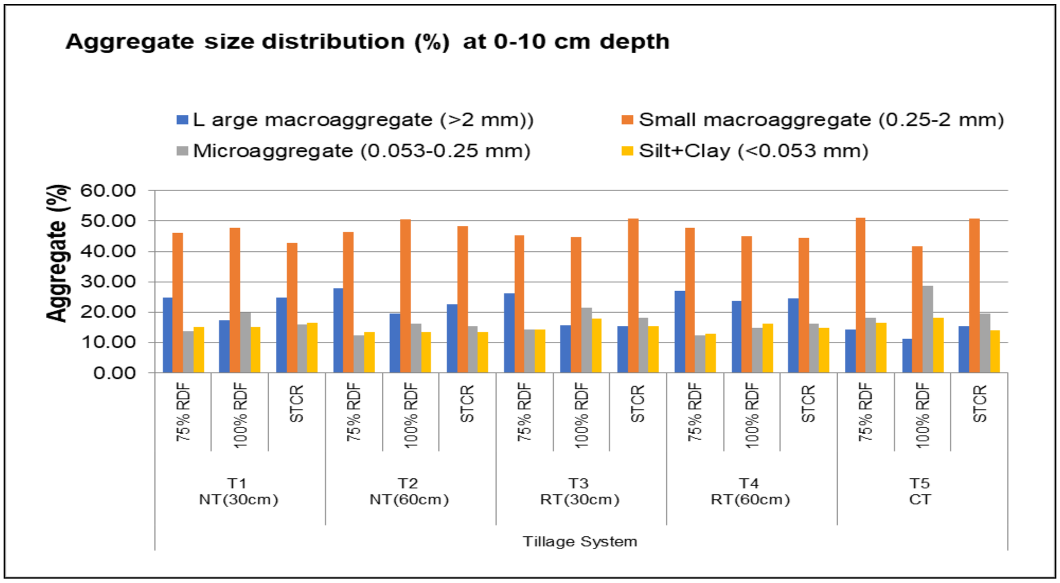


Fig 2.13 Effect of conservation agriculture on aggregate size distribution (%) under different tillage and nutrient management practices at 0-10 cm soil depths.

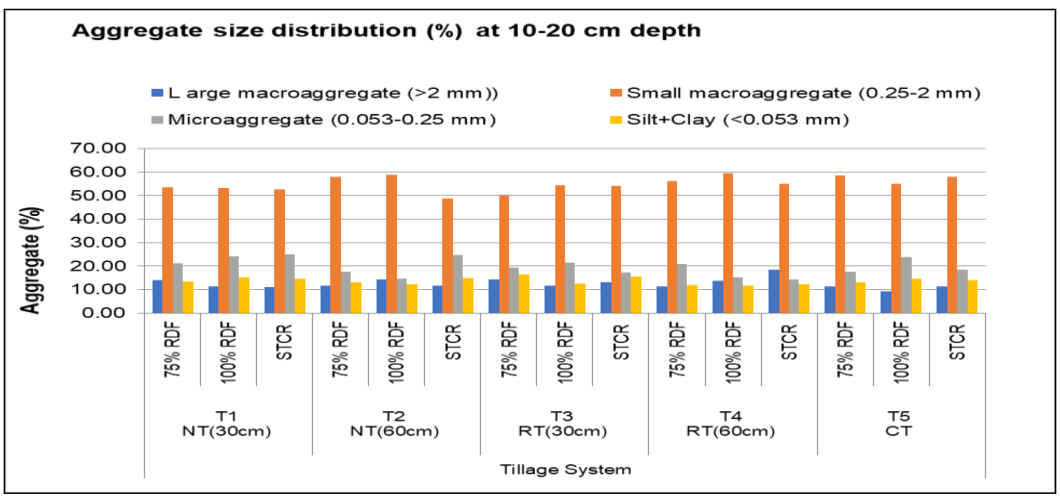


Fig 2.14 Effect of conservation agriculture on aggregate size distribution (%) under different tillage and nutrient management practices at 10-20 soil depth.

The percentage of associated carbon was highest in large macroaggregates (LM), followed by small macro-aggregates (SM) and micro-aggregates (M) (Fig 2.15 and 2.16). The results showed that the aggregate-associated C content increased with aggregate size and it was in the following order of large macroaggregate (LM) >small macroaggregate (SM)> microaggregate (M) in the soil samples. The large macro-aggregates (LM), Small macroaggregates and Macggregates were significantly affected by tillage system at both 0–10 and 10-20cm depths Overall, LM aggregates had the largest aggregate C and it increased with increasing size of aggregates. Tillage practices and cropping systems had a significant effect (P-0.005) on aggregate C for LM-SM and M. There was more LM-C under NT with 60cm height residue (0.73%) and RT with 60cm height residue (0.727%) at 0–10-cm depth than CT (0.471%).

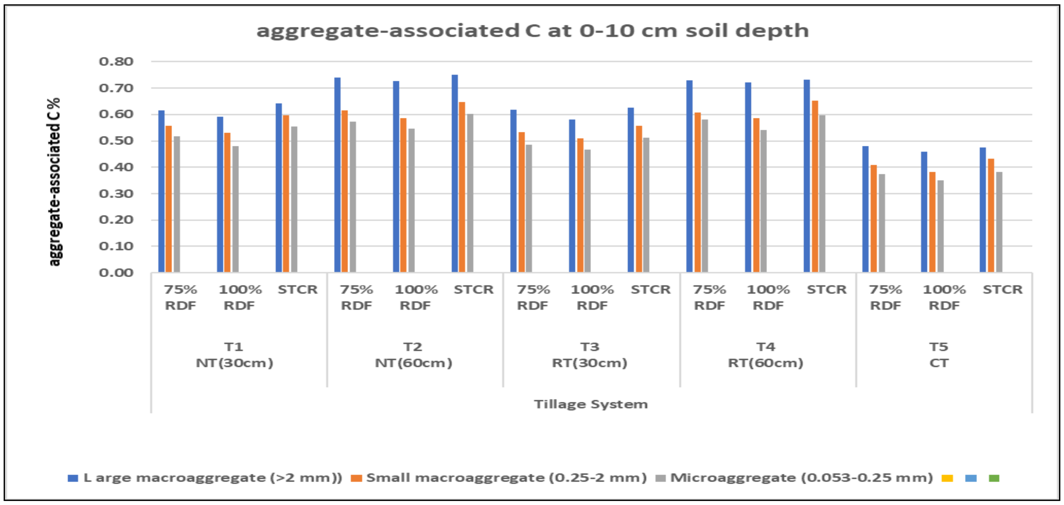


Fig 2.15 Effect of conservation agriculture on aggregate associate carbon (%) under different tillage and nutrient management practices at 0-10 cm soil depths

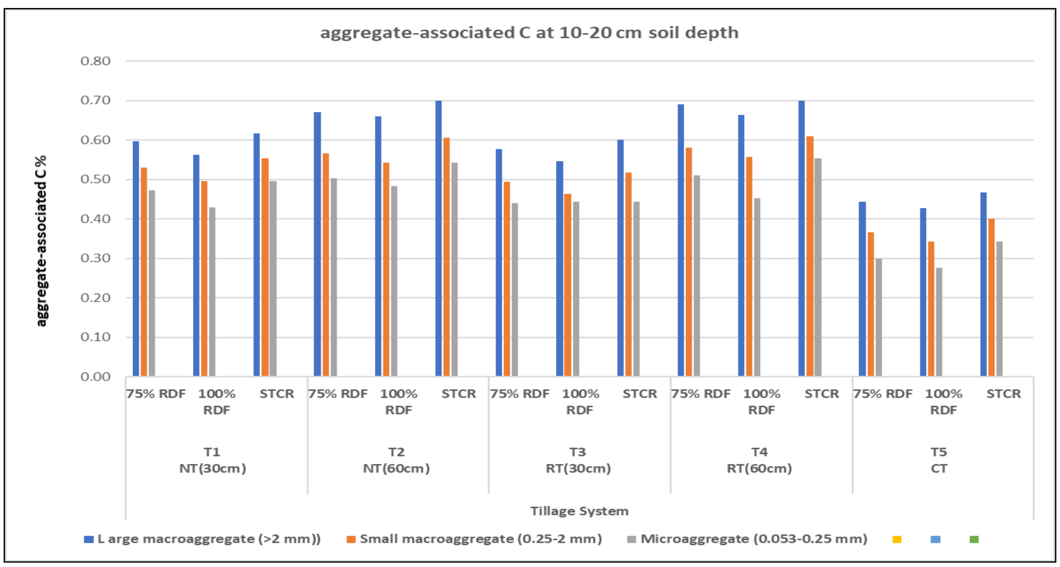


Fig 2.16 Effect of conservation agriculture on aggregate associate carbon (%) under different tillage and nutrient management practices at 10-20 cm soil depths

C. Tensile Strength and soil aggregates

At ICAR-IARI, New Delhi under Maize -Wheat Cropping System, it was observed that there was decrease in the tensile strength of soil aggregates under CA by 31.4, 13.1 and 3.2% compared to CT at 0-5, 5-15 and 15-30 cm soil depths, respectively (Table 2.3). The friability of soil aggregates decreased respectively by 6.9, 12.9 and 16% at 0-5, 5-15 and 15-30 cm soil depth under CA compared to CT. Tensile strength tells about the strength that the roots have to overcome while growing geotropically. Higher tensile strength of soil resist mechanical disturbance to greater limit. Friability on the other hand, is defined as the tendency of soil mass to disintegrate under applied stress and is a useful indicator of soil tilth. Among the conservation tillage practices, retention of crop residue resulted in significant reduction in the tensile strength and friability of soil aggregates at 0-5 cm soil depth.

Table 2.3.Tensile strength and Friability of soil aggregates under conservation and conventional agriculture practices at 0-5, 5-15 and 15-30 cm soil depth after wheat 2020-21.

Treatment	Tensile strength (kPa)				Friability			
	0-5 cm	5-15 cm	15-30 cm	Mean	0-5 cm	5-15 cm	15-30 cm	Mean
Zero tillage (ZT)	1189	1900	1946	1678	0.610	0.423	0.525	0.520
ZT + Residue	1046	1652	1553	1417	0.411	0.674	0.455	0.514
Broad bed (BB)	1098	2336	2089	1841	0.581	0.287	0.627	0.498
BB + Residue	1082	2237	1685	1668	0.532	0.279	0.460	0.424
Narrow bed (NB)	1427	1527	1486	1480	0.700	0.229	0.481	0.470
NB + Residue	1118	1499	1350	1322	0.403	0.244	0.516	0.388
Flat Bed	1577	2066	1580	1741	0.482	0.458	0.568	0.503
Mean	1220	1888	1670	1593	0.531	0.371	0.519	0.474

D. Bulk density (BD)

The bulk density (BD) of soil increased with soil depth under Maize-wheat cropping system at ICAR-IARI, New Delhi. There was decrease in the BD by 10, 2.7 and 5.8% under CA compared to conventional tillage at 0-5, 5-15 and 15-30 cm, respectively (Figure 2.2). In the CA system retention of residue further reduced the BD compared to residue removal at 0-5 cm soil depth. Among the CA practices minimum BD at 0-5 cm soil depth was recorded under permanent narrow bed with residue retention.

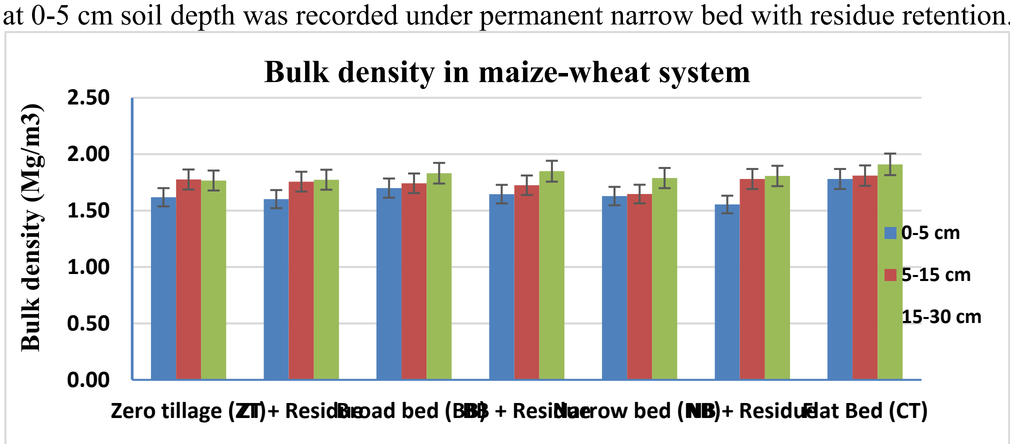


Fig.2.2. Bulk density of soil as influenced by conventional and conservation agriculture practices in maize-wheat system

The soil bulk density (BD) under different tillage and residue management treatments varied from 1.58 to 1.66 g cm^{-3} and 1.74-1.77 g cm^{-3} in 0-15 and 15-30 cm soil depth, respectively at ICAR-CSSRI, Karnal under rice-wheat cropping system (Fig. 2.3). It was more in lower depth (15-30 cm) than upper depth (0-15 cm) irrespective of the treatment. The lowest BD in both the soil depths (1.58 and 1.74 g cm^{-3} at 0-15 and 15-30 cm, respectively) was reported in reduce tillage with $1/3^{rd}$ residue incorporation (RTDSR+RI/RTW+RI). The zero-tillage with $1/3^{rd}$ residue retention (ZTDSR+RR/ZTW+RR) had the highest BD in 0-15 cm depth (1.66 g cm^{-3}) while in 15-30 cm depth, it was the highest in in treatment representing conventional farmers' practice (PTR/CTW; 1.77 g cm^{-3}).

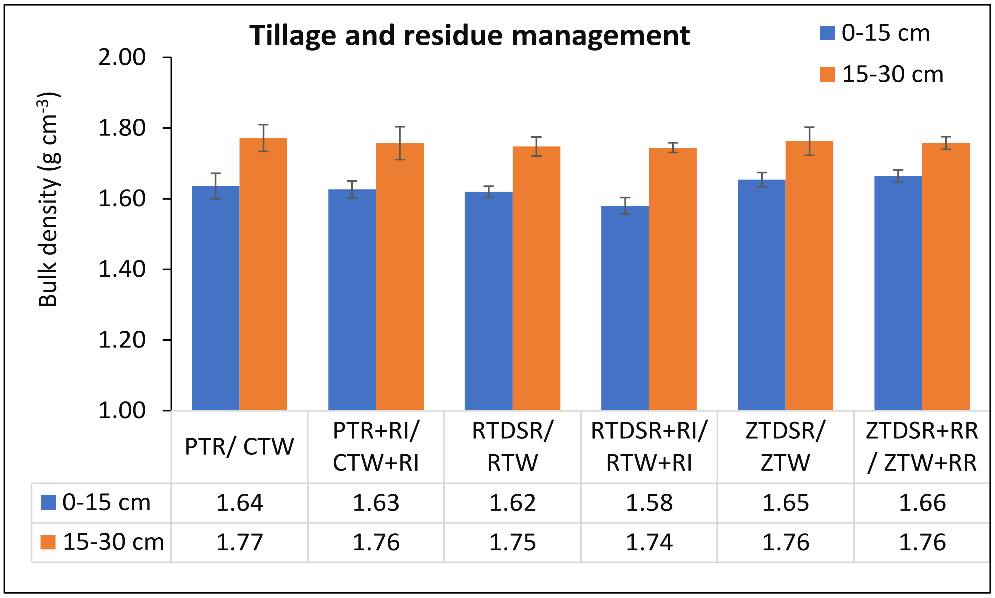


Figure 2.3: Soil bulk density as influenced by different tillage and crop residue management practices.

(Note: PTR- Puddled transplanted rice; RTDSR- Direct seeded rice in reduced tillage; ZTDSR- Direct seeded rice in zero tillage; CTW- Conventional tilled wheat; RTW- Reduced tilled wheat; ZTW- Zero tilled wheat; RI- Residue incorporation; RR- Residue retention/ anchored).

The soil BD was also influenced by different irrigation systems (Fig.2.4). It varied from 1.57-1.64 and 1.70-1.77 g cm^{-3}at 0-15 and 15-30 cm soil depth respectively. The conventional farmers' practice (PTR/CTW) had the highest BD at both the soil depths i.e., 1.64 and 1.77 g cm^{-3} at 0-15 and 15-30 cm soil depth, respectively. Surface irrigation system (SIS-RTDSR/ZTW+RM) had the lowest BD at 0-15 cm soil depth (1.57 g cm^{-3}) while the lowest BD (1.70 g cm^{-3}) at 15-30 cm soil depth was in drip irrigation system (DRIP-RTDSR/ZTW+RM).

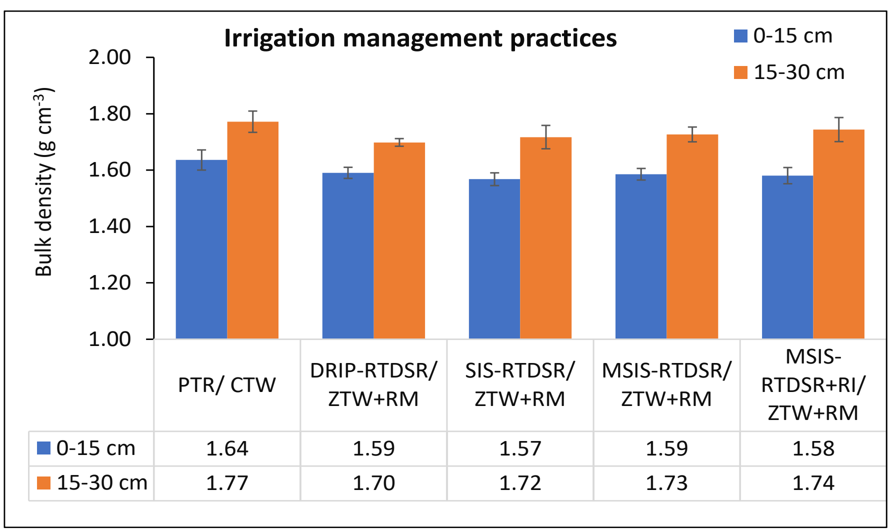


Figure 2.4. Soil bulk density as influenced by the different irrigation systems

(Note: PTR- Puddled transplanted rice; RTDSR- Direct seeded rice in reduced tillage; ZTDSR- Direct seeded rice in zero tillage; CTW- Conventional tilled wheat; ZTW- Zero tilled wheat; RI- Residue incorporation; RM- Residue retention/mulch)

At ICAR-IISS, Bhopal, data pertaining to soil BD at 0-5 and 5-10 cm soil depth under soybean-wheat cropping system after harvest of wheat are shown in the table 2.4 and Fig. 2.5. The statistical analysis shows that BD was non-significant under tillage system and nutrient dose at harvest of *rabi* crop. However, depth had significant impact on BD at harvest stage. The mean value varied from 1.15 to 1.24 Mg m^{-3} at harvest stage of wheat at surface to subsurface layers. BD value increased with the soil depth. At subsurface layer maximum BD was obtained under CT (1.26 Mg m^{-3}) followed by NT and RT. At the harvest stage maximum BD value (1.17 and 1.26 Mg m^{-3}) was found under T5 (Conventional tillage) followed by NT and RT at surface and sub-surface layer of soil. At harvest stage, maximum value of BD was recorded (1.16 Mg m^{-3}) under N3 at 0-5 cm depth while subsurface recorded higher BD value (1.25 Mg m^{-3}) under N1 (75% RDF) treatment. The interaction of tillage system x nutrient dose, tillage system x depth, nutrient dose x depth and tillage system x nutrient dose x depth have not shown significant effect on BD during *rabi* season at harvest stage of wheat.

Table 2.4 Soil bulk density (Mg m^{-3}) after *rabi* season as influenced by different tillage system and nutrient management practices at different soil depths.

Treatment	**Bulk Density (Mg m^{-3})**		
Tillage	**0-5 cm**	**5-10 cm**	**Mean**
T1 - NT with 30cm height residue	1.15	1.24	1.19
T2 - NT with 60cm height residue	1.12	1.23	1.17
T3 - RT with 30cm height residue	1.15	1.23	1.19
T4 - RT with 60cm height residue	1.16	1.24	1.21
T5 – CT (Conventional Tillage)	1.17	1.26	1.21
Mean	1.15	1.24	1.20
Nutrient levels			
N1- 75% RDF	1.15	1.25	1.20
N2-100% RDF	1.15	1.24	1.19
N3- STCR dose	1.16	1.24	1.20
Mean	1.15	1.24	1.20
Interaction	SE (d)	SEm±	CD (PD 0.05)
Tillage System (TS)	0.017	0.012	NS
Nutrient Dose (ND)	0.011	0.008	NS
TS X ND	0.024	0.017	NS
Depth (D)	0.007	0.005	0.014*
TS X D	0.015	0.011	NS
ND X D	0.012	0.008	NS
TS X ND X D	0.026	0.018	NS

T_1- No Tillage (NT) with 30cm height residue; T_2- No Tillage (NT) with 60cm height residue; T_3- Reduced Tillage with 30cm height residue; T_4- Reduced Tillage with 60cm height residue; T_5- Conventional Tillage (CT)/Farmers practices; N_1-75% RDF (Recommended Dose of Fertilizer); N_2-100% RDF; N_3- STCR dose (Soil Test Crop Response); TS- Tillage System; ND- Nutrient Dose; D- Depth; *significant at $P \leq 0.05$; NS- Non-Significant at $P \leq 0.05$.

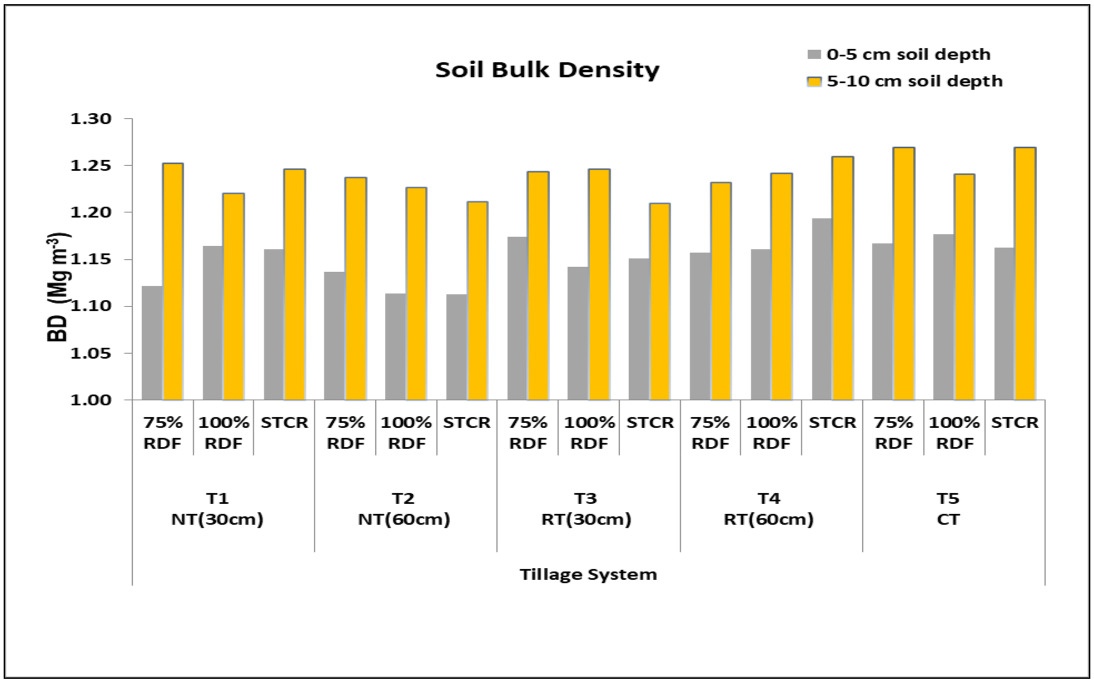


Fig 2.5 Effect of conservation agriculture on bulk density (Mg m^{-3}) after *rabi* season (2020-21) under different tillage and nutrient management practices at different soil depths.

Impact of six years of residue retention under no till soybean-wheat cropping system on soil bulk density, carbon and nitrogen stocks and soil CN ratio is presented in (Table 2). The mean annual C inputs during 2014-2020 from the crop residue biomasses are summarized in (Table 2a). It is evident from the table that retention of residue did not affect soil bulk density. Bulk density of soil under different treatments ranged between 1.40 and 1.41 in 0-10 cm of soil depth, whereas it was between 1.39 to 1.45 in 10-20 cm of soil depth. Soil bulk density was found higher in lower soil depth as compared to surface soil.

Table 2.5 Soil bulk density as affected by different level of residue retention

Treatments	**Bulk density (Mg m^{-3})**
1a. 0-10 cm soil depth	
NT-0% R	**1.40 (0.01)**
NT-30% R	**1.41 (0.01)**
NT-60% R	**1.41(0.01)**
NT-90% R	**1.41(0.02)**
CD (P=0.05)	**NS**
CD (P=0.01)	**NS**
1b. 10-20 cm soil depth	**Bulk density (Mg m^{-3})**
NT-0% R	**1.39 (0.04)**
NT-30% R	**1.43 (0.01)**
NT-60% R	**1.45 (0.01)**

NT-90% R	**1.45 (0.03)**
CD (P=0.05)	**NS**
CD (P=0.01)	**NS**

At ICAR-IIFSR, Modipuram, adoption of conservation agriculture among different cropping systems recorded lower bulk density as compared to conventional tillage practices. Among the cropping systems, sugarcane+greengram-ratoon-wheat (CA) recorded lowest bulk density (1.473 Mg/m^3) followed by maize(cob)-mustard-greengram (CA) (1.497 Mg/m^3) and maize-wheat (CP) (1.518 Mg/m^3) cropping systems.

Similar results were reported from ICAR-CRIDA, Hyderabad under Pearl millet based CA systems> they also observed slight decrease in bulk density (1.58 g/cc) in ZT compared to CT (1.64 g/cc) (Fig. 11).

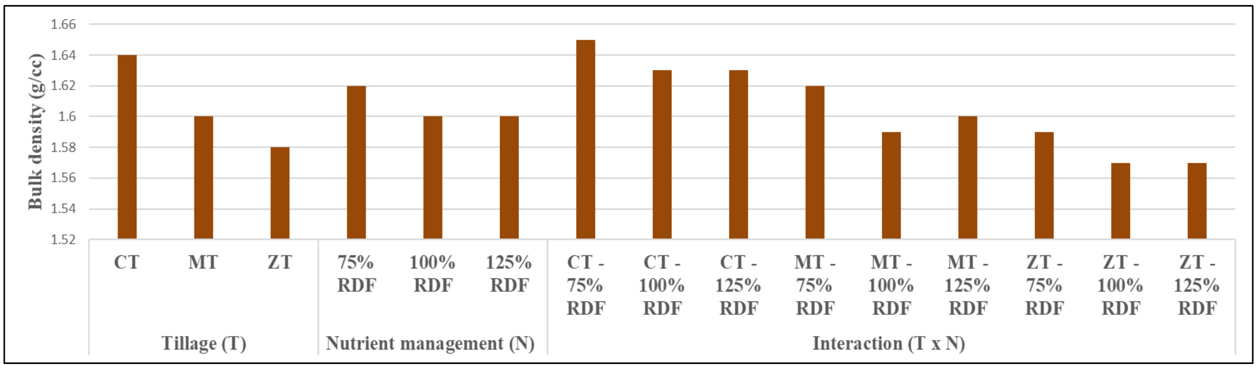


Fig 2.6. Impact of tillage and different doses of fertilizers on bulk density of soil after 5 years of experimentation

E. Soil Penetration Resistance

Soil penetration resistance under maize -wheat cropping System was measured at ICAR-IARI, New Delhi. It was observed that there was a compact layer at 20-40 cm soil depth as evidenced from the soil penetration resistance values (Figure 8). The CA practices registered significantly lower cone penetration resistance than the conventional tillage at all the soil depths. Retention of residues has significantly reduced the soil penetration resistance especially in the surface soil layers. Among the CA practices, zero tilled flat bed with residue retention registered the lowest penetration resistance of soil.

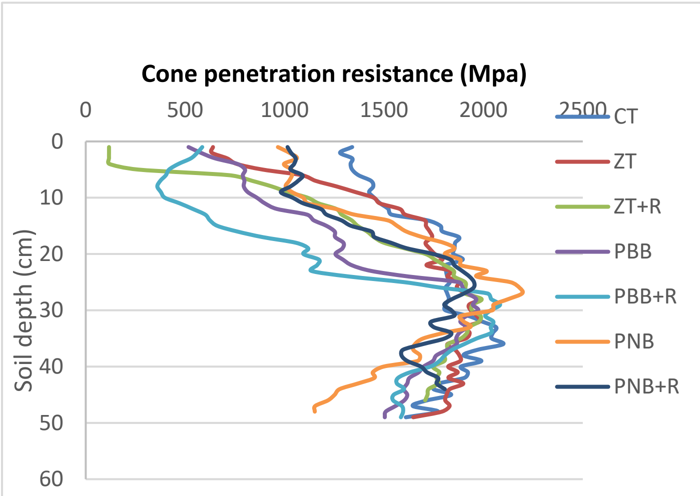


Fig 2.7 Cone penetration resistance of soil under conventional and conservation agriculture practices in maize-wheat system

Soil penetration resistance (SPR) was influenced by tillage and residue management treatments at ICAR-CSSRI, Karnal under rice-wheat cropping system. The SPR increased steadily in 0-15 cm depth, then increased suddenly and reached to peak in the subsoil depth (15-25 cm) and decreased thereafter in all the treatments (Fig. 9). In 5-15 cm depth, the SPR was higher in reduced tillage with residue incorporation (RTDSR+RI/RTW+RI) and zero tillage with residue retention (ZTDSR+RR/ZTW+RR) treatments than PTR/CTW. It was 4 and 84% higher in RTDSR+RI/RTW+RI treatment at 5.0 and 12.5 cm depth, respectively, than PTR/CTW. Likewise, ZTDSR+RR/ZTW+RR had 39 and 61% higher SPRat 5.0 and 12.5 cm depth, respectively, than PTR/CTW. The SPR below 15 cm depth followed the reverse trend as that of in 0-15 cm depth i.e.,it was higher in PTR/CTW than RTDSR+RI/RTW+RI and ZTDSR+RR/ZTW+RR treatments. Further, the magnitude was maximum in the 20-25 cm soil depth. The SPR in this depth was 13-16% and 39-50% higher in PTR/CTW than RTDSR+RI/RTW+RI and ZTDSR+RR/ZTW+RR treatments, respectively. Published studies corroborate these results that SPR remains higher under puddling than under ZT/RT (Jat et al., 2009). The critical mechanical impedance for wheat root development is around 1750 to 2000 KPa (Sharma and Bhushan, 2001). Reports suggest that with each centimeter reduction in rooting depth, wheat yield may decrease by 0.4% (Sadrás and Calvino, 2001). In our case, SPR at depths > 20 cm was found greater than the critical value (1750 kPa) for wheat root development in PTR/CTW and RTDSR/RTW treatment. However, RTDSR+RI/RTW+RI and ZTDSR+RR/ZTW+RR treatments, maintained lower SPR in the root zone compared with conventional practice (PTR/CTW) and the critical limit (Fig. 9).

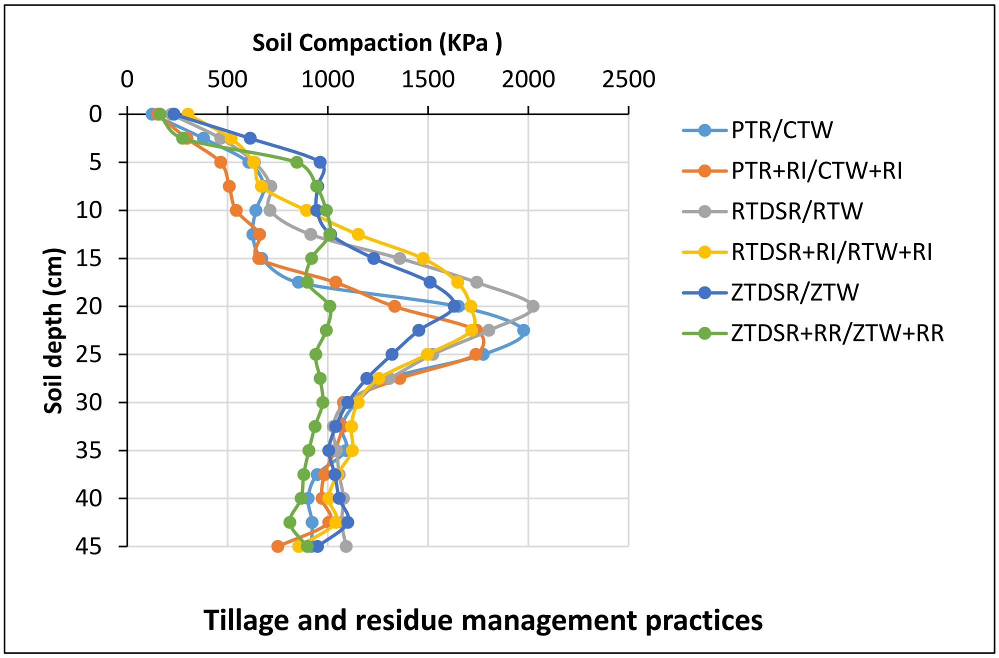


Fig 2.8 Effect of different tillage and crop residue management practices on soil penetration resistance

The SPR was influenced by different irrigation systems in tillage and residue management practices (Fig. 10). The SPR increased linearly in 0-17.5 cm depth, increased suddenly and reached to peak in 20-30 cm depth and thereafter deceased rapidly almost remain stable upto 45 cm soil depth in all the treatments. The SPR in different irrigation system treatments was higher than PTR/CTW in 0-17.5 cm and 32.5-45.0 cm soil depth while it was lower than PTR/CTW in 20-30 cm soil depth. In 5.0 cm soil depth, it was 37-83% higher under different irrigation system treatments than PTR/CTW. In 20-30 cm depth, SPR was 10-20 % higher in PTR/CTW than different irrigation system treatments. Further the highest SPR was also recorded in this depth (20-30 cm depth) in all the treatments. Except conventional practice (PTR/CTW), SPR remained lower than threshold limit (1750 kPa) in all other treatments.

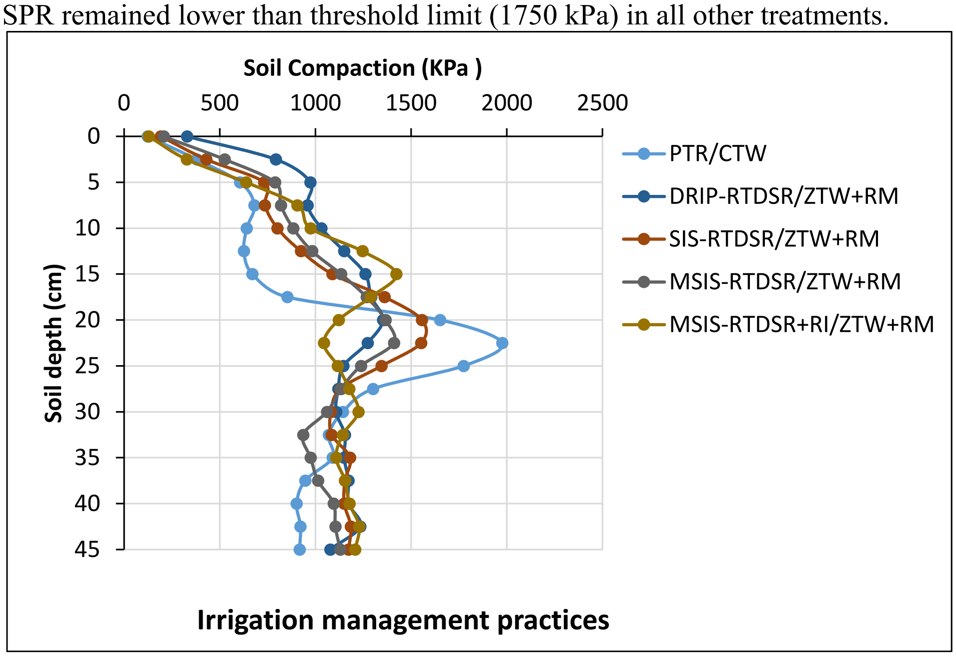


Fig 2.9 Effect of different irrigation systems on soil penetration resistance

F. Infiltration Rate and Cumulative Infiltration

Infiltration rate as influenced by different tillage and residue management practices was measured after harvesting of wheat crop in the month of the April, 2021 ICAR-CSSRI, Karnal under rice-wheat cropping system. The steady state infiltration rate was the lowest in PTR/CTW (0.3cm hr^{-1}) while the highest in zero-tillage with 1/3rd residue retention (ZTDSR+RR/ZTW+RR; 0.75 cm hr^{-1}) (Fig.2.10). Decreasing tillage intensity (from conventional tillage to reduce and zero-tillage) and residue management (addition/incorporation) both increased steady state infiltration rate. Crop residue added treatments (PTR+RI/CTW+RI; RTDSR+RI/RTW+RI and ZTDSR+RR/ZTW+RR) had higher steady state infiltration rate than their respective tillage treatments without crop residue (PTR/CTW; RTDSR/RTW and ZTDSR/ZTW). It was 0.55, 0.50 and 0.75 cm hr^{-1} in PTR+RI/CTW+RI, RTDSR+RI/RTW+RIandZTDSR+RR/ZTW+RR, respectively, while PTR/CTW, RTDSR/RTW and ZTDSR/ZTW had steady state infiltration rate of 0.30, 0.40 and 0.55 cm hr^{-1}, respectively. The cumulative infiltration rate followed the same trend as that of steady-state infiltration rate (Fig.2.11). The cumulative infiltration after 6.5 hr. was the lowest in PTR/CTW (14.2 cm) while the highest in ZTDSR+RR/ZTW+RR (26.0 cm). The cumulative infiltration after 6.5 hr. in ZTDSR+RR/ZTW+RR (26.0 cm), RTDSR+RI/RTW+RI (18.6 cm) and PTR+RI/CTW+RI (17.5 cm) was 84, 31 and 24% higher than PTR/CTW, respectively. The data on steady-state infiltration rate over the years (2010-2021) showed that it increased over time in all the treatments except in PTR/CTW treatment where it remained similar to its initial value (Fig. 2.12). The steady state infiltration rate increased by 1.1 and 1.5 mm hr^{-1} in ZTDSR/ ZTW and ZTDSR+RR/ ZTW+RR, respectively, over its initial value. The lowest steady state infiltration rate in PTR/CTW was due to puddling done in rice crop.Puddling destroys soil aggregation and drastically decreases infiltration rates are a well-known process. In fact, one of the objectives of puddling in rice is to lower infiltration to allow water stagnation in rice fields.Puddling decreases infiltration directly by destroying soil aggregates, decreasing total porosity and macro-porosity, increasing BD, and causing subsoil compaction. Indirectly, puddling disperses clay in floodwater, which settles over time, partially or completely blocking the macropores responsible for a majority of infiltration. The recovery of soil structure after puddled (TPR) is rather slow, unless some corrective measures are taken. That is why the effect of puddling on infiltration persisted even with wheat in the rotation. On the other hand, zero-tillage with crop residue (ZTDSR+RR/ ZTW+RR) addition improved soil aggregationwith higher steady-state infiltration rate.

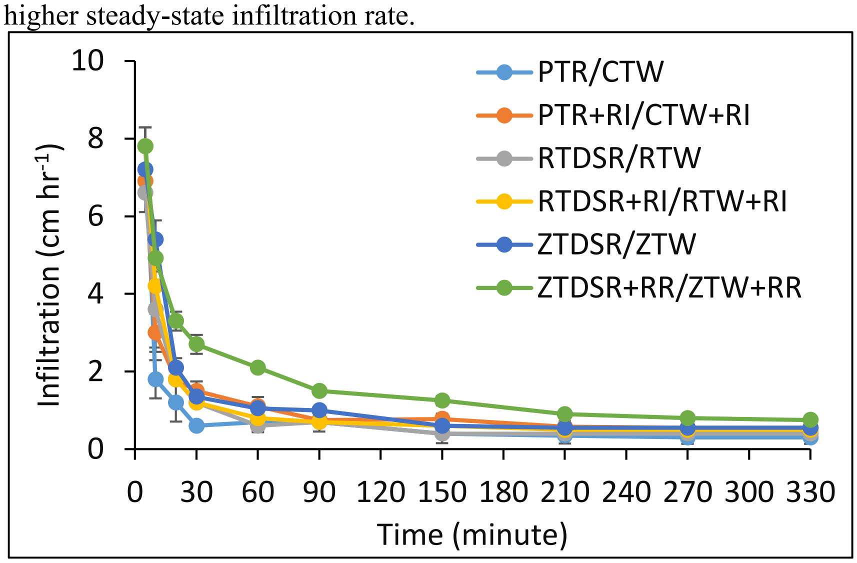


Fig 2.10 Effect of different tillage and crop residue management practices on infiltration rate

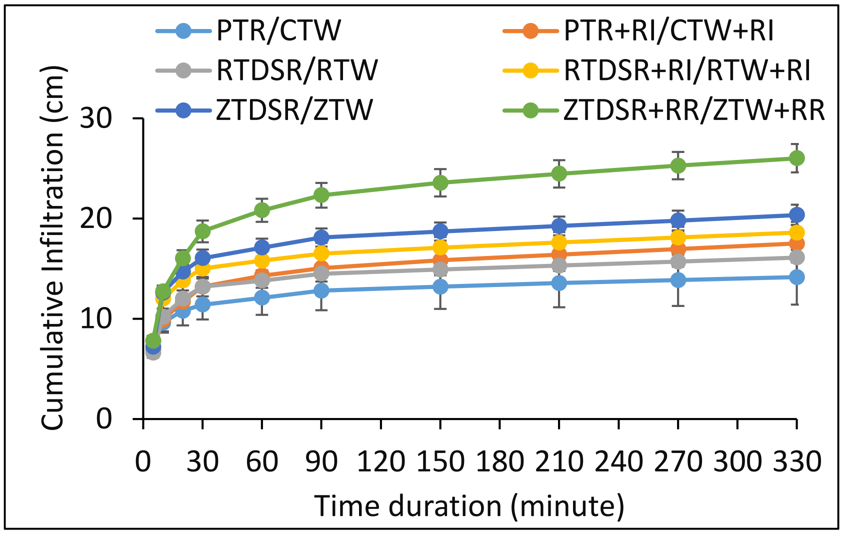
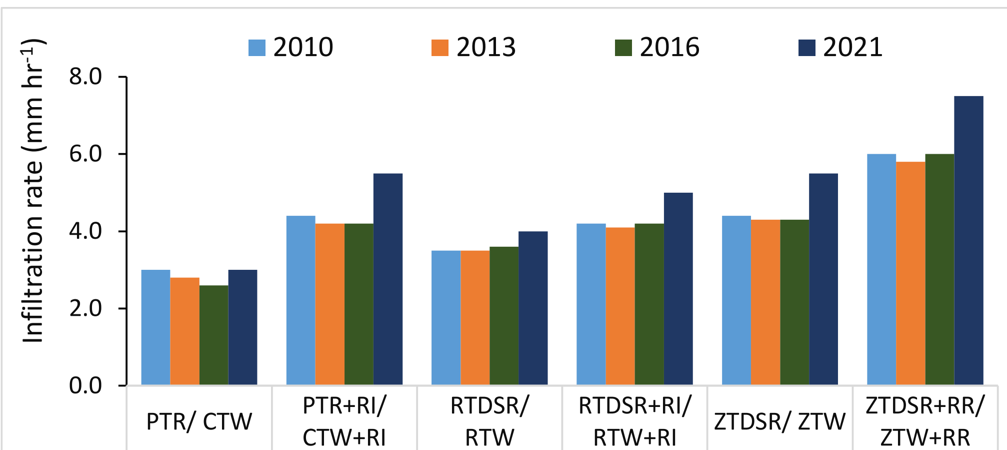


Fig 2.11 Effect of different tillage and crop residue management practices on cumulative infiltration rate



	PTR/ CTW	PTR+RI/ CTW+RI	RTDSR/ RTW	RTDSR+RI/ RTW+RI	ZTDSR/ ZTW	ZTDSR+RR/ ZTW+RR
2010	3.0	4.4	3.5	4.2	4.4	6.0
2013	2.8	4.2	3.5	4.1	4.3	5.8
2016	2.6	4.2	3.6	4.2	4.3	6.0
2021	3.0	5.5	4.0	5.0	5.5	7.5

Fig 2.12 Long-term effect of different tillage and crop residue management practices on steady-state infiltration rate in rice-wheat system

G. Soil Moisture Content

Soil moisture data recorded at different time interval and their statistical significance with respect to tillage system, nutrient level and soil depths under soybean-wheat cropping system at ICAR-IISS, Bhopal (Table 2.6). The statistical analysis showed that SMC was significantly different under tillage system at harvest stage of rabi crop. Highest value of SMC was recorded (13.90 and 15.30%) was observed under T4 (RT with 60 cm residue height) at surface and sub-surface layer at harvest stage. However, minimum value of SMC was observed under T5 (CT) surface layer (12.22%) at harvest stage. At harvest stage maximum value of SMC was found under N3 (STCR) at 0-5 cm (12.94%) and under N1 (N 75% RDF) at 5-10 cm depth (14.88%). While minimum value of SMC was found in N1 at surface layer (12.49) and N2 under deeper soil layer (14.27%). The mean value of SMC varied from 12.73% to 14.58% from 0-5 cm to 5-10 cm soil depth, respectively. The interaction of tillage system x nutrient dose, tillage system x depth, nutrient dose x depth and tillage system x nutrient dose x depth have not shown significant effect on SMC at harvest stage of wheat.

Table 2.6 Soil moisture content (%, wt/wt) under different stages of wheat during *rabi* season as influenced by different tillage system and nutrient management practices at different soil depths.

Treatment	**SMC (%, wt/wt) at harvest in wheat**		
	0-5 cm	**5-10 cm**	**Mean**
Tillage			
T1 - NT with 30cm height residue	12.73	14.44	13.59
T2 - NT with 60cm height residue	12.40	14.47	13.44
T3 - RT with 30cm height residue	12.40	14.35	13.38
T4 - RT with 60 cm height residue	13.90	15.30	14.60
T5 – CT (Conventional Tillage)	12.22	14.35	13.29
Mean	12.73	14.58	13.66
Nutrient levels			
N1- 75% RDF	12.49	14.88	13.91
N2-100% RDF	12.76	14.27	13.52
N3- STCR dose	12.94	14.59	13.54
Mean	12.73	14.58	13.66
Interaction	SE(d)	SEm±	C.D (P.D±)ac
Tillage System (TS)	0.378	0.267	0.87*
Nutrienst Dose (ND)	0.531	0.376	NS
TS X ND	1.188	0.840	NS
Depth (D)	0.187	0.132	0.38*
TS X D	0.418	0.295	NS
ND X D	0.324	0.229	NS
TS X ND X D	0.724	0.512	NS

T_1- No Tillage (NT) with 30cm height residue; T_2- No Tillage (NT) with 60cm height residue; T_3- Reduced Tillage with 30cm height residue; T_4- Reduced Tillage with 60cm height residue; T_5- Conventional Tillage (CT)/Farmers practices; N_1- 75% RDF (Recommended Dose of Fertilizer); N_2- 100% RDF; N_3- STCR dose (Soil Test Crop Response); TS- Tillage System; ND- Nutrient Dose; D- Depth; *significant at $P \leq 0.05$; NS- Non-Significant at $P>0.05$.

2. Soil Chemical Properties

A. SOC, Carbon Stock and Carbon Sequestration

Despite many studies reported conservation agriculture (CA) impacts on soil organic carbon (SOC) sequestration, the impacts of long-term permanent bed planting under CA on SOC sequestration are rarely reported. Hence, this study assessed the permanent bed planted CA impacts on SOC sequestration rates in both surface (0-30 cm) and deep (30-60 cm) soil layers along with SOC pools under a cotton (*Gossypium hirsutum*)-wheat (*Triticum aestivum*) system in the Indo-Gangetic Plains (IGP) at ICAR-IARI, New Delhi (Table 2.7). There were seven treatments: conventional tillage (CT), permanent narrow bed (PNB) and PNB with residue retention (PNB+R), permanent broad bed (PBB) and PBB with residue retention (PBB+R), zero tillage (ZT) and ZT with residue retention (ZT+R). Labile and recalcitrant C and total SOC concentrations and total SOC stocks were measured (Tables 2.7 and 2.8). Results indicated that the total SOC content was ~33, 30 and 29% higher in CA plots (PBB+R, PNB+R and ZT+R) than CT plots (farmers' practice), respectively, in the topsoil (0-5 cm depth). In the surface layers (0-30 cm), the plots under PBB+R, PNB+R and ZT+R had ~32, 28 and 31% more SOC stock than CT plots. In the deep soil layer (30-60 cm), the PBB+R, PNB+R and ZT+R plots had ~16, 23 and 15% higher SOC stock compared with that of CT (Table 18). The microbial biomass C (MBC) content of PBB+R in the 0-5 and 5-15 cm soil layers were ~52 and 64% higher than CT, respectively. The SOC sequestration rates (over CT plots) in the PBB+R, PNB+R and ZT+R plots were similar and the mean value was ~0.76 Mg C $ha^{-1}yr^{-1}$ that was significantly more than mean value (~0.44 Mg C $ha^{-1}yr^{-1}$) of PBB, PNB and ZT plots in the 0-30 cm layer. Interestingly, these PBB+R, PNB+R and ZT+R plots had appreciably high total SOC sequestration (~0.24 Mg C $ha^{-1}yr^{-1}$) compared to CT plots in deep soil layer (30-60 cm), resulting total SOC sequestration rate (in CA plots over CT) ~1.0 Mg C $ha^{-1}yr^{-1}$ in the 0-60 cm layer. Thus, the adoption of raised beds with residue retention has great potential in higher carbon sequestration in deeper layers and can be recommended for sustainable intensification of land.

Table 2.7 Total SOC stock in surface layer (0-30 cm) and deep layers (30-60 cm) as influenced by long-term conservation agriculture under a cotton-wheat cropping system in an Inceptisol

Treatments	Total SOC stock	
	0-30 cm	**30-60 cm**
CT	24.54 c	12.96 ns
PNB	28.99 b	14.40 ns
PNB+R	31.66 a	16.04 ns
PBB	29.37 b	15.02 ns
PBB+R	32.43 a	14.98 ns
ZT+R	32.18 a	14.94 ns
ZT	28.33 b	13.62 ns

CT = conventional tillage, PNB = permanent narrow bed, PNB+R = PNB with residue retention, PBB = permanent broad bed, PBB+R = PBB with residue retention, ZT+R = zero tillage with residue retention, ZT= zero tillage. Means within a column with different lowercase letters are significantly different according to Tukey's HSD test at $P<0.05$.

Table 2.8 Walkley-Black carbon (WBC), labile C and recalcitrant C as influenced by long-term CA under a cotton-wheat system in an Inceptisol in the 0-5 cm soil depth

Treatments	WBC (g kg^{-1})	Labile C (g kg^{-1})	Recalcitrant C (g kg^{-1})
CT	4.78 c	2.85 e	3.44 c
PNB	5.08 c	3.21 de	3.52 c
PNB+R	6.28 a	3.73 ab	4.49 a
PBB	5.71 b	3.42 bcd	3.87 b
PBB+R	6.32 a	3.80 a	4.58 a
ZT+R	6.16 a	3.57 abc	4.57 a
ZT	5.54 b	3.25 cd	4.03 b

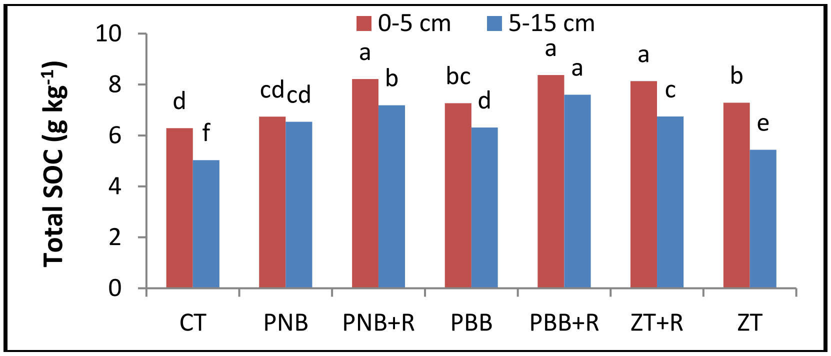


Fig 2.17 Total soil organic carbon (SOC) as influenced by long-term CA under a cotton-wheat cropping system in an Inceptisol in the 0-5 cm and 5-15 cm depths.

CT = conventional tillage, PNB = permanent narrow bed, PNB+R = PNB with residue retention, PBB = permanent broad bed, PBB+R = PBB with residue retention, ZT+R = zero tillage with residue retention, ZT= zero tillage. Bars for a soil depth with different lowercase letters are significantly different according to Tukey's HSD test at P<0.05.

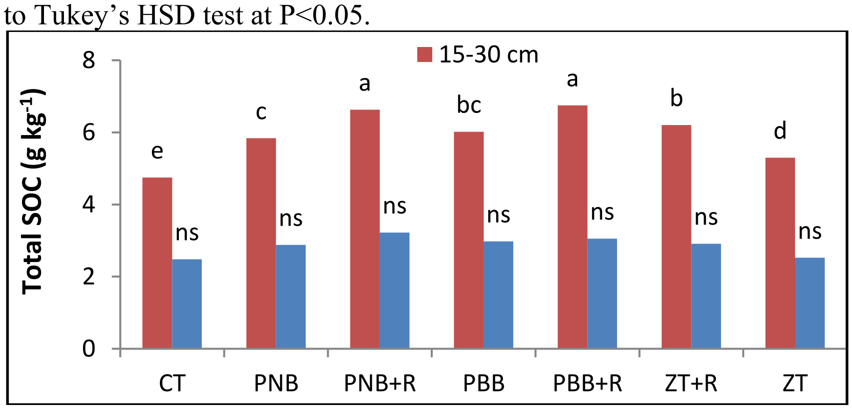


Fig 2.18 Total soil organic carbon (SOC) as influenced by long-term CA under a cotton-wheat cropping system in an Inceptisol in the 15-30 cm and 30-60 cm depth.

CT = conventional tillage, PNB = permanent narrow bed, PNB+R = PNB with residue retention, PBB = permanent broad bed, PBB+R = PBB with residue retention, ZT+R = zero tillage with residue retention, ZT= zero tillage. Bars for a soil depth with different lowercase letters are significantly different according to Tukey's HSD test at P<0.05.

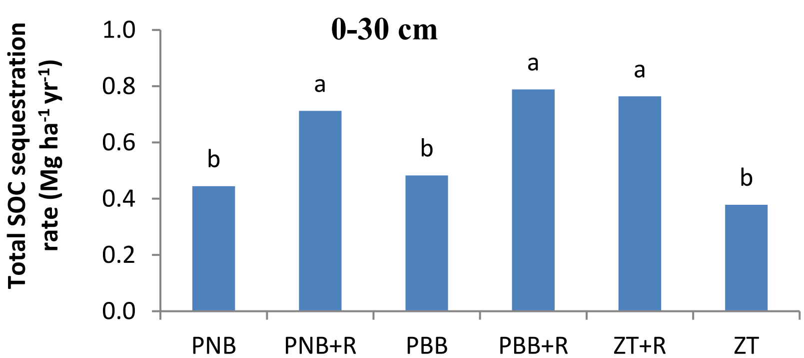


Fig 2.19 Total soil organic carbon (SOC) sequestration rate (Mg ha^{-1} yr^{-1}) as influenced by long-term CA under a cotton-wheat cropping system in an Inceptisol in the 0-30 cm depth

PNB = permanent narrow bed, PNB+R = PNB with residue retention, PBB = permanent broad bed, PBB+R = PBB with residue retention, ZT+R = zero tillage with residue retention, ZT= zero tillage. Bars with different lowercase letters are significantly different according to Tukey's HSD test at P<0.05.

The data of SOC recorded at the end of *rabi* season at ICAR-IISS, Bhopal under different tillage and nutrients dose treatments and their statistical analysis with respect to tillage systems, nutrient doses and soil depths has been shown in Table 2.9 and Fig. 2.20. Tillage system effect was not significant on SOC at the end of *rabi* sampling. At the end of *rabi* sampling, T4 (RT with 60 cm residue height) found highest SOC amount (0.84%) at 0-10 cm and at the sub-surface layer higher SOC content was found under T3 and T4 (RT with 30 and 60 cm residue height). However, minimum amount of SOC (0.72 and 0.61) was also found in conventional tillage (T5) at 0-10 and 10-20 cm soil depth. Mean value was varied from 0.63 to 0.80 under end of *rabi* season means that surface layer (0-10 cm) recorded higher SOC compared to lower soil depth (10-20 cm). Nutrient management treatments were found not significant effect on SOC at the end of *rabi* sampling. Highest SOC (0.82 and 0.65%) was recorded under N2 (N100% RDF) and N3 (STCR) while minimum SOC (0.79 and 0.61) recorded under N1 (N 75%% RDF) at both of the soil depth (0-10 and 10-20 cm).
The interaction of tillage system x nutrient dose, nutrient dose x depth and tillage system x nutrient dose x depth have not shown significant effect on SOC in the end of *rabi*.

Table 2.9 Soil organic carbon (%) at the end of *rabi* season as influenced by different tillage system and nutrient management practices at different soil depths.

Treatment	**SOC (%) at the end of *Rabi***		
	0-10 cm	**10-20 cm**	**Mean**
Tillage			
T1 - NT with 30cm height residue	0.81	0.63	0.72
T2 - NT with 60cm height residue	0.83	0.62	0.73
T3 - RT with 30cm height residue	0.80	0.66	0.73
T4 - RT with 60cm height residue	0.84	0.66	0.75
T5 – CT (Conventional Tillage)	0.72	0.61	0.67
Mean	0.80	0.63	0.72
Nutrient levels			
N1- 75% RDF	0.79	0.61	0.70
N2-100% RDF	0.82	0.64	0.73
N3- STCR dose	0.80	0.65	0.73
Mean	0.80	0.63	0.72
Interaction	SE(d)	SEm±	C.D. (P≤0.05)
Tillage System (TS)	0.032	0.023	NS
Nutrient Dose (ND)	0.020	0.014	NS

TS X ND	0.044	0.031	NS
Depth (D)	0.012	0.009	0.025*
TS X D	0.027	0.019	NS
ND X D	0.021	0.015	NS
TS X ND X D	0.047	0.033	NS

T_1- No Tillage (NT) with 30cm height residue; T_2- No Tillage (NT) with 60cm height residue; T_3- Reduced Tillage with 30cm height residue; T_4- Reduced Tillage with 60cm height residue; T_5- Conventional Tillage (CT)/Farmers practices; N_1- 75% RDF (Recommended Dose of Fertilizer); N_2- 100% RDF; N_3- STCR dose (Soil Test Crop Response); TS- Tillage System; ND- Nutrient Dose; D- Depth; *significant at $P \leq 0.05$; NS- Non-Significant at $P > 0.05$.

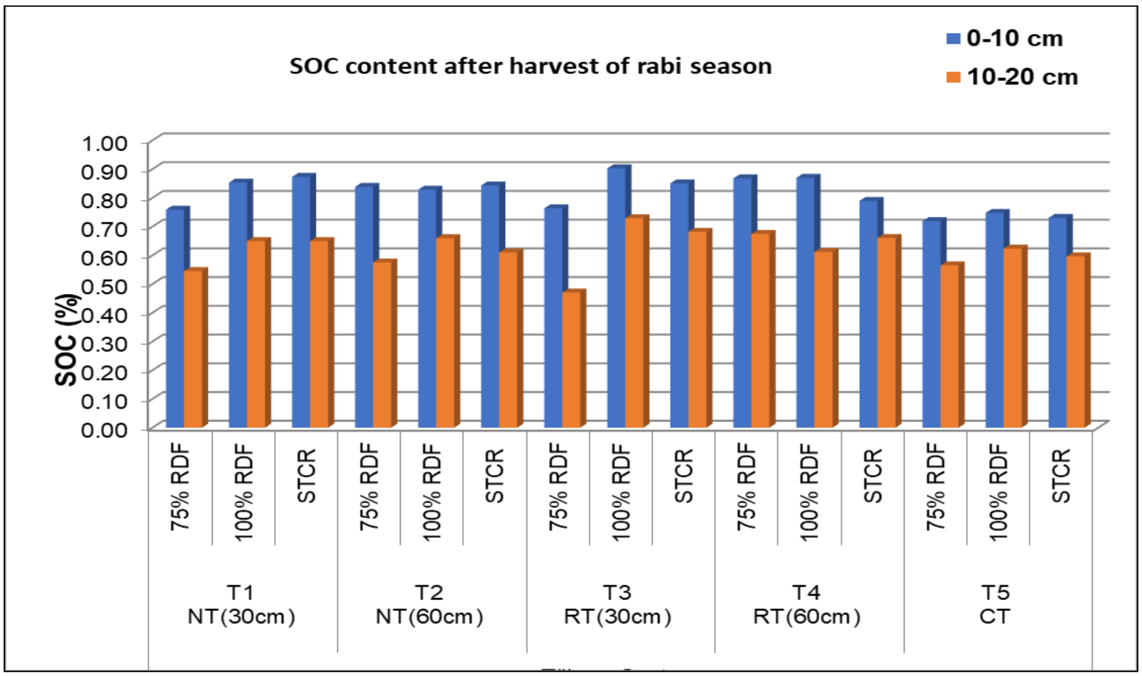


Fig 2.20 Effect of conservation agriculture on Soil organic carbon (%) at the end of *rabi* season under different tillage and nutrient management practices at different soil depths.

B. Active or $KMnO_4$ oxidizable carbon

In this study the active fraction of carbon (active C) was determined end of *rabi* season. The detailed results are presented here. An attempt was made to quantify active (labile) fraction of carbon as influenced by contrasting tillage and nutrient management practices (Fig.2.21). Tillage systems registered not significant effect ($P< 0.05$) on active carbon end of *rabi* sampling. Higher active C (780.7 mg C kg^{-1}) was recorded under reduced tillage (RT with 60 cm residue height) compared to no tillage (NT) than conventional tillage (CT) practices in the end of *rabi* sampling. Minimum active carbon content was recorded under CT (662.2 mg C kg^{-1}) at the end of *rabi* sampling. Nutrient management practices had significant ($P <0.05$) effect on labile carbon. Among the all-nutrient levels compared, STCR dose was significantly higher active C content. The value of active C recorded under at end of rabi (782.5 mg C kg

$^{-1}$) followed by 75% and 100% RDF. The interaction effects between tillage system and nutrient dose was non - significant (P >0.05) on active C.

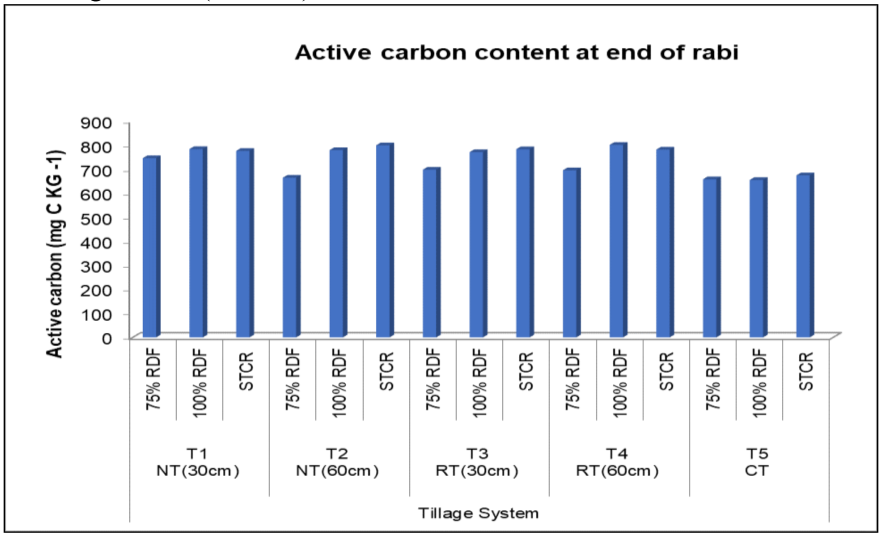


Fig 2.21 Effect of conservation agriculture on Active carbon (mg C kg $^{-1}$) at *rabi* season under different tillage and nutrient management practices.

Under soybean-wheat cropping system, after six years of experimentation, 30, 60 and 90 % of retention of residue resulted in 8.75, 22.5, and 38.75% improvement in oxidisable carbon concentration as compared to no residue retention treatment (Table 2.10). The trend was similar for increase in TOC concentration also. There was gradual increase in TOC concentration with increment in retention of residue of previous crop. Here also, retention of 60 and 90% of residue of previous crop resulted in 15.8 and 26% increase in TOC concentration over the no residue retained plot. The highest concentration of 11.1 and 15.9 g kg-1 of OC and TOC was recorded in 90% of residue retained plot.

Oxidisable carbon content ranged from 5.5 to 6.3 g kg-1 under the different treatments. There was 50% reduction in soil oxidisable carbon concentration in 10-20 cm of soil depth in comparison to 0-10 cm of depth in 90% residue retention plot. Similarly, TOC and TN concentration also decreased with increase in soil depth.

Table 2.10a & 2.10b: Effect of residue retention on soil OC, TOC and TN concentration in soil

Treatments	**OC**	**TOC**	**TN**
	(g kg^{-1})	**(g kg^{-1})**	**(g kg^{-1})**
1a. 0-10 cm soil depth **NT-0% R**	8.0 (0.4)	12.6 (0.6)	1.2 (0.05)
NT-30% R	8.7 (0.2)	13.0 (0.2)	1.1 (0.03)
NT-60% R	9.8 (0.6)	14.6 (0.8)	1.3 (0.06)
NT-90% R	11.1 (0.8)	15.9 (0.6)	1.4 (0.06)
CD (P=0.05)	1.58	1.83	0.16
CD (P=0.01)	2.19	2.54	0.23
1b. 10-20 cm soil depth	6.30 (0.4)	10.0 (0.5)	0.95 (0.1)

NT-0% R			
NT-30% R	5.7 0 (0.1)	9.2 (0.2)	0.91 (0.0)
NT-60% R	5.7 (0.2)	9.8 (0.4)	0.91 (0.1)
NT-90% R	5.5 (0.4)	9.5 (0.3)	0.91 (0.0)
CD (P=0.05)	NS	NS	NS
CD (P=0.01)	NS	NS	NS

Impact of six years of residue retention under no till soybean-wheat cropping system on carbon and nitrogen stocks and soil CN ratio under soybean-wheat rotation is presented in Table 2.11 a & 2.11b. The mean annual C inputs during 2014-2020 from the crop residue biomasses are summarized in (Table 2.11a). Annual carbon input was found to be the function of quantity of residue retained. As expected, it was lowest (2.04 Mg ha- y^{-1}) in 0% of residue retained plot and maximum in 90% of residue retained plot (4.43 Mg ha- y^{-1}). For all the NT treatment, the annual C inputs were derived from the crop residues (including straw and roots and also root exudates). It was observed that 90% of residue retained plot contributed 117% higher carbon input every year in comparison to nil residue retained plot. Retention of residue significantly ($P \leq 0.01$) impacted soil total carbon stock in 0-10 cm of soil depth. The SOC measurements and computation of SOC and TN stocks demonstrated that the residue retention practice influenced the SOC and nitrogen stocks only at the surface layer (0-10 cm) (Table 2.11a). Soil carbon stock under the different treatments ranged between 17.69 to 22.44 Mg ha^{-1} in 0-10 cm of soil depth. In 0-10 cm of soil depth, retention of 30, 60and 90% residue of previous crops resulted in 3.7, 16.7 and 26.9% improvement in soil carbon stock in comparison to no residue retained plot. The trend was similar for soil nitrogen stock also. Here also, retention of residue significantly ($P \leq 0.01$) increased soil nitrogen stock in 0-10 cm of soil depth. There was 24.4% improvement in soil nitrogen stock due to 90% retention of previous crop residue. It was observed retention of 60% or more only resulted in significant increase in soil N stock. No significant impact of residue retention on soil CN ratio was noticed. The CN ratio of soil ranged from 10.77 to 11.53 under the different treatments.

The effect of residue retention on carbon and nitrogen stock and soil CN ratio in 10-20 cm of soil depth is depicted in (Table 2.11b). In lower depth, no significant impact of residue retention on soil carbon & nitrogen stock was observed. Similarly, CN ration was also found to be unaffected by addition of different levels of residue. Except soil carbon and nitrogen stock was much lower in 10-20 cm of soil depth in comparison to 0-10 cm of soil depth.

Table 2.11a & 2.11b: C inputs, soil organic carbon and nitrogen stocks and soil CN ratio as affected by different level of residue retention

Treatments	**Mean annual C input**	**Carbon stock**	**Nitrogen stock**	**CN ratio**
	(Mg ha^{-1})	**(Mg ha^{-1})**	**(Mg ha^{-1})**	
1a. 0-10 cm soil depth				
NT-0% R	2.04	17.69 (0.78)	1.64 (0.06)	10.77 (0.12)
NT-30% R	2.78	18.34 (0.28)	1.59 (0.05)	11.53 (0.30)
NT-60% R	3.56	20.64 (1.08)	1.81 (0.08)	11.42 (0.33)
NT-90% R	4.43	22.44 (0.80)	2.04 (0.11)	11.15 (0.63)
CD (P=0.05)	-	2.43	0.25	NS
CD (P=0.01)	-	3.36	0.35	NS
1b. 10-20 cm soil depth				

	Carbon stock ($Mg\ ha^{-1}$)	Nitrogen stock ($Mg\ ha^{-1}$)	CN ratio
NT-0% R	13.95 (0.74)	0.95 (0.1)	10.66 (0.20)
NT-30% R	13.18 (0.25)	0.91 (0.0)	10.19 (0.33)
NT-60% R	14.25 (0.65)	0.91 (0.1)	10.87 (0.33)
NT-90% R	13.72 (0.54)	0.91 (0.0)	10.45 (0.30)
CD (P=0.05)	NS	NS	NS
CD (P=0.01)	NS	NS	NS

Relationship between the cumulative carbon input and change in soil carbon stock (0-10 cm depth) is depicted in Figure 2.22. A linear relationship between cumulative carbon input and change in soil carbon stock was observed. A highly significant correlation existed between the amount of C addition and change in SOC content ($R^2 = 0.968$, $p \leq 0.01$). The intercept of the equation (0.915 Mg C ha^{-1}) represent the annual C loss of SOM. Equating this intercept with K x Cs of the Jenkinson (1988) equation and setting the initial SOC at 17.69 Mg ha^{-1} C in surface 10 cm soil layer, the decay rate of native SOC was 0.0517 y^{-1} that indicated C loss from native SOC during 6 years was 5.1% of the initial SOC content. The $t_{1/2}$ was worked out to be 19.34 years, indicating that in the event of no addition of carbon to these soils C levels will decline sharply as there is more labile fraction or active pool of carbon in these soils.

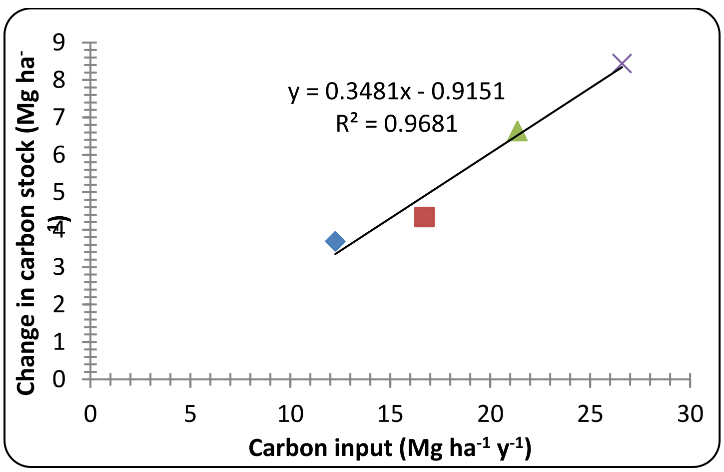


Fig 2.22 Relationship between carbon input and change in soil carbon stock

C) Soil Carbon Pools

The effects of residue retention on the soil carbon pools were more pronounced on the surface than in the subsurface soil layers; these effects were significant at a depth of 0 to 5 cm (Table 2.12a & 2.12b). It was observed that retention of residue significantly increased very labile (VL) pool of soil organic matter. Retention of residue mainly contributed carbon to very labile pool. Very labile pool of carbon ranged from 4.6 g kg^{-1} in 0% residue retained plot to as high as 6.9 g kg^{-1} in 90% of residue retained plot. The 90% of residue retention resulted in 50% increase in very labile pool of soil organic carbon. Retention of 30 and 60% of residue also resulted in 15 and 20% improvement in very labile pool of carbon, respectively. Nevertheless, the observed differences between the two treatments at these two layers did not reach significant level ($P \leq 0.05$). No significant difference in labile pool of carbon was recorded amongst the treatments. Labile pool of carbon ranged between 1.5 and 2.6 g kg^{-1} under different levels of residue retention. There was significant effect of residue retention on less labile pool of soil organic carbon. It was found the lowest under 0% of residue retention plot and significantly higher in plots where residues were retained. It was observed that retention of residue resulted in 125 to 150% improvement in less labile pool of soil organic carbon. Table 3a clearly depicts that retention of residue did not affect recalcitrant or non labile pool of soil organic carbon. The non labile pool of soil organic carbon ranged from 4.3 to 4.9 g kg^{-1} under the different treatments. In the 10–20 layer (Table 2.12b), the carbon pool concentrations under different treatment were lesser as compared to 0-10 cm of soil depth. Nevertheless, the observed differences between treatments at 10-20 cm layer did not reach significant level ($P \leq 0.05$).

Table 2.12a & 12.12b: Residue retention impact on very labile (VL), labile (L), less labile (LL) and non-labile (NL) fractions of soil carbon pools

2.12a. (0-10cm soil depth)

Treatments	VL (g kg^{-1})	L (g kg^{-1})	LL (g kg^{-1})	NL (g kg^{-1})
NT-0% R	4.6 (0.3)	2.6 (0.3)	0.8 (0.20)	4.6 (0.29)
NT-30% R	5.3 (0.2)	1.5 (0.3)	1.8 (0.18))	4.3 (0.06)
NT-60% R	5.5 (0.8)	2.2 (0.8)	2.0 (0.29)	4.8 (0.30)
NT-90% R	6.9 (0.4)	2.4 (0.4)	1.8 (0.30)	4.9 (0.23)
CD (P≤0.05)	1.29	NS	0.79	NS
CD (P≤0.01)	NS	NS	NS	NS

2.12b. (10-20 cm soil depth)

NT-0% R	3.77 (0.27)	0.68 (0.19)	1.84 (0.33)	3.75 (0.20)
NT-30% R	2.97 (0.13)	0.91 (0.24)	1.79 (0.20)	3.54 (0.18)
NT-60% R	2.82 (0.21)	0.81 (0.10)	2.09 (0.27)	4.10 (0.38)
NT-90% R	3.45 (0.31)	0.56 (0.19)	1.48 (0.46)	3.96 (0.41)
CD (P=0.05)	NS	NS	NS	NS
CD (P=0.01)	NS	NS	NS	NS

The effects of retention of residue on the POM-C and POM-N were more pronounced on the surface (0-10 cm) than in the subsurface soil layers (10-20 cm) under soybean-wheat rotation at ICAr-IISS, Bhopal; these effects were highly significant at a depth of 0 to 10 cm (Table 4a, $P \leq 0.05$). Retention in 90% of residue of previous crops over a period of six years resulted in an increased POM-C by 54.5% and POM-N by 47% in the 0–10cm layer compared to the no residue retained treatment. It was observed that with increase in quantity of residue retention, there was gradual increase in POM-C concentration. Retention of 30 and 60% of residue also resulted in 22 and 39.7% improvement in POM-C concentration over no residue retention. The POM-N content of the soil was also significantly affected by retention of residue (Table 2.13). The POM-N content varied from 0.53 to 0.78 g kg^{-1} under different levels of residue retention. In case of POM-N, only 60 and 90% of residue retention treatments could significantly affect the POM-N content while, retention of 30% residue of previous crop failed to make any significant change in POM-N concentration. In case of, mineral associated carbon and nitrogen (MAC and MAN) no significant impact of residue retention was recorded. In general, mineral associated carbon was found lesser than the POM-C concentration. Whereas, mineral associated nitrogen concentration was found more than the POM-N concentration. The concentrations of POM-C and POM-N were conspicuously lower at deeper soil layer. However, no significant impact of residue retention on concentrations of POM-C, POM-N, MAC and MAN were recorded.

Table 2.13a & 2.13b: Soil particulate organic matter carbon (POM-C), mineral associated carbon (MAC), particulate organic matter nitrogen (POM-N) and mineral associated nitrogen (MAN) content as affected by different level of residue retention

4a. (0-10 cm soil depth)

Treatments	POM-C (mg kg^{-1})	MAC (mg kg^{-1})	POM-N (mg kg^{-1})	MAN (mg kg^{-1})
NT-0% R	6.8 (0.32)	5.8 (0.50)	0.53 (0.05)	0.69 (0.04)
NT-30% R	8.3 (0.30)	4.7 (0.30)	0.44 (0.05)	0.69 (0.08)
NT-60% R	9.5 (0.70)	5.1 (0.50)	0.68 (0.07)	0.76 (0.08)
NT-90% R	10.5 (0.60)	5.4 (0.50)	0.78 (0.07)	0.65 (0.06)
CD (P=0.05)	1.47	NS	0.2	NS
CD (P=0.01)	2.03	NS	0.27	NS

4b. (10-20 cm soil depth)

NT-0% R	3.6 (0.4)	7.4 (0.3)	0.12 (0.10)	0.80 (0.09)
NT-30% R	3.7 (0.3)	6.4 (0.2)	0.26 (0.03)	0.64 (0.02)
NT-60% R	4.6 (0.4)	6.8 (0.4)	0.22 (0.07)	0.69 (0.09)
NT-90% R	3.7 (0.3)	6.8 (0.2)	0.19 (0.03)	0.72 (0.06)
CD (P=0.05)	NS	NS	NS	NS
CD (P=0.01)	NS	NS	NS	NS

***D) In-situ* decomposition of wheat, maize and soybean residues as affected by placement method**

Residues decomposition in field and subsequent mineralization/immobilization of nutrients is an important process having large influence on soil quality and organic matter formation. An eight month long field study was conducted to investigate the decomposition and nitrogen dynamics from surface-placed and incorporated wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and soybean (*Glycine max* L.) residues under soybean-wheat cropping sequence using the nylon mesh bag technique in central India. Residues mass loss (Figure 2.23) and carbon mineralization (Figure 2.24) followed first order decomposition kinetics. The decomposition was much faster under incorporated residue in comparison to surface retained. On mass basis, wheat residue decomposed to the extent of 46.8 and 68.9% in surface retained and incorporated condition, respectively. During the same period, wheat residue carbon was mineralized to the tune of 37 and 75% in surface retained and incorporated conditions, respectively. The trend was almost similar for maize residue. It was decomposed 51 and 73% in surface retained and incorporated condition, respectively. Maize residue carbon was mineralized to the extent of 58 and 74% in surface retained and incorporated condition, respectively. In case of soybean, the decomposition was much faster in comparison to wheat and maize residues. Here, 68 and 80% of soybean residue was decomposed under surface retained and incorporated condition, respectively. Soybean residue carbon mineralized to the tune of 69 and 79% under surface retained and incorporated condition, respectively. Nitrogen concentration in surface residues of wheat and maize increased throughout the decomposition cycle due to microbiological immobilization whereas both in case of surface placed and incorporated soybean residues, nitrogen immobilization occurred in first three months only thereafter nitrogen mineralization occurred. In case of subsurface incorporated wheat and maize residues, immobilization occurred in initial five months thereafter net mineralization occurred.

Table 2.14 Residue carbon input (Mg ha^{-1})

	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	Total
NT-0% R	2.063	2.183	2.48	1.22	1.521	2.782	12.2
NT-30% R	2.063	2.183	2.48	2.314	2.755	4.914	16.7
NT-60% R	2.063	2.183	2.48	3.404	4.209	7.017	21.4
NT-90% R	2.063	2.183	2.48	4.637	5.685	9.552	26.6

Fig 2.23

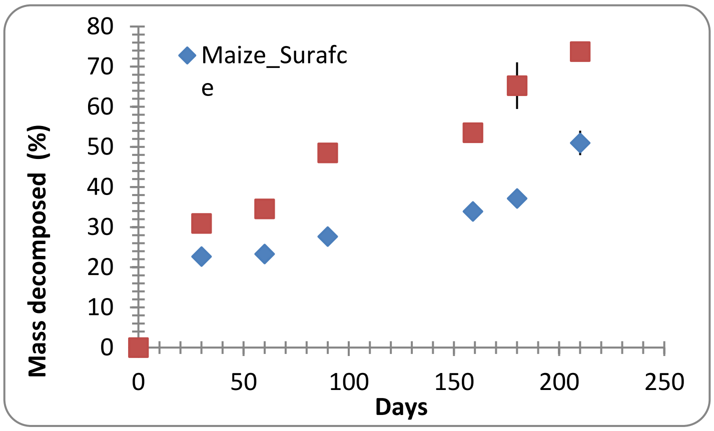
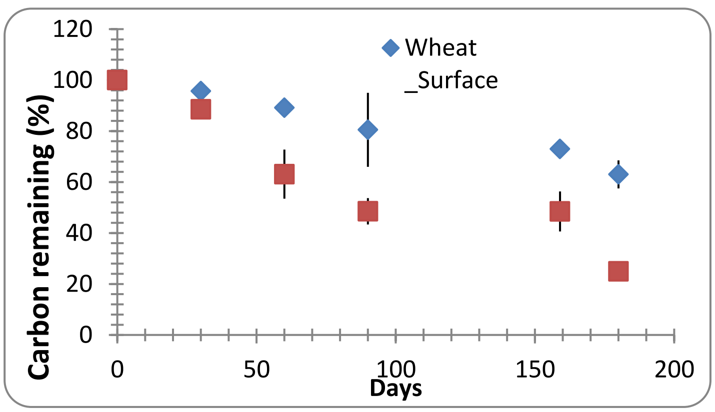
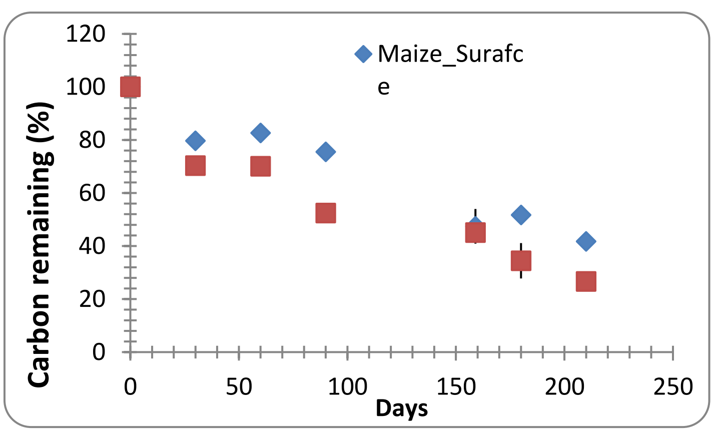
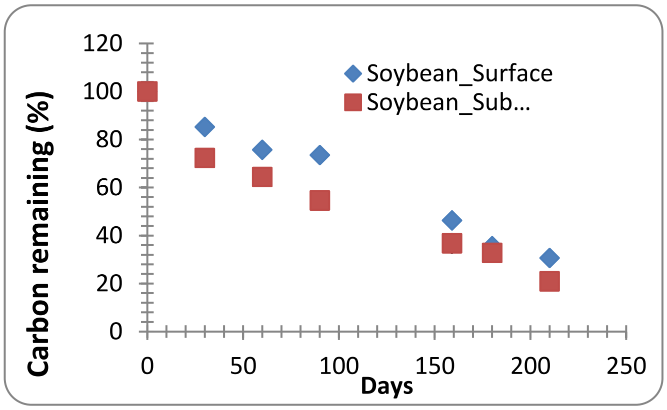
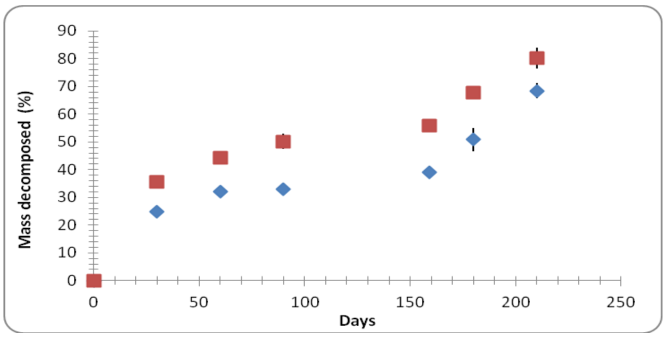


Fig 2.24









The total organic carbon of surface soil (0-15 cm) was found significantly higher in zero tillage DSR practice (ZT-DSR-ZT-GG) compared to conventional and zero tillage TPR (ZT-TPR-ZT-GG) system at NRRI, Cuttack (Table 2.15). The increase in total carbon was 16.90 and 7.04% higher in ZT-DSR-ZT-GG compared to CT-DSR-CT-GG and ZT-TPR-ZT-GG, respectively, while CT-DSR-CT-GG had a lower value than the initial. On retention of residue in ZT-DSR-ZT-GG led to a significantly ($p < 0.05$) higher (7%) total SOC concentration in the surface layer compared with ZT-TPR-ZT-GG. The increase in total SOC under ZT-DSR-ZT-GG (double ZT with residue retention) was mainly because of no tillage and continuous addition of fresh organic matter which promoted less disruption of soil aggregates and consequently greater physical protection of SOC inside macro aggregates, thus forming particulate organic matter. Maintenance of a low temperature regime and increased water retention slowed down decomposition of SOMon CA plots. Surface retention of residue protected the soil surface from raindrop impact.Although the same amount of residue was retained on both the ZT-DSR-ZT-GG and ZT-TPR-ZT-GG plots, the latter treatment led to more SOC oxidation due to disturbance during mechanical transplanting in rice. However, both the CA based treatments showed higher SOC compared to conventional tillage practice (CT-DSR-CT-GG). The magnitude of different pools of OC in soils extracted under a gradient of oxidizing conditions varied significantly ($p < 0.05$) with different management practices (Table 2.15). Permanganate oxidizable carbon content of the soils also varied significantly among the treatments ($p < 0.05$). On average, ZT-DSR-ZT-GG (339.05 mg kg^{-1}) treatment had a much higher amount of permanganate oxidizable carbon (Pox) than CT-DSR-CT-GG (293.3 mg kg^{-1}). It is interesting to note that, the ZT-TPR-ZT-GG showed non-significant difference in all the carbon pools with ZT-DSR-ZT-GG. However, there was significant variation in the magnitude of different pools of OC in soils with values ranging from 293.3 to 339.05, 117 to 184.06, 871.2 to 1295.7 and 133.8 to 303.7 mg kg^{-1} constituting, on average, about 4.7 to 4.9, 1.98 to 2.70, 14.7 to 18.2 and 2.2 to 4.2 % of the TOC for POx-C, WSC, POC and MBC, respectively at 0-15 cm soil depth.

Table 2.15 Carbon fraction and carbon stock in soil as influenced by tillage and residue management after 5 years of conservation agriculture practices

Tillage Practices (T)	POx-C	WSC	POC	MBC	TOC	C Stock	Total C sequestration
	(mg kg^{-1})	(mg kg^{-1})	(mg kg^{-1})	(mg kg^{-1})	(g kg^{-1})	(Mg ha^{-1})	(Mg C ha^{-1})
CT-DSR-CT-GG	293.3C	117B	871.2C	133.8	5.9C	12.2C	-0.22C
ZT-TPR-ZT-GG	322.8AB	178.06A	1089.2B	254.6	6.6B	14.1B	1.70B
ZT-DSR-ZT-GG	339.05A	184.06A	1295.7A	303.7A	7.1A	15.5A	3.13A
LSD (P ≤ 0.05)	15.7	14.5	118.2	16.4	0.3	0.8	0.078
Green gram varieties(M)							
IPM 2-3	252.4	115.8	1054.08	213.7B	5.9B	12.5	0.08C
IPM 02-14	257.03	119	1093.4	241.3A	6.8A	14.5	2.08B
Local check	262.9	114.6	1108.7	237.2A	6.9	14.7	2.28A
LSD (P ≤ 0.05)	NS	NS	NS	11.7	0.3	0.7	0.084
Interaction (P ≤ 0.05)							
T*M	23.3	NS	NS	23.1	0.6	1.2	NS

POx-C: Permanganate oxidizable carbon, WSC: Water soluble carbon, POC: Particulate organic carbon, MBC: Microbial biomass carbon and TOC: Total organic Carbon. Allocation of SOC into passive pools of longer residence time helped to achieve higher C-sequestration in soils. In all the treatments non-labile pools(SOC_{NL}) was the largest fraction of total SOC, followed by very-liable (SOC_{VL}), liable (SOC_{L}) and less liable (SOC_{LL}) (Supplementary Fig. 2.15). Among the treatments, ZT-TPR-ZT-GG had the highest values of SOC_{VL} and SOC_{NL} pools compared to conventional system. However, the CA practices had greater impact on the SOC_{VL}. Compared with CT-CT, SOC_{VL} concentration increased significantly with the adoption of zero tillage and residue retention in both crops (ZT-ZT). Dey *et al.,* 2018 demonstrated that residue retention (ZT-ZT+R) resulted an increase in SOC_{VL} with values higher by ~50% ($p < 0.05$) over conventional tillage system under 6 year of experiment. The present investigation revealed that although the SOC_{VL} was increased in zero tillage over conventional system but the difference was less. This implied that 5 years of CA were not sufficient to alter these relatively more recalcitrant pools of SOC. However, even with long perturbations for cultivation with different management practices, a net enrichment in SOC was observed with CA based practices. Annual cumulative C sequestration into the experimental soils through conservation treatments during the long 5 years of continuous cropping varied from 0.56Mg C ha^{-1} yr^{-1} in ZT-TPR-ZT-GG the to as high as 1.04 Mg C ha^{-1} yr^{-1} in ZT-DSR-ZT-GG system (Table 3). However, a negative C sequestration potential (-0.071 Mg C ha^{-1} yr^{-1}) was observed in CT-DSR-CT-GG. Again, ZT-DSR-ZT-GG system also exhibited a higher rate of sequestration of C (1.042 Mg C ha^{-1}yr^{-1}) over the other treatments. It is important to note that, the selected green gram varieties showed significant variation in total C stock and total C sequestration. The data presented in Table 3 revealed that the local check showed highest C sequestration potential (0.760 Mg C ha^{-1} yr^{-1})over other varieties.

By virtue of improved aggregation, CA-based systems provided better soil physical environment, which provided enhanced protection for soil organic matter (SOM) (Bhattacharyya et al., 2019).Under ZT-based CA practices, the SOC from the retained crop residues gets enough time to encapsulated, undergo bio-chemical transformation towards chemical recalcitrance(Jatetal.,2019). An array of literatures showed that crop residues retained over surface decompose 1.5 to3 times slower than the incorporated residues.
A stable thermal regime prevails ZT-TPR-ZT-GG and ZT-TPR-ZT-GG due to residue retention on soil surface, which further, restrict the rapid decomposition of SOM. This is responsible for huge build-up of

total SOC over initial values under these treatments. Therefore, these CA-based plots ensured significantly higher C sequestration potential in the long-run as compared with CT-DSR-CT-GG system. In addition of adding stable SOC content in soil surface-retained residues protect the soil from raindrop impact, resulting less erosion, in turn enhancing stability of SOC.

A field experiment was conducted to study the effect of different establishment methods on rice grain yield, soil organic carbon and energy use efficiency under zero tillage (ZT) practice. The main plot treatments consisted of two establishment methods (1) wet direct seeded rice (WDSR) and (2) puddle transplanted rice (TPR). Two subplot treatments consisted of (1) with residue and (2) without residue retention. Same treatment combinations were taken under conventional tillage as control with three replications. Therefore, a total of eight treatment combinations were: ZT-WDSR with residue (T1), ZT-WDSR without residue (T2), ZT-TPR with residue (T3), ZT-TPR without residue (T4), conventional-WDSR with residue (T5), conventional-WDSR without residue (T6), conventional-TPR with residue (T7), conventional-TPR without residue (T8). The data of rice grain yield, soil organic carbon and energy use efficiency under zero tillage were collected and calculated using standard methodology. A total of eight treatment combinations were evaluated using Hierarchical Agglomerative Clustering (dendrogram) to check the similarity/ dissimilarity among the treatments. The dendrogram is presented in Fig.2.15. Based on the effect of treatments on yield, change in SOC and their associated energy use efficiency, the dendrogram constructed showed two major clusters: cluster 1, which includes conventional-WDSR and conventional-TPR with residue and without residue (T5, T6, T7 and T8); and cluster 2, which includes ZT- WDSR and ZT-TPR with residue and without residue (T1, T2, T3 and T4). The interpretation of dendogram showed that, T5 and T6 were the most similar group and having 2nd level of similarity with T8. Further, in cluster 2, T3 and T4 exhibited a second level of similarity. Again, ZT-WDSR with residue (T1) is similar to ZT-TPR with residue (T3), ZT-TPR without residue (T4) at 3rd level of similarity.

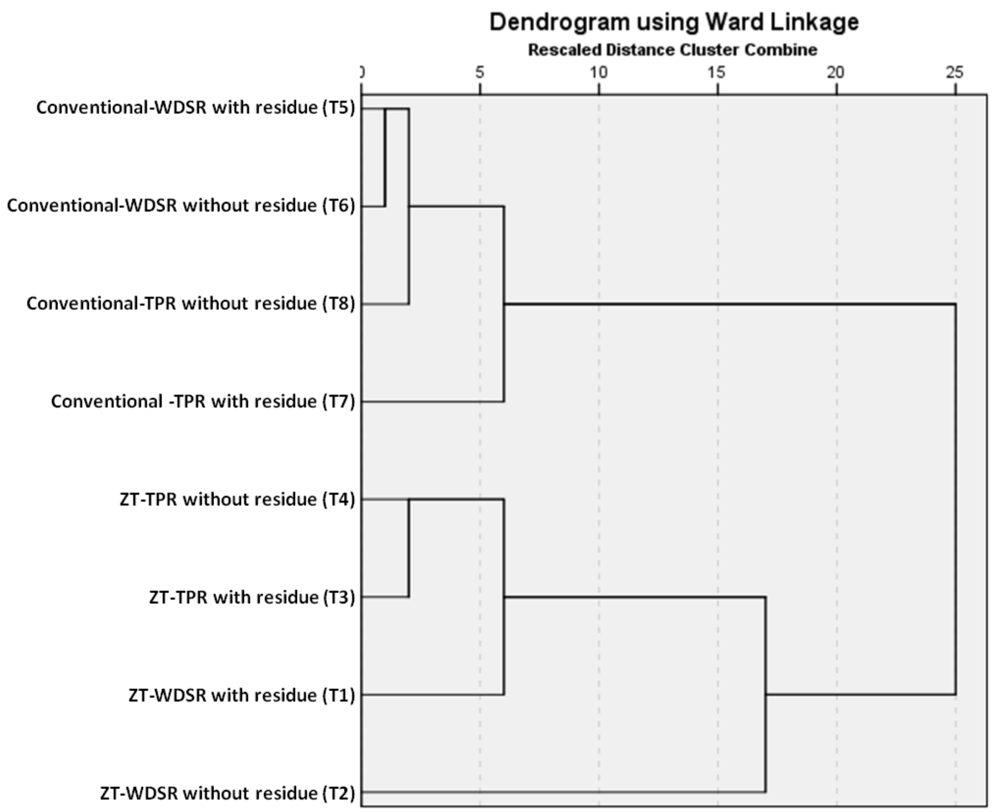
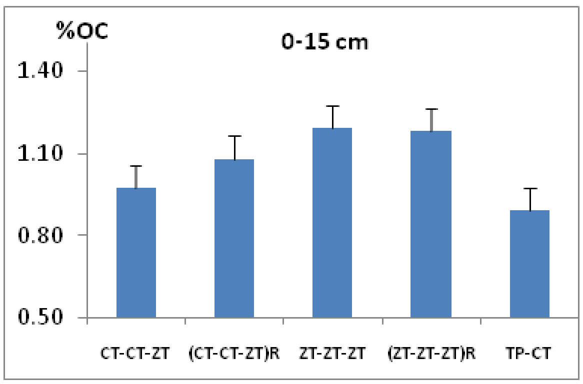
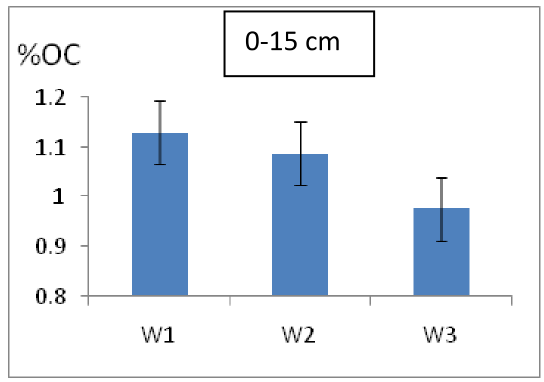


Fig 2.25 Based on the study, ZT is found to be completely different from conventional tillage. Another important highlight is similar clustering of ZT-TPR (with and/or without residues) and ZT-WDSR with residue. This lay emphasis on the role of residue in WDSR. Therefore, it may be concluded that ZT-TPR or ZT-WDSR may not be recommended to be replaced by each other, but simply add another rice crop establishment methodology for ZT rice cultivation, for the farmers to choose from on needed basis.

At ICAR-DWR, Karnal, analysis of soil samples from an ongoing long-term field trial shows that the SOC content of surface layer (0-15 cm depth) changed significantly due to conservation practices followed during the last 8 years (Fig 2.26a). The SOC content was lowest in the plots where the traditional practice of transplanted TPR-CT-ZT was practiced. The practice of CT-DSR-CT-ZT showed significant improvement in SOC content over traditional TP-CT-ZT. The recycling of crop residues in CTR-CTR-ZTR significantly improved the SOC content over CT-CT-ZT alone treatment. The highest SOC was recorded under ZT-ZT-ZT and ZTR-ZTR-ZTR. However, the SOC content of sub-surface soil layer (15-50 cm) did not vary among the tillage treatments tested. This indicated that the benefit of tillage and crop residue recycling in terms of SOC built-up has not reached below plough layer till now.



a. Effect of tillage



b. Effect of weed control measures

Fig 2.26 Effect of conservation practices and weed control measure on SOC content in rice-wheat-green gram sequence.

Among the weed management practices, weedy check plots showed the highest SOC content; and the plots where herbicides were integrated weed management with herbicide rotation showed the lowest SOC in surface layer (Fig 2.26b). Gigantic growth of weed biomass and its subsequent recycling in the soil, season after season, during the last 8 years could be the possible reason behind the highest SOC level as observed under weedy check. The integrated weed management with herbicide rotation plots encountered relatively lower weed biomass recycling compared to continuous use of recommended herbicides.

Similarly, at ICAR-IIFSR, Modipuram, WBC ranged from 3.94 g/kg to 5.48 g/kg among the different cropping systems (Table 2.16). Among the cropping systems, the rice-wheat cropping systems both in conventional and conservation agricultural practices recorded highest WBC as compared to other cropping systems. In case of soil depths, the surface soil samples recorded significantly higher (4.15 g/kg) WBC over the sub-surface soil samples.

Table 2.16 Various soil chemical properties as influenced by different resource conservation practices.

	WBC (g kg^{-1})
R-W (CP)	5.40
R-W-GRG (CA)	5.48
M-W (CP)	3.36
M(cob)-Must-GRG (CA)	4.80
M-W-GRG(CA)	5.15
R-W-Ses(CA)	4.21
S-R-W(CP)	3.95
S+GRG-R-W(CA)	3.94
Sem (±)	0.370
C.D.	1.075
Soil Depth	
0-15 cm	4.15
15-30 cm	3.68
Sem (±)	0.185
C.D.	NS

E. Available Nutrients (N, P, K) in Conservation Agriculture

In the CA-based rice-wheat cropping system at ICAR-IARI, New Delhi, a triple ZT system i.e.,MbR+ZTDSR-RR+ZTW-WR+ZTMb and a double ZT system i.e, WR+ZTDSR-RR+ZTW led to significantly higher values of N and K at 0-5 cm soil depth but with respect to N at 5-15 cm soil layer, WR+ZTDSR+BM-RR+ZTW proved superior to others except ZTDSR+BM-ZTW and WR+ZTDSR-RR+ZTW treatments, and had significantly higher value of N (Table 2.17). However, these treatments were superior to TPR-CTW. With respect to K, WR+ZTDSR+BM-RR+ZTW and WR+ZTDSR-RR+ZTW treatments were comparable with each other. Available P at 0-5 cm soil depth was significantly higher in WR+ZTDSR+BM-RR+ZTW (~107 kg/ha) than conventional TPR-CTW system and other CA systems.

Table 2.17 CA practices effects on available N, P, and K (kg/ha) in soil of the rice-wheat system

Treatment	Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)	
	0-5 cm	5-15 cm	0-5cm	5-15 cm	0-5 cm	5-15 cm
ZTDSR-ZTW	229^{bc}	216^{b}	62.12^{d}	45.8^{c}	762^{b}	301^{e}
ZTDSR+BM-ZTW	250^{ab}	223^{ab}	68.89^{cd}	49.7^{bc}	798^{ab}	331^{cd}
WR+ZTDSR-RR+ZTW	285^{a}	223^{ab}	72.87^{c}	52.7^{ab}	874^{a}	436^{a}
WR+ZTDSR+BM-RR+ZTW	264^{ab}	250^{a}	107^{a}	51.9^{ab}	800^{ab}	437^{a}
ZTDSR-ZTW-ZTMb	229^{bc}	216^{b}	47.3^{e}	32.4^{d}	440^{d}	304^{de}
MbR+ZTDSR-RR+ZTW-WR+ZTMb	278^{a}	202^{b}	93.1^{b}	54.7^{a}	866^{a}	397^{b}
TPR-ZTW	229^{bc}	223^{ab}	97.5^{b}	49.1^{bc}	727^{b}	337^{c}
TPR-CTW	202^{c}	195^{b}	93.1^{b}	49.5^{bc}	627^{c}	321^{cde}

LSD (P=0.05)	42.1	29.8	8.32	4.16	81.2	28.1

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F. NH_4 - N and NO_3 – N Concentration (mg kg $^{-1}$)

NH_4 - N and NO_3 - N concentration under different tillage and cropping systems was presented in (Table 2.18). Overall, NH_4 – N and NO_3 - N concentration in the end of *rabi* samplings were not significantly influenced (P > 0.05) by tillage systems. However, nutrient levels had a significant effect on NH_4 – N and NO_3 - N concentration at the study stages. In general, the higher concentration of NH_4– N recorded in RT with 60 cm residue height in end of *rabi* samples (47.29 mg kg $^{-1}$). Conventional tillage had lower NH_4 – N value than NT and RT systems. Among the nutrient management treatments had a significant (P < 0.05) effect. In general, among nutrient dose STCR dose were higher (45.13 mg kg $^{-1}$) in NH_4 - N than other systems. The data indicated that the concentration of NO_3 -N increased under RT (RT with 60 cm residue height) as compared to NT and CT in the end of *rabi* samples (135.76 mg kg $^{-1}$). Minimum value recorded under CT (127.05 mg kg $^{-1}$). Nutrient dose had a significant effect (P <0.05) on NO_3 – N. Maximum value was observed under STCR dose (136.44 mg kg $^{-1}$) at the study stages. Interaction of effect of tillage system and nutrient dose did not find significant effect on NH_4 – N.

Table 2.18 NO_3-N and NH_4-N concentration (mg kg $^{-1}$) at the end of *rabi* season (2020-21) as influenced by different tillage system and nutrient management practices.

Treatment	**NO_3-N concentration (mg kg $^{-1}$)**	**NH_4-N concentration (mg kg $^{-1}$)**
	End of *rabi*	**End of *rabi***
Tillage		
T_1 - NT with 30cm height residue	129.41	44.31
T_2 - NT with 60cm height residue	134.29	42.96
T_3 - RT with 30cm height residue	129.83	40.55
T_4 - RT with 60cm height residue	135.76	47.29
T_5 – CT (Conventional Tillage)	127.05	35.11
Mean	131.27	42.04
SEm ±	2.437	3.632
CD (P≤ 0.05)	NS	NS
Nutrient levels		
N_1 - 75% RDF	123.47	36.45
N_2 -100% RDF	133.90	44.55
N_3 - STCR dose	136.44	45.13

Mean	131.27	42.04
SEm ±	1.169	1.331
CD (P≤ 0.05)	3.472*	3.955*
Interation (TSXND)		
SEm±	3.239	4.370
CD (P≤ 0.05)	NS	NS

T_1- No Tillage (NT) with 30cm height residue; T_2- No Tillage (NT) with 60cm height residue; T_3- Reduced Tillage with 30cm height residue; T_4- Reduced Tillage with 60cm height residue; T_5- Conventional Tillage (CT)/Farmers practices; N_1- 75% RDF (Recommended Dose of Fertilizer); N_2- 100% RDF; N_3- STCR dose (Soil Test Crop Response); TS- Tillage System; ND- Nutrient Dose; D- Depth; *significant at P≤ 0.05; NS- Non-Significant at P>0.05.

Under cotton-wheat system at ICAR-IARI, New Delhi the values of N were significantly higher in ZTFB+R and ZTBB+R compared to CT and most other CA treatments at 0-5 and 5-15 cm depths of soil. Available P was highest with ZTFB+R at 0-5 cm soil and with ZTBB+R at 5-15 cm depth of soil. Available K was significantly higher in the ZTBB+R at both 0-5 and 5-15 cm depths but ZTFB+R recorded comparable value at 0-5 cm soil.

Table 2.19 CA practices effects on available N, P, and K (kg/ha) in soil of the cotton-wheat system

Treatment	Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
CT	223^{de}	188^{c}	94.5^{bc}	47.7^{b}	535^{b}	267^{d}
ZTNB-R	223^{de}	209^{bc}	63.3^{e}	24.0^{f}	400^{c}	246^{e}
ZTNB+R	243^{bc}	223^{ab}	94.3^{bc}	30.0^{d}	746^{a}	346^{b}
ZTBB-R	229^{cd}	216^{bc}	86.6^{d}	43.4^{c}	599^{b}	230^{e}
ZTBB+R	257^{ab}	250^{a}	99.7^{b}	58.7^{a}	806^{a}	559^{a}
ZTFB+R	271^{a}	229^{ab}	108^{a}	31.0^{d}	759^{a}	306^{c}
ZTFB-R	209^{e}	188^{c}	91.5^{cd}	27.0^{e}	577^{b}	204^{f}
LSD (P=0.05)	18.1	33.7	6.89	2.26	71.7	19.0

Study on soil phosphorous fractions (0-5and 5-15 cm soil depth) was done through modified Hedley sequential fractionation scheme to extract seven soil P fractions (Water Soluble P (Solution P), $NaHCO_3$-Pi (inorganic), $NaHCO_3$-Po (organic), NaOH-Pi, NaOH-Po; HCI-P, and residual-P) under maize-mustard conservation agriculture (CA) system at ICAR-IARI, New Delhi and result revealed reduced tillage with crop residue retention and inclusion of mungbean enhanced the availability of P in soil. The highest fraction was contributed by Ca-bound fraction followed by residual fraction (Table 2.20). The zero tillage with residue retention practices significantly increased the water soluble P (Solution P), $NaHCO_3$ extractable fraction (labile P) in both 0-5 cm and 5-15 cm soil layer whereas it didn't significantly affect NaOH extractable fraction as well as HCl extractable fraction. The results of this study would enhance the understanding of P transformation in soil and prove useful in rationalizing nutrient management practice under CA.

Table 2.20 Impact of conservation agricultural practices on different Phosphorus fractions in 0-5 cm soil layer under maize-mustard cropping system

Treatments	Labile P			Moderately labile P		Non labile P	
	Solution P (ppm)	$NaHCO_3$_Pi (ppm)	$NaHCO_3$_Po (ppm)	NaOH_Pi (ppm)	NaOH_Po (ppm)	HCl _P (ppm)	Residual P (ppm)
ZTMz-ZTMs	3.64^{b}	53.1^{bc}	159^{c}	69.2^{bcd}	150^{abc}	209^{c}	195^{a}
ZTMz+BM-ZTMs	6.32^{ab}	53.7^{bc}	161^{c}	77.8^{ab}	154^{ab}	208^{c}	192^{a}
ZTMz(+R)-ZTMs (+R)	8.47^{ab}	54.74^{bc}	165^{c}	72.9^{abc}	145^{cd}	$211b^{c}$	197^{a}
ZTMz(+R)+BM-ZTMs (+R)	9.54^{ab}	62.8^{ab}	187^{b}	79.4^{a}	151^{abc}	209^{c}	196^{a}
ZTMz-ZTMs-ZTSMB	7.29^{ab}	54.2^{bc}	163^{c}	74.0^{abc}	146^{bcd}	204^{c}	199^{a}
ZTMz (+R)-ZTMs(+R)-ZTSMB(+R)	13.8^{a}	69.2^{a}	208^{a}	81.0^{a}	158^{a}	218^{ab}	197^{a}
CTMz-ZTMs	6.00^{ab}	49.9^{c}	148^{d}	67.6^{cd}	141^{d}	224^{a}	192^{a}
CTMz-CTMs	3.57^{b}	48.3^{c}	144^{d}	63.3^{d}	138^{d}	218^{ab}	191^{a}
Pi :Inorganic; Po :Organic; Means followed by similar letter in each site are not significantly different at $P \leq 0.05$ according to Tukey's HSD test							

Nitrogen availability in soil is highly affected by soil and crop management practices, sources of N fertilizers, input of N, climatic conditions, types of crop etc. Thus, it becomes very important to study and explain the effect of tillage, land configuration, and residue retention of CA practices on N transformation in cotton soils at ICAR-IARI, new Delhi. Data on nitrogen fractionation revealed that the total nitrogen (total-N) content in soil varied from 1.09 (CT) to 1.34 (FB) and 1.41 mg kg^{-1} (FB+R) (Figure 2.27).Total-N was found to be the highest in residue retained plots as compared to without residue retained and conventional tillage (CT) plots. Among treatments, total N was significantly highest in treatments T7 (1.41 mg kg^{-1}) and T3 (1.39 mg kg^{-1}) as compared to rest of the treatments.

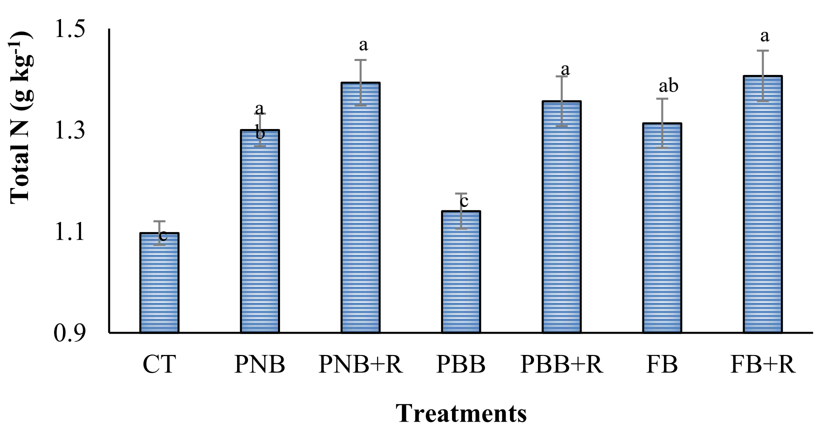


Fig 2.27 Total-N (g kg^{-1}) of soil (0-15 cm) in cotton crop under conservation agriculture. Means followed by same letters are not significantly different at P < 0.05 according to Tukey's HSD test.

Hydrolysable amino sugar N (HASN) in soil ranged from 5% (PNB+R) to 10.2% (CT) of THN. Among treatments highest HASN was recorded 0.10 mg kg^{-1} (T1, T2, and T3) whereas lowest HASN recorded 0.06 mg kg^{-1} (T4, T5 and T7).

Unidentified hydrolysable N (UHN) varied from 0.09 mg kg^{-1} (PBB+R) to 0.24 mg kg^{-1} (FB). Maximum UHN was recorded in treatment T6 (0.24 mg kg^{-1}) followed by treatment T7 (0.22 mg kg^{-1}) > T2 (0.20 mg kg^{-1}) > T4 (0.16 mg kg^{-1}) > T1 (0.15 mg kg^{-1}) > T3 (0.12 mg kg^{-1}) > T5 (0.9 mg kg^{-1}) which was 22.2, 17.7, 19.3, 18.1, 15.6, 10.1, 8.8 % of total hydrolysable N respectively (Table 20).

Non hydrolysable N (NHN) constitutes 12.4% (FB+R) to 22.7% (PBB) of total-N concentration present in soil among different treatment (Table 2.21). The highest NHN was recorded in treatment T6 (0.28 mg kg^{-1}) and it was significantly higher than without residue retained treatments and CT treatment, but statistically at par to residue retained treatments. In general, the fractions which are easily mineralizable or going to be mineralized were higher in residue retained treatments as compared to without residues and conventional tillage treatments. The total hydrolysable N (THN) by 6N HCl and the non-hydrolysable N (NHN) are found to be 82.5% and 17.5% of the total N. The remaining fractions of total hydrolysable N are found to be 28.84 %, 48.07 %, 7.69 %, and 15.38 % are hydrolysable amino N, hydrolysable amino N, hydrolysable amino sugar N, and unidentified hydrolysable N, respectively. It may be concluded that continuous retention of crop residues led to buildup of substantial amount of total N by adoption of CA under cotton-wheat system. Residue retention also led to considerable accumulation in HAN fraction as compared to without residue retained plots with zero tillage, although intensity of increment was varied with tretaments. Among different organic fractions of nitrogen, HAAN concentration was maximum followed by HAN > UHN > HASN. Most importantly, residue retention led to decreased UHN concentration in soil as compared to without residue retained plots under CA.

iv) Organic nitrogen fractions

The Hydrolysable amino acid N (HAAN) constitute 44.2% (PNB) to 54.9 % (PNB+R) of total hydrolysable nitrogen (THN). The minimum HAAN was recorded in treatment T4 and it was statistically similar to CT (T1) and PNB (T2) treatments whereas statistically inferior to rest of the treatments (Table 17). Among residue retained plots highest HAAN concentration was recorded in treatments T7 (0.62 mg kg^{-1}) and T3 (0.58 mg kg^{-1}) which was statically superior to treatment T5 (0.53 mg kg^{-1}) (Table 2.21).

Table 2.21 Distribution of N fractions (mg kg^{-1}) in soil (0-15 cm) of cotton under conservation agriculture.

Treatments	THN	HAN	HAAN	HASN	UHN	NHN
T1 (CT)	0.94^{d}	0.24^{d}	0.46^{d}	0.10^{ab}	0.15^{cd}	0.16^{c}
T2 (PNB)	1.03^{c}	0.28^{c}	0.46^{de}	0.10^{ab}	0.20^{b}	0.27^{ab}
T3 (PNB+R)	1.16^{b}	0.37^{ab}	0.57^{b}	0.10^{a}	0.12^{d}	0.23^{b}
T4 (PBB)	0.88^{e}	0.25^{cd}	0.42^{e}	0.06^{c}	0.16^{c}	0.26^{ab}
T5 (PBB+R)	0.98^{d}	0.38^{a}	0.45^{de}	0.06^{c}	0.09^{e}	0.23^{b}
T6 (FB)	1.06^{c}	0.25^{cd}	0.50^{c}	0.07^{bc}	0.24^{a}	0.28^{a}
T7 (FB+R)	1.24^{a}	0.33^{b}	0.62^{a}	0.06^{c}	0.22^{ab}	0.17^{c}
Mean	1.04	0.30	0.50	0.08	0.17	0.23
Tukey HSD (P≤0.05)	0.04	0.03	0.03	0.02	0.02	0.03

CT: Conventional tillage; PNB: Planting on permanent narrow beds with zero tillage (ZT); PNB+R: PNB with residue retention; PBB: Planting on permanent broad beds with ZT; PBB+R: PBB with residue retention; F: Zero tillage; ZT+R: ZT with residue retention. Total Hydrolysable N (THN); Hydrolysable amino N (HAN); Hydrolysable amino acid N (HAAN); Hydrolysable amino sugar N (HASN); Unidentified Hydrolysable N (UHN); Non-Hydrolysable N (NHN). Means followed by same letters within a column are not significantly different at $P < 0.05$ according to Tukey's HSD test.

The soil samples collected at the harvest of *kharif* crops showed that the treatments under conservation agricultural practices recorded higher available nitrogen content over the conventional practices at both the depth of soil samplesat ICAR-IIFSR, Modipuram. Among the cropping systems, rice-wheat-greengram (CA) recorded significant highest (134.0 mg/kg) available N content followed by maize (cob)-mustard-greengram (CA) (130.5 mg/kg) and maize-wheat-greengram (CA) (130.5 mg/kg) (Table 2.22). The available P content at 0-15 cm soil depth among all the soil sample was found 27.51 kg/ha; while 20.91 kg/ha available P content was recorded at 15-30 cm soil depth. Among the cropping systems; rice-wheat-sesbania (CA) recorded 37.29 kg/ha available P content followed by maize (cob)-mustard-greengram(CA) (34.70 kg/ha) and sugarcane + greengram-ratoon-wheat (CA) (34.62 kg/ha) cropping systems. Residue retention in the conservation agriculture treatments resulted in higher available potassium (K) among CA treatments as compared to conventional practices. Among the cropping systems; sugarcane + greengram-ratoon-wheat (CA) recorded significant highest (277.5 kg/ha) available K content followed by maize (cob)-mustard-greengram (CA) (230.1 kg/ha) and sugarcane-ratoon-wheat (CP) (227.3 kg/ha). The surface soil sample (0-15 cm) recorded significant highest (229.1 kg/ha) available K content as compared to sub-surface soil samples. Among the cropping systems

Table 2.22 Various soil chemical properties as influenced by different resource conservation practices.

	Avail. N (mg/kg)	Avail. P (kg/ha)	Avail. K (kg/ha)
Cropping Systems (CS)			
R-W (CP)	102.9	30.03	139.3
R-W-GRG (CA)	134.0	33.56	161.6
M-W (CP)	111.5	30.58	144.3
M(cob)-Must-GRG (CA)	130.5	34.70	230.1
M-W-GRG(CA)	130.5	31.54	175.6
R-W-Ses(CA)	106.4	37.29	167.0
S-R-W(CP)	112.1	28.33	227.3
S+GRG-R-W(CA)	115.9	34.62	277.5
Sem (±)	10.41	1.319	14.33
C.D.	NS	3.827	41.58
Soil Depth			
0-15 cm	120.9	27.51	229.1
15-30 cm	115.0	20.91	151.5
Sem (±)	5.206	0.659	7.163
C.D.	NS	1.913	20.79

Where; Avail. N= available nitrogen; Avail. P= available phosphorus; Avail. K= available potassium; R-W=Rice-wheat; R-W-GRG=Rice-wheat-green gram; M-W=maize-wheat; M(cob)-must-GRG=Maize(cob)-mustard-green gram; M-W-GRG=Maize-mustard-green gram; R-W-Ses. = Rice-wheat-*Sesbania*; S-R-W=Sugarcane-ratoon-wheat; S+GRG-R-W= Sugarcane + green gram-ratoon-wheat cropping systems. CP=Conventional practices; CA=Conservation agriculture.

Nitrogen Use Efficiency under Different Irrigation Systems at CSSRI, Karnal

Application of nitrogen fertilizer/urea by using leaf colour chart, always maintained at LCC No 4/5. The nitrogen through urea was applied via fertilizer tank @ 2.5 kg with irrigation water on scheduled day. The results of nitrogen use efficiency (NUE) for wheat crop presented in Table 2.23.

1. Nitrogen Use Efficiency Vs Mini Sprinkler Irrigation System
Nitrogen use efficiency in mini sprinkler irrigation system was almost doubled than the CTW (34.0 kg grain kg^{-1} N applied) and it varied from 69.3 to 70.9 kg grain kg^{-1}N applied. Fertigation in mini sprinkler irrigation used 80 kg N ha^{-1} which was about 46% lower than the recommended dose nitrogen (150 kg urea ha^{-1}) as compared to conventional tilled wheat (CTW).

2. Nitrogen Use Efficiency Vs Drip Irrigation Method in Wheat Crop
Nitrogen use efficiency in drip irrigation system was 37.9 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 (Table 2.23).

Table 2.23. Effect of different irrigation systems on wheat yield, irrigation water requirement, water productivity, saving of water and nitrogen use efficiency during *rabi*2020-21.

RCTs	Conventional Wheat Sowing	Zero Tilled Wheat with100% Rice Mulch			
Treatments	PTR/CTW	DRIP-RTDSR/ ZTW+RM	SIS-RTDSR/ ZTW+RM	MSIS-RTDSR/ ZTW+RM	MSIS-RTDSR+RI/ ZTW+RM
Mode of irrigation	Surface (T_1)	Drip (T_7)	Surface (T_8)	Mini – Sprinkler(T_9)	Mini – Sprinkler(T_{10})
Irrigation criteria	Growth stages	(Previous 7 days CPE)	Growth stages	(Previous 7 days CPE)	(Previous 7 days CPE)
Grain yield (tha^{-1})	5.10	5.68	5.55	5.67	5.54
Irrigation water applied (ha-mm)	256	163	256	182	182
Rainfall received (mm)	67	67	67	67	67
Total water (Irr. +rainfall; ha-mm)	322	230	322	248	248
Irrigation water productivity (kg m^{-3})	1.99	3.48	2.17	3.12	3.05
Total water productivity (kg m^{-3})	1.58	2.47	1.72	2.29	2.23
Irrigation water saving (%)	-	36.2	0.0	29.0	29.0
N applied (kg ha^{-1})	150	150	150	80	80
NUE (kg grain kg^{-1} nitrogen)	34.0	37.9	37.0	70.9	69.3
% Saving of N	-	0.0	0.0	46.7	46.7
CPE= Cumulative potential evaporation					

(Note: PTR- Puddled transplanted rice; RTDSR- Direct seeded rice in reduced tillage; CTW-Conventional tilled wheat; ZTW- Zero tilled wheat; RI- Residue incorporation; RM- Residue mulch; DRIP- Drip irrigation system; SIS- Surface irrigation system; MSIS- Sprinkler irrigation system)

3. Nitrogen use efficiency vs surface irrigation method in wheat crop

Under surface irrigation method nitrogen use efficiency was 37.0 kg grain kg^{-1} N in zero tilled wheat sown by Turbo/happy seeder in 100% rice crop residue mulch (SIS-CTW+RM), 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.

Table 2.24 Effect of different irrigation systems on wheat yield, irrigation water requirement, water productivity, saving of water and nitrogen use efficiency during *rabi*2020-21.

Rcts	Conventional Wheat Sowing	Zero Tilled Wheat With100% Rice Mulch			
Treatments	PTR/CTW	DRIP-RTDSR/ ZTW+RM	SIS-RTDSR/ ZTW+RM	MSIS-RTDSR/ ZTW+RM	MSIS-RTDSR+RI/ ZTW+RM
Mode of irrigation	Surface (T_1)	Drip (T_7)	Surface (T_8)	Mini – Sprinkler(T_9)	Mini – Sprinkler(T_{10})
Irrigation criteria	Growth stages	(Previous 7 days CPE)	Growth stages	(Previous 7 days CPE)	(Previous 7 days CPE)
Grain yield (tha^{-1})	5.10	5.68	5.55	5.67	5.54
Irrigation water applied (ha-mm)	256	163	256	182	182
Rainfall received (mm)	67	67	67	67	67
Total water (Irr. +rainfall; ha-mm)	322	230	322	248	248
Irrigation water productivity (kg m^{-3})	1.99	3.48	2.17	3.12	3.05
Total water productivity (kg m^{-3})	1.58	2.47	1.72	2.29	2.23
Irrigation water saving (%)	-	36.2	0.0	29.0	29.0
N applied (kg ha^{-1})	150	150	150	80	80
NUE (kg grain kg^{-1} nitrogen)	34.0	37.9	37.0	70.9	69.3
% Saving of N	-	0.0	0.0	46.7	46.7
CPE= Cumulative potential evaporation					

(Note: PTR- Puddled transplanted rice; RTDSR- Direct seeded rice in reduced tillage; CTW-Conventional tilled wheat; ZTW- Zero tilled wheat; RI- Residue incorporation; RM- Residue mulch; DRIP- Drip irrigation system; SIS- Surface irrigation system; MSIS- Sprinkler irrigation system)

Retention of residue significantly impacted total N concentration in soil at 0-10 cm of depth under soybean-wheat cropping system at ICAR-IISS, Bhopal. Total N concentration ranged from 1.1 to 1.4 g kg^{-1} under the different residue level treatments. The lowest concentration of 1.1 g kg^{-1} was recorded in

30% of residue retained plot which was on par with no residue retained plot. Retention of 60 and 90% residue of previous crop significantly increased total N concentration in soil. It was observed that 90% of residue retention increased total N by 27% over the nil and 30% of residue retained plots.

G. Available Micro-nutrients (Zn, Cu, Fe and Mn)

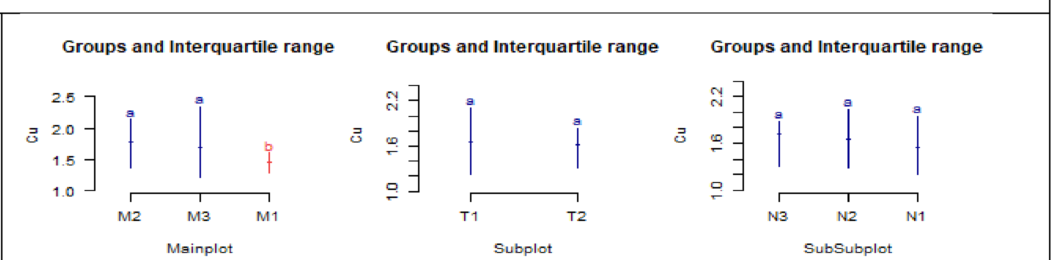
At ICAR-CSSRI, Karnal, CA practices led to enhancement in Zn content of soil, the highest 10.9 mg/kg and 3.9 mg/kg at 0-5 and 5-15 cm depths respectively with the WR+ZTDSR+BM-RR+ZTW treatment. The Zn content was significantly higher in this practice than conventional till (CT) farmer practice (Table 2.25). But, Cu and Fe contents were significantly higher TPR-CTW at both depths, indicating Fe and CU content lower in almost all the CA based practices than CT (~TPR-CTW). The Mn content did not differ significantly among the treatments across depths although had higher values in the CA practices than CT in the rice-wheat system.

Table 2.25 CA practices effects on Zn, Cu, Fe and Mn concentration (mg/kg) in soil of the rice-wheat system

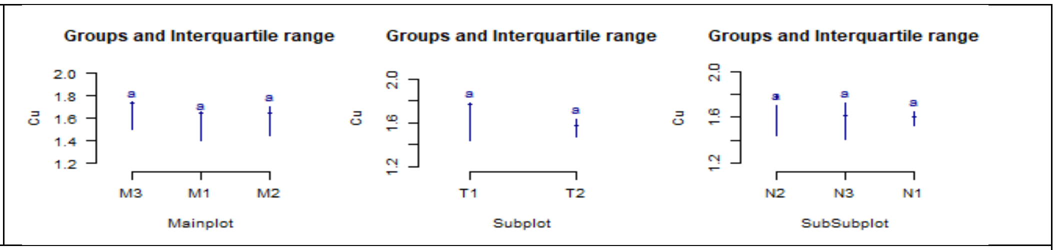
Treatment	Zn (mg/kg)		Cu (mg/kg)		Fe (mg/kg)		Mn (mg/kg)	
	0-5 cm	5-15cm	0-5 cm	5-15cm	0-5 cm	5-15cm	0-5 cm	5-15cm
ZTDSR-ZTW	5.57^{c}	2.40^{d}	2.70^{cd}	2.40^{bc}	8.23^{c}	9.90^{bc}	10.6	11.1
ZTDSR+BM-ZTW	6.87^{b}	3.60^{ab}	2.67^{d}	2.33^{bc}	7.90^{c}	9.03^{bcd}	12.6	11.3
WR+ZTDSR-RR+ZTW	6.97^{b}	3.33^{bc}	2.97^{c}	2.73^{ab}	7.83^{c}	10.57^{b}	14.7	12.8
WR+ZTDSR+BM-RR+ZTW	10.9^{a}	3.90^{a}	2.97^{c}	2.37^{bc}	8.13^{c}	8.63^{cd}	15.6	13.0
ZTDSR-ZTW-ZTMb	4.67^{d}	3.07^{c}	1.67^{f}	2.00^{c}	5.97^{d}	7.57^{d}	13.0	13.1
MbR+ZTDSR-RR+ZTW-WR+ZTMb	6.03^{c}	3.70^{ab}	2.23^{e}	2.67^{ab}	6.37^{d}	9.03^{bcd}	13.4	13.6
TPR-ZTW	3.13^{e}	2.23^{d}	3.30^{b}	2.93^{a}	18.7^{b}	17.4^{a}	12.1	11.1
TPR-CTW	3.50^{e}	2.43^{d}	3.67^{a}	2.93^{a}	20.0^{a}	17.3^{a}	9.53	12.8
LSD (P=0.05)	0.57	0.44	0.27	0.42	1.01	1.74	ns	ns

Whereas Reduced tillage along with trash-retention and nutrient management ($M_3S_1N_3$) practices exhibited significant differences in Cu and Zn content were observed in top soil (0-5 cm) under conventional tillage +10% RDF as basal+ 90% through fertigation over reduced tillage practices.

Table 2.26 Changes in available micro-nutrients (mg kg^{-1}) content under different tillage system, crop residues and nutrient management practices in 0-5 & 5-15 cm soil depth

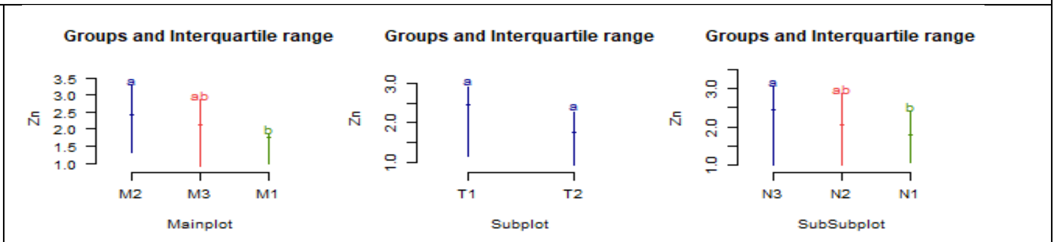
Micronutrients (mg kg^{-1})	
Copper (Cu)	
Soil depth 0-5 cm	

Soil depth 5-15 cm

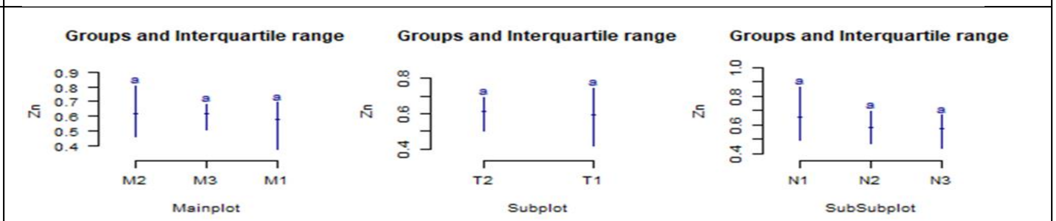


Zinc(Zn)

Soil depth 0-5 cm



Soil depth 5-15 cm



M3: RT + RDF (40% SORF + 50% fertigation

M4: Farmers practices

Fig 2.29 Comparison of best tillage, crop residue and nutrient management treatments over farmers practice

H. Boron (B) and Sulphur (S) Concentration

IARI

In rice-wheat system (Table 2.27), B content was significantly higher (~1.51 mg/kg) in WR+ZTDSR-RR+ZTW treatment compared to TPR-CTW and other CA treatment at both 0-5 and 5-15 cm depths of soil, but WR+ZTDSR+BM-RR+ZTW was comparable in this regard at 0-5 cm soil. Similarly, S content was significantly higher in this WR+ZTDSR-RR+ZTW treatment at 0-5 cm depth and in TPR-ZTW treatment at 5-15 cm depth.

Table 2.27 CA practices effects on boron (B) and sulphur (S) concentration of the rice-wheat system

Treatment	B (mg/kg)		S (mg/kg)	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm
ZTDSR-ZTW	1.31^{b}	0.90^{c}	12.1^{g}	5.67^{f}
ZTDSR+BM-ZTW	1.31^{b}	0.82^{d}	17.3^{b}	5.17^{g}
WR+ZTDSR-RR+ZTW	1.51^{a}	1.07^{a}	25.6^{a}	9.50^{c}
WR+ZTDSR+BM-RR+ZTW	1.51^{a}	0.90^{c}	12.5^{fg}	8.17^{d}
ZTDSR-ZTW-ZTMb	1.09^{d}	0.95^{b}	13.0^{ef}	7.00^{e}
MbR+ZTDSR-RR+ZTW-WR+ZTMb	1.25^{c}	0.63^{f}	13.1^{e}	8.33^{d}
TPR-ZTW	0.92^{e}	0.88^{c}	15.8^{c}	14.3^{a}
TPR-CTW	0.91^{e}	0.76^{e}	14.5^{d}	11.1^{b}
LSD (P=0.05)	0.014	0.04	0.52	0.44

IIFSR

Maize-Wheat-Greengram (CA) recorded exceptionally highest (30.02 mg/kg) available S content among all the cropping systems. At the same time; all the cropping systems both in conventional and conservation agriculture were found at par with each other for available S content. Significant highest available S content (18.16 mg/kg) was found in surface soil samples (0-15 cm) as compared to sub-surface soil samples.

Table 2.28 Various soil chemical properties as influenced by different resource conservation practices.

	Avail. S (mg/kg)
R-W (CP)	12.53
R-W-GRG (CA)	13.47
M-W (CP)	15.78
M(cob)-Must-GRG (CA)	14.34
M-W-GRG(CA)	30.02
R-W-Ses(CA)	13.00
S-R-W(CP)	12.02
S+GRG-R-W(CA)	14.18
Sem (±)	1.002
C.D.	2.908
0-15 cm	18.16
15-30 cm	13.17
Sem (±)	0.501
C.D.	1.454

Energy budgeting and GHG emission in rice-wheat system under different tillage and residue management practices

Energy input (CSSRI)

The resource and operation-wise energy input/consumption was computed for the tillage and residue management practices for RWCS.The results are the pooled average of the four years from 2014-18. Total energy consumption under different tillage and residue management practices ranged from 51.9 GJ ha^{-1}in reduced tillage (RTDSR/RTW) to 64.9 GJ ha^{-1}in conventional tillage (PTR/CTW) (Table 2.29).The source-wise energy utilization pattern revealed that fertilizers contributed highest energy (32.1-40.2%) followed by electricity (24.1-26.5%), irrigation water (16.8-19.0%) and diesel (6.0-14.2%) to the total energy consumption (Fig 2.30). The operation-wise energy utilization pattern revealed that irrigation water had major share (40.5–44.3%) followed by chemical/inorganic fertilizers (32.1–40.2%), field preparations (6.2–10.6%) and seed and sowing (5.5–6.5%) (Table 2.29). The contrast analysis revealed that exclusion of tillage operations and lower water use in ZT accounted for 19.6% and 6.7% lower energy inputs, respectively in comparison to CT and RT. Overall energy consumption in residue added (+R) treatments was 0.5% higher than residue removed (–R) treatments.

Energy input-output relationship

Total energy output of RWCS ranged from 170 GJ ha^{-1} (ZTDSR+RR/ZTW+RR) to 195 GJ ha^{-1} (PTR+RI/CTW+RI) (Table 7). The highest output energy (195 GJ ha^{-1}) and net energy (NE) (130 GJ ha^{-1}) were recorded in conventional tillage practice with residue incorporation (PTR+RI/CTW+RI). The energy use efficiency (EUE) (3.39) and energy productivity (EP) (0.23 kg GJ^{-1}) were the highest in zero tillage (ZTDSR/ZTW) treatment while conventional tillage (PTR/CTW) had the lowest EUE (2.77) and EP (0.19 kg GJ^{-1}). Conservation tillage (RT and ZT) enhanced the NE from 3.4% (ZTDSR+RR/ZTW+RR) to 11.8% (RTDSR+RI/RTW+RI), EUE from 17.1% (RTDSR/RTW) to 22.4% (ZTDSR/ZTW) and EP from 15.8% (ZTDSR+RR/ZTW+RR) to 21.0% (ZTDSR/ZTW) as compared to conventional practice (PTR/CTW). Contrast analysis elucidated that RT and ZT had significantly ($P < 0.05$) higher EUE (13.1% and 15.4%), and EP (12.8% and 15.4%), respectively as compared to PTR/CT.

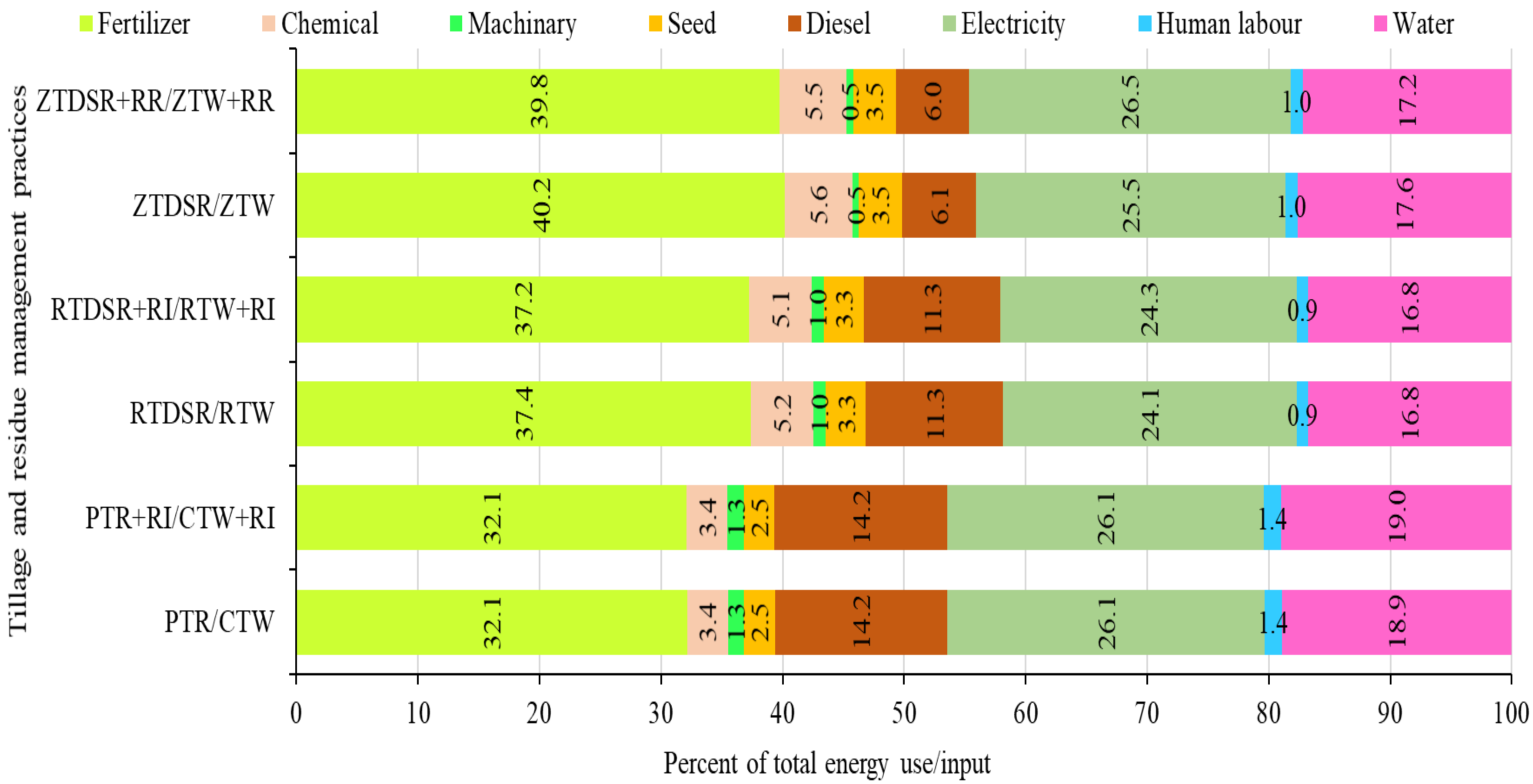


Fig 2.30 Source-wise energy use pattern in rice-wheat cropping system in relation to tillage and residue management practices.

Table 2.29 Operation-wise energy utilization pattern in rice-wheat cropping system under different tillage and residue management practices (results are average of four-years)

Agronomic practices	Energy consumption (GJ ha^{-1})					
	PTR/CTW	PTR+RI/CTW+RI	RTDSR/RTW	RTDSR+RI/RTW+RI	ZTDSR/ZTW	ZTDSR+RR/ZTW+RR
Field preparations	6.89 (10.6)	6.89 (10.6)	3.45 (6.2)	3.45 (6.2)	0.00 (0.0)	0.00 (0.0)
Seed and sowing	3.57 (5.5)	3.57 (5.5)	3.37 (6.0)	3.37 (6.0)	3.37 (6.5)	3.37 (6.4)
Fertilizer application	20.84 (32.1)	20.84 (32.1)	20.84 (37.4)	20.84 (37.2)	20.84 (40.2)	20.84 (39.8)
Plant protection	2.19 (3.4)	2.19 (3.4)	2.88 (5.2)	2.88 (5.1)	2.88 (5.6)	2.88 (5.5)
Irrigation	28.71 (44.3)	28.76 (44.3)	22.58 (40.5)	22.78 (40.7)	22.11 (42.6)	22.66 (43.2)
Harvesting and threshing	2.67 (4.1)	2.67 (4.1)	2.67 (4.8)	2.67 (4.8)	2.67 (5.1)	2.67 (5.1)
Total	64.86(100.0)	64.91 (100.0)	55.78 (100.0)	55.98 (100.0)	51.87 (100.0)	52.42 (100.0)

Figures in parenthesis are percentage contribution of operation–wise input energy

(Note: PTR- Puddled transplanted rice; RTDSR- Direct seeded rice in reduced tillage; ZTDSR- Direct seeded rice in zero tillage; CTW- Conventional tilled wheat; RTW- Reduced tilled wheat; ZTW- Zero tilled wheat; RI- Residue incorporation; RR- Residue retention/ anchored)

Greenhouse gas emissions from rice-wheat system

The annual GHG emission from rice-wheat system (2014-2018) among different treatments ranged from 6116 kg CO_2–eq ha^{-1} (ZTDSR+RR/ZTW+RR) to 8132 kg CO_2–eq ha^{-1}(PTR+RI/CTW+RI) (Table 2.30). The GHG emission reduced by 13% in RT and 16% in ZT as compared to PTR/CT. Addition of crop residues in conventional practice (PTR+RI/CTW+RI) increased GHG emission by 11.3%. Residue management had negligible effect on GHG emission from different sources except CH_4 emission in PTR/CTW (743 kg CO_2–eq ha^{-1}) and PTR+RI/CTW+RI (1555 kg CO_2–eq ha^{-1}). The direct N_2O emissions remained relatively lower in PTR/CT and accounted for 24–36% of the total emission (Table 8). Direct N_2O emission in PTR/CT was ~15% lower than ZT or RT.

The source-wise GHG emission pattern showed that direct N_2O emission from the soil was the major driver of GHG followed by irrigation water (Table 2.30). Together these accounted for ~58% of total GHG emission. Pumping of irrigation water in PTR/CT accounted for 20.3 and 22.4% higher GHG emission than RT and ZT, respectively. Emission of GHG for production of urea was almost similar under all the treatments and it accounted for ~22% of total GHG emission. The indirect emission of N_2O from volatilization and leaching of applied fertilizer–N ranged between 379 to 437 kg CO_2–eq ha^{-1}. Among different tillage treatments, indirect N_2O emission in PTR/CT was ~15% lower than RT and ZT. The CH_4 emission was estimated in PTR/CT treatments only and remained ~52% lower in PTR/CTW compared to PTR+RI/CTW+RI treatment. Contribution of diesel fuel to GHG emission ranged between 178 kg CO_2–eq ha^{-1} to 518 kg CO_2–eq ha^{-1}. Fossil fuel derived GHG emissions in ZT was 66% and 54% lower than PTR/CT and RT, respectively. The GHG emission through herbicides production in PTR/CT and RT remained 57% and 45% lower than ZT, respectively. Likewise, the GHG emission through seeds was ~10% higher in ZT and RT compared to PTR/CT (77 kg CO_2–eq ha^{-1}).

Table 2.30 GHG emission, carbon accumulation and carbon footprints of rice-wheat cropping system under different treatments of long-term tillage and residue management practices (average of four-years).

Treatments	GHGs emission (kg CO_2-eq ha^{-1})								
	Diesel	Urea	Direct N_2O	Indirect N_2O	Methane	Herbicides	Irrigation water	Seed	Total
PTR/CTW	518	1500	1904	379	743	22	2162	77	7304
PTR+RI/CTW+RI	518	1500	1920	379	1555	22	2162	77	8132
RTDSR/RTW	387	1500	2198	437	0	28	1714	85	6350
RTDSR+RI/RTW+RI	387	1500	2198	437	0	28	1731	85	6367
ZTDSR/ZTW	178	1500	2189	437	0	51	1678	85	6119
ZTDSR+RR/ZTW+RR	178	1500	2185	437	0	51	1679	85	6116

Means followed by different lowercase letters within a column differed significantly ($P<0.05$, Tukey's Honest Significant Difference)

(Note: PTR- Puddled transplanted rice; RTDSR- Direct seeded rice in reduced tillage; ZTDSR- Direct seeded rice in zero tillage; CTW- Conventional tilled wheat; RTW- Reduced tilled wheat; ZTW- Zero tilled wheat; RI- Residue incorporation; RR- Residue retention/ anchored)

DWR

The environmental benefit of rice-wheat-greengram cultivation under conservation agriculture

An environmental benefit of rice-wheat-greengram cultivation under conservation agriculture was measured by computing the reduction in greenhouse gases (GHG), air pollutants and creation of theoretical energy potential (TEP) from the farmers' fields. Two years data (2019-21) of Patan locality was computed for the study (Table 2.31 and Fig 2.31). A GHG as CO_2equivalent reduction of 18675 kg/ha, air pollutants reduction of 1232.4 kg/ha and TEP creation of 49.1×10^4 MJ/ha was obtained for two years by practicing the conservation agriculture in rice-wheat-greengram cropping system at farmers fields.

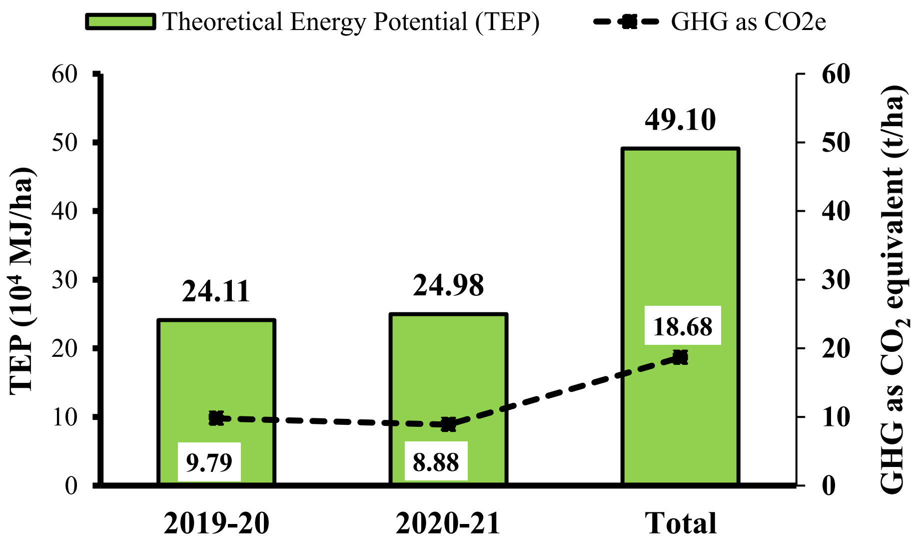


Fig 2.31 TEP generation global warming potential reduction by practicing the CA in rice-wheat greengram cropping system at farmers' fields of Patan locality

Table 2.31 GHGs and air pollutants reduction by practicing the CA in rice-wheat-greengram cropping system at farmers' fields of Patan locality

Particulars		Emission (kg/ha)				
		Rice		Wheat		Total
		2020	2021	2019-20	2020-21	(two year)
GHGs emission	CO_2	5514.25	4678.58	2117.60	2287.36	14597.78
	CH_4	44.93	38.12	4.21	4.54	91.80
	N_2O	2.25	1.91	0.88	0.95	5.98
	GWP (CO_2 e)	7307.62	6200.17	2484.08	2683.23	18675.09
Air pollutants emission	$PM_{2.5}$	38.89	32.99	9.01	9.73	90.61
	PM_{10}	42.63	36.17	6.75	7.30	92.86
	SO_2	0.84	0.72	0.47	0.51	2.54
	CO	435.71	369.68	33.18	35.84	874.40
	NO_X	10.68	9.06	2.01	2.18	23.94
	NH_3	19.21	16.30	1.54	1.66	38.71
	NMVOC	32.80	27.83	8.30	8.96	77.88
	EC	2.39	2.03	0.19	0.20	4.81
	OC	14.01	11.89	0.34	0.37	26.61
	PAH	0.02	0.02	0.00	0.00	0.05
	Total	597.17	506.67	61.80	66.76	1232.41

GWP: Global warming potential, GHG: Greenhouse gas

3. Soil Biological Properties
IARI
A. Glomalin and soil enzyme activities under CA-based rice-wheat system

Microbes are important regulators of the terrestrial nutrient (C, N etc) budget through their influences on the mineralization, immobilization and emission of these nutrients in soil ecosystems. Plots under mungbean residue + DSR – ZTW + rice residue retention (RR) – ZT summer mungbean + wheat residue retention (DSR + MBR-ZTW + RR-ZTMB+WR) had better microbial indices (except soil ergosterol content) than TPR-CTW in the topsoil and higher MBC and dehydrogenase activity in the 5-15 cm layer than TPR-CTW plots. Plots under DSR + brown manuring (BM)-ZTW + RR (CA module 1) had ~53, 26 and 32% higher ergosterol, glomalin and MBC contents, respectively, in the topsoil (0-5 cm layer) than DSR + BM-ZTW plots (Table 20). Similarly, plots under CA module 2 had ~23 and 29% higher ergosterol and glomalin contents, respectively, than DSR + MBR-ZTW plots. Plots under CA module 2 also had ~47% more alkaline phosphatase activity than farmers' practice in the topsoil. These plots also had ~247 and 100% more large macroaggregates in the 0-5 and 5-15 cm soil layers than TPR-CTW. However, there were less small macroaggregates in plots under CA module 2 than TPR-CTW in the topsoil. There were significant positive relationships between glomalin, carboxy-methyl cellulase activity and MBC with large macroaggregates in the topsoil and between glomalin and MBC in the 5-15 cm soil layer, indicating the role of glomalin in soil aggregation. Thus, DSR + MBR-ZTW + RR-ZTMB treatment resulted in an improved soil microbial environment after four years of rice–wheat cropping in the IGP, and this practice may be adopted. The enhanced soil properties was mainly due to residue retention of crop residues, zero tillage (ZT) in two crops (in the first three years) and triple ZT (in the fourth year), and growing of a legume crop in the conventional rice-wheat system in the IGP.

Table 2.32 Impacts of conservation tilled rice-wheat system on soil microbiological properties in the 0-5 and 5-15 cm soil layers

Treatments*	β-glucosidase (µg PNP g^{-1} h^{-1})		Glomalin (µg g^{-1}soil)		Cmcase (IU g^{-1})		Alkaline phosphatase (µg PNP g^{-1} h^{-1})	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
DSR-ZTW	56.5^{b}	70.7^{a}	18.0^{d}	27.0^{c}	192.9^{c}	200.5^{d}	81.8^{b}	57.8^{d}
DSR-ZTW + RR	46.2^{cd}	67.9^{ab}	13.4^{e}	13.6^{e}	291.5^{a}	271.1^{bc}	85.6^{b}	65.7^{cd}
DSR + BM-ZTW	57.7^{b}	71.4^{a}	24.1^{c}	30.7^{b}	205.4^{c}	257.8^{c}	86.3^{b}	63.9^{cd}
DSR + BM-ZTW + RR (CA module 1)	56.5^{b}	65.1^{b}	17.2^{d}	19.9^{d}	315.1^{a}	306.8^{b}	56.0^{c}	59.3^{d}
DSR + MBR-ZTW-ZTMB	69.9^{a}	57.3^{c}	30.3^{ab}	20.6^{d}	168.7^{d}	198.3^{d}	101.0^{a}	70.3^{c}
DSR + MBR-ZTW + RR –ZTMB + WR (CA module 2)	50.4^{c}	39.5^{e}	35.6^{a}	31.5^{b}	251.7^{b}	355.1^{a}	98.1^{a}	85.5^{b}
TPR – ZTW	38.8^{d}	48.3^{d}	14.1^{e}	29.3^{bc}	189.6^{c}	286.5^{bc}	82.0^{b}	107.7^{a}
TPR – CTW	53.3^{bc}	48.9^{d}	5.80^{f}	35.2^{a}	159.3^{d}	272.5^{bc}	66.7^{c}	94.0^{ab}

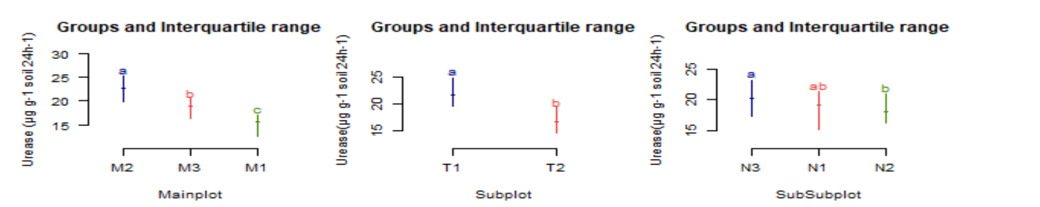
NIASM

Urease enzymes activity varied significantly under all tillage, crop residues and nutrients practices at both soil depths (Table 2.33).

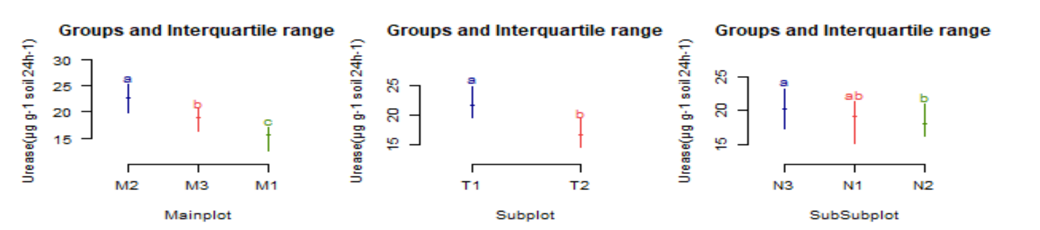
Table 2.33 Changes in urease enzyme activity under different tillage system, crop residues and nutrient management practices in 0-5 & 5-15 cm soil depth

Urease Enzyme Activity

Soil depth 0-5 cm



Soil depth 5-15 cm



IIFSR

The data depicted in table 2 showed that all the enzymes which are related to carbon, nitrogen and phosphorus hydrolysis in soil were significantly influenced because of both resource conservation techniques and soil depths. The dehydrogenase (DHA) which is known as the respiratory enzyme in the soil varied 28.27 µg TPF g^{-1} soil 24 h^{-1} to 41.80 µg TPF g^{-1} soil 24 h^{-1} among the different cropping systems. At the same time, it was found superior in the surface soil (0-15cm) layer as compared to the sub-surface soil layer (Table 2.34).

Phosphatases enzymes plays a crucial role in mineralization of organic phosphate compounds and release inorganic phosphorus in soil. The acid phosphatases enzyme was found superior (122.6 µg pNP g^{-1} soil h^{-1}) in maize-wheat-green gram (CA) cropping system among all the adopted cropping systems followed by sugarcane-ratoon-wheat (CP) and rice-wheat (CP) cropping systems. At the same time, the highest alkaline phosphatase enzyme activity (356.9µg pNP g^{-1} soil h^{-1}) was found in rice-wheat (CP) followed by rice-wheat-green gram (CA) (326.5 µg pNP g^{-1} soil h^{-1}) and maize-wheat-green gram (CA) (297.0 µg pNP g^{-1} soil h^{-1}) cropping systems.

Urea hydrolysis into ammonia and carbon dioxide is catalyzed by the urease enzyme in the soil. In the present study both resource conservation techniques and soil depths significantly affected the urease enzyme activity. Rice-wheat-green gram cropping system under conservation agriculture practices (CA) recorded highest (115.8urea g^{-1} soil h^{-1}) urease enzyme activity among all the cropping systems. Whereas; sugarcane-ratoon-wheat cropping system both in conservation (CA) (101.3 urea g^{-1} soil h^{-1}) and conventional practices (CP 102.9 urea g^{-1} soil h^{-1}) were statically at par with in terms of urease enzyme activity (Table 2.34).

β-glucosidase are key enzymes in the carbon cycle and play a crucial role in hydrolytic processes during organic matter decomposition.The hydrolysis products of β-glucosidase are an important source for soil microorganisms. Overall, the superior β-glucosidase enzyme activity was observed among the cropping systems under conservation agriculture (CA) practices as compared to conventional practices. Among all the cropping systems, maize-wheat-green gram (CA) produced significant highest (94.37µg pNPG g^{-1} soil h^{-1}) β-glucosidase enzyme activity followed by the other cropping systems. In case of soil depths, the surface soil (0-15cm) produced significant higher β-glucosidase enzyme over the sub-surface (15-30cm) layer.

To measure the total microbial activity in any soil, fluorescein diacetate activity (FDA) is an accurate and simple technique. Many free and membrane bound enzyme i.e. lipase, protease and esterase etc. are included as synonyms of FDA activity in soil. In the present research investigation, the FDA activity ranges from 177.3 (µg F g^{-1} dry soil h^{-1}) in sugarcane + green gram-ratoon-wheat cropping system to as high 466.5 (µg F g^{-1} dry soil h^{-1}) in maize-wheat-green gram cropping system (Table 2.34). Among all the cropping systems under study, the maized based cropping systems produced significant highest FDA activity over the other cropping systems both in surface and sub-surface soil layers.

Table 2.34 Soil enzymes as influenced by different resource conservation practices

	DHA (µg TPF g^{-1} soil 24 h^{-1})	ACP (µg pNP g^{-1} soil h^{-1})	ALP (µg pNP g^{-1} soil h^{-1})	Urease µg (urea g^{-1} soil h^{-1})	B-glucosidase(pNPG g^{-1} soil h^{-1})	FDA (µg F g^{-1} dry soil h^{-1})
Cropping Systems (CS)						
R-W (CP)	28.27	90.5	356.9	108.2	88.70	355.4
R-W-GRG (CA)	38.81	70.4	326.5	115.8	67.87	235.9
M-W (CP)	27.97	60.5	216.6	103.7	58.53	126.0
M(cob)-Must-GRG (CA)	32.05	78.2	234.0	102.4	59.53	191.1
M-W-GRG(CA)	36.67	12 2.6	297.0	105.6	94.37	466.5
R-W-Ses(CA)	36.91	71.4	208.8	101.6	77.70	263.2
S-R-W(CP)	24.50	113.9	269.5	102.9	64.70	379.1
S+GRG-R-W(CA)	41.80	61.0	177.0	101.3	77.87	177.3
Sem (±)	2.622	13.61	29.65	2.873	6.488	48.36
C.D.	5.380	27.92	60.84	5.896	13.314	99.24
Soil Depth						
0-15 cm	37.54	104.3	339.6	105.3	89.03	366.3
15-30 cm	29.20	62.9	181.9	105.0	58.28	182.3
Sem(±)	2.69	6.80	14.82	NS	3.244	24.18
C.D.	1.31	13.96	30.42	NS	6.657	49.62

Where: DHA= dehydrogenase enzyme; ACP=Acid phosphatase enzyme; ALP=Alkaline phosphatase enzyme; FDA=Fluorescein diacetate. R-W=rice-wheat; R-W-GRG=rice-wheat-green gram; M-W=maize-wheat; M(cob)-must-GRG=Maize(cob)-mustard-green gram; M-W-GRG=maize-mustard-green gram; R-W-Ses-rice-wheat-sesbania; S-R-W=sugarcane-ratoon-wheat; S+GRG-R-W=sugarcane+green gram-ratoon-wheat cropping systems. CP=Conventional practices; CA=conservation agriculture.

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Enzymatic Activities

Dehydrogenase activity, a measure of soil total catabolic activity also responded positively with retention of residue. Dehydrogenase activity in soil varied from 66.34 to 103.51 µg TPF g^{-1} soil 24 h^{-1}. In comparison to 0% of residue retention, dehydrogenase activity increased by 56% with 90% in 60 and 90% of residue retained plot in 0-10 cm of soil depth. However, no significant impact of residue retention on soil urease activity was noticed. Similarly, active C as measured by modified Blair method, also could not be influenced by addition of different levels of residue. Water soluble carbon, a readily available substrate for microbes was found be significantly affected by retention of residue. Water soluble carbon was found the lowest (110 mg kg^{-1}) under the 0% residue retained plot and was the highest (126 mg kg^{-1}) under 90% of residue retained treatment. Here also, no significant impact of residue retention on soil nitrogen mineralization potential, dehydrogenase and urease activity, active and water soluble carbon was recorded (Table 2.35b).

Table 2.35a & 2.35b Residue retention under no till system effect on soil nitrogen mineralization, dehydrogenase activity, urease activity, active C and water soluble C content

Table 2.35a.	(0-10 cm soil depth)	
Treatments	Dehydrogenase activity	Urease activity
	(µg TPF g^{-1} soil 24 h^{-1})	(µg NH_4 g^{-1} soil h^{-1})
NT-0% R	66.34 (7.33)	143 (11.4)
NT-30% R	70.76 (6.92)	125 (13.0)
NT-60% R	79.16 (5.93)	104 (8.8)
NT-90% R	103.51 (3.42)	144 (20.3)
CD (P=0.05)	20.30	NS
CD (P=0.01)	NS	NS
Table 2.35b.	(10-20 cm)	
NT-0% R	48.01 (7.76)	37.74 (6.32)
NT-30% R	46.68 (7.56)	31.88 (2.00)
NT-60% R	47.80 (6.98)	38.92 (6.75)
NT-90% R	53.47 (10.36)	29.62 (3.31)
CD (P=0.05)	NS	NS
CD (P=0.01)	NS	NS

CRIDA

Enzyme activity in pigeonpea- castor cropping system

In pigeonpea- castor cropping system, ZT averaged over crop residues recorded 39 and 23 % higher acid phosphatase, 35 and 27 % alkaline phosphatase, 43 and 16 % higher dehydrogenase as compared to CT and RT averaged over residues respectively (Table 2.36). The 10 cm and 30 cm anchored residues recorded 31 and 38 % higher acid phosphatase, 19 % and 27 % higher alkaline phosphatase, 28 % and 14 % higher dehydrogenase activity as compared to R0. This was due to addition of crop residues which has enhanced the availability nutrients for microbial growth and activity. ZT+ 30 cm anchored residues along with dhaincha recorded significantly ($p<0.05$) higher enzyme activities viz., dehydrogenase (3.24 µg TPF/g soil/h), acid phosphatase (7.08 µg p-nitrophenol/g soil/h), alkaline phosphatase (16.15 µg p-nitrophenol/g soil/h) and urease (3.24 µg NH_4/g soil/h) activities as compared to conventional tillage and reduced tillage with residues. ZT with residues recorded 36 and 59 % higher alkaline phosphatase, 56 and 62 % higher acid phosphatase enzyme activity as compared to ZT and CT, respectively. ZT with crop residues recorded 58, 51 and 36 % higher dehydrogenase activity as compared to CT and ZT respectively.

Table 2.36 Effect of tillage and residue management on enzyme activities in 0-10 cm soil at 35 days after sowing

Tillage	Residue	Urease activity (mg NH_4-N/kg soil/h)	Dehydrogenase activity (mg TPF/kg soil/h)	Acid phosphatase (mg PNP/kg soil/h)	Alkaline phosphatase (mg PNP/kg soil/h)	Phosphodiesterase (mg PNP/kg soil/h)
Minimum tillage	S0: No residue application	67.6	1.12	23.8	3.79	77.1
	S1: Cutting at 35 cm height (1/3 rd height)	79.8	1.20	24.0	3.43	91.0
	S2: Cutting at 60 cm height	81.8	1.23	26.3	3.60	96.7
Conventional tillage	S0: No residue application	72.8	1.09	26.3	3.80	94.4
	S1: Cutting at 35 cm height (1/3rd height)	84.1	1.06	25.5	4.10	88.1
	S2: Cutting at 60 cm height	85.7	1.19	27.7	4.97	81.2
CD (P=0.05)						
Tillage		NS	NS	NS	NS	NS
Residues		NS	NS	NS	NS	NS
T X R		NS	NS	NS	NS	NS

In sorghum-blackgram system after 9 years microbial biomass C (MBC) in 0-10 cm soil at 35 days after sowing the MBC was not significantly influenced by tillage but increase in residue increased MBC. 59% higher MBC was recorded with higher residue retention (S_2) over no residue (Table 2.37).

Table 2.37 Effect of tillage and residue management on microbial biomass carbon (MBC) in 0-10 cm soil at 35 days after sowing

Tillage	Residue	MBC (mg/kg)
Minimum tillage	S0: No residue application	137.8
	S1: Cutting at 35 cm height (1/3 rd height)	191.7
	S2: Cutting at 60 cm height	216.6
Conventional tillage	S0: No residue application	130.2
	S1: Cutting at 35 cm height (1/3rd height)	170.0
	S2: Cutting at 60 cm height	208.9
CD (P=0.05)		
Tillage		NS

Residues		28.09
T X R		NS

RCER

Soil enzymatic activity

Soil microbial biomass carbon (SMBC) was significantly influenced across soil depth (0-15, 15-30, 30-45 cm) by diverse CERM and post-rainy season crops. Prominent effect of CERM on SMBC was noted in upper soil layer (0-15 cm) in comparison to lower soil layers (15-30 & 30-45 cm). ZTDSR production system had 55.3, 27.2 and 34.7% higher SMBC in 0-15, 15-30 and 30-45cm soil depth, correspondingly in comparison to TPR. Effect of residue management was more in ZTDSR system. In general, rice-pulses sequence had higher SMBC and it was 26 (0-15 cm), 30.5 (15-30 cm) and 34.1% (30-45 cm) higher in comparison to rice-oilseed systems (Table 2). Dehydrogenase activity (DHA) was influenced markedly by diverse CERM and post-rainy season crops. ZTDSR had more DHA on surface soil (0-15 cm) in comparison to lower soil depths (15-30 &30-45 cm). ZTDSR production system had 45.9 and 29.3% more DHA on surface soil than TPR and CTDSR, respectively. Among cropping systems, rice-pulse sequences had 16.7% more DHA in comparison to rice-oilseed systems in surface soil. In case of fluorescein-diacetate activity (FDA), ZTDSR/CTDSR was equally effective but significantly better compared to TPR in surface soil. FDA activity was 9.6% more in ZTDSR compared to TPR system. Rice-pulse cropping systems had higher FDA in comparison to rice-oilseed sequences. Similar trends werenoted forlower soil depths (15-30 & 30-45 cm).Urease-activity was significantly improved with the diversification of rice-fallowsystem across soil depth (Table3). ZTDSR production system had 32 and 27% more urease activity in comparison to TPR and CTDSR, respectively in surface soil layers. The effect of residue management in improving the urease activity was more for CTDSR and TPR in comparison to ZTDSR system. Urease activity improved by ~3% when legumes were planted during winter season in comparison to oilseeds.

Microbial population

Highest population of fungi was noted in ZTDSR, which was 1.71 and 0.36 times more in comparison to TPR and CTDSR production systems, respectively. Cultivating pulses in rice-fallows system markedly enhanced microbial populations in soil. Rice-pulse cropping systems had 63.6% more fungal counts in comparison to rice-oilseed sequences (Table 4). Among the cropping sequences, rice-chickpea rotations had the highest fungal counts. Effect of CERM was more intense in ZTDSR compared to TPR and CTDSR production systems. Similar trends were observed in case of bacterial counts also, where ZTDSR had 1.14 and 0.15 times higher bacterial abundance in comparison to TPR and CTDSR, respectively. Rice-pulse sequences had 0.3 times more bacterial counts compared to rice-oilseed systems. Effect of residue management followed the trend of TPR>ZTDSR>CTDSR. ZTDSR had 61 and 14.5% more actinomycetes counts in comparison to TPR and CTDSR systems, respectively. Trend of actinomycetes count was followed in order of ZTDSR>CTDSR>TPR. Irrespective of CERM, actinomycetes count was maximum with rice-oilseed cropping system. Rice-safflower rotation had the highest actinomycetes count and the lowest was rice-lentil cropping sequence. The effect of residue management in actinomycetes counts followedthe trend of TPR>ZTDSR>CTDSR. Free living diazotrophs was highest in ZTDSR production system, which was 1.09 and 0.77 times more compared to TPR and CTDSR, respectively. Free living diazotrophs count was 20% higher in rice-oilseed sequences in comparison to rice-pulse production systems. The effect of residue management was more intense in ZTDSR followed by TPR.

Earthworm

Major species of earthworm population in experimental plots consisted of *Amynthas* spp., *Metaphire* spp., *Eudrilus* spp. Earthworm counts in CA i.e., ZTDSR was significantly higher than TPR production system(Table 5).Earthworm population in ZTDSR was 2.3 and 1.2 times more in comparison to TPR and CTDSR, respectively. Irrespective of the CERM practices, rice-lentil and rice-linseed systems had recorded the highest and lowest earthworm counts, respectively. Fresh weight of earthworms in ZTDSR was markedly higher compared to TPR system. ZTDSR had 3.5- and 2.1-timeshigher earthworm fresh weight compared to TPR and CTDSR, respectively. Rice-pulse system had significantly higher population (0.74 times) and fresh biomass of earthworm than rice-oilseed cropping sequences.

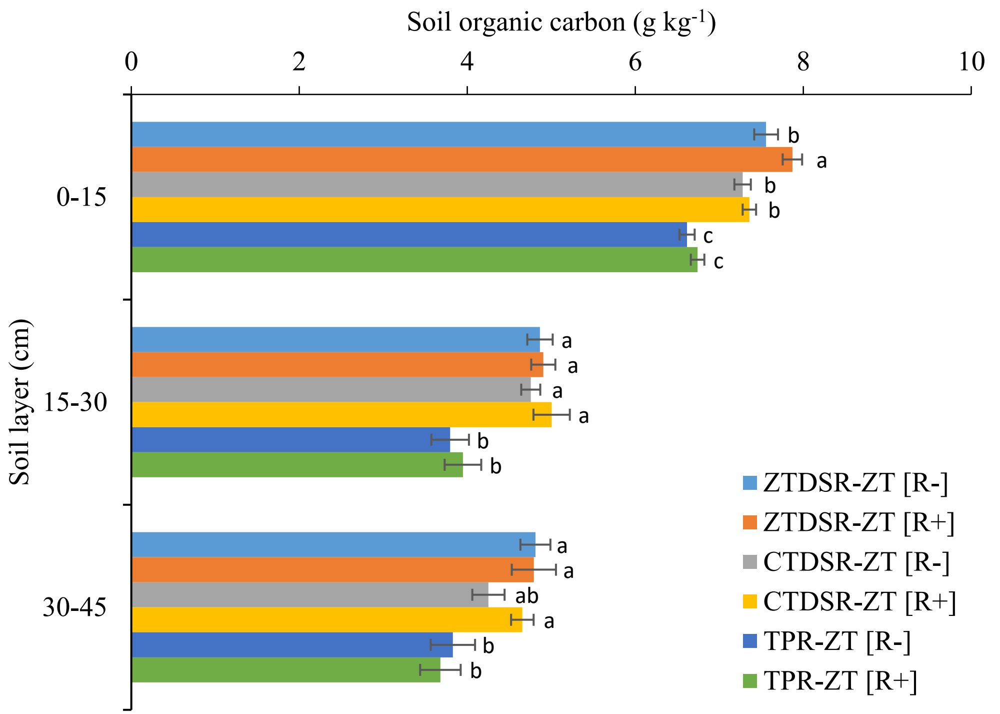

Fig 2.32 Soil organic C (g kg^{-1}) as influenced by different crop establishment-cum-residue management (CERM) practices. ZTDSR: zero-till-direct seeded rice; CTDSR: conventional-till-direct seeded rice, TPR: transplanted puddled rice; R^{+}: residue retention (30% RT), R^{-}: control; Different small case letters in a particular soil layer indicate significant variations in different CERM practices by *Duncan's Multiple Range Test* (*p*=0.05); Horizontal bars represent standard error of mean.

Table 2.38 Effect of crop establishment and residue management (CERM) and winter season crops on grain yield, rice equivalent yield (REY) and system productivity (SREY) under Rainfed Rice-Fallow Agro-Ecosystem of Eastern India

CERM		Rice yield (t ha^{-1})	Seed yield (Mg ha^{-1})					Rice equivalent yield (Mg ha^{-1})					Mean	System productivity (Mg ha^{-1})					Mean
			Chickpea	Lentil	Safflower	Linseed	Mustard	Chickpea	Lentil	Safflower	Linseed	Mustard		R-C	R-L	R-SF	R-Li	R-M	
ZTDSR	R^{-}	3.79^{F}	1.77^{B}	1.76^{B}	1.63^{B}	1.07^{C}	1.56^{C}	4.62±0.4	4.55±0.39	4.54±0.21	2.01±0.12	3.69±0.09	3.88^{B}	8.41±0.33	8.35±0.33	8.34±0.22	5.8±0.17	7.49±0.15	7.74^{C}
	R^{+}	4.04^{E}	2.01^{A}	1.99^{A}	1.87^{A}	1.27^{A}	1.75^{A}	5.24±0.37	5.11±0.36	5.21±0.29	2.38±0.08	4.14±0.10	4.41^{A}	9.27±0.30	9.15±0.30	9.25±0.25	6.41±0.13	8.17±0.14	8.48^{AB}
CTDSR	R^{-}	4.19^{D}	1.54^{C}	1.51^{C}	1.26^{D}	0.98^{DE}	1.47^{E}	4.01±0.21	3.88±0.22	3.51±0.11	1.84±0.12	3.48±0.02	3.34^{C}	8.2±0.23	8.07±0.24	7.7±0.17	6.03±0.18	7.67±0.13	7.53^{C}
	R^{+}	4.50^{C}	1.76^{B}	1.73^{B}	1.45^{C}	1.16^{B}	1.65^{B}	4.59±0.28	4.43±0.26	4.05±0.18	2.17±0.13	3.91±0.13	3.83^{B}	9.09±0.30	8.93±0.28	8.55±0.20	6.67±0.20	8.41±0.20	8.33^{B}
TPR	R^{-}	5.00^{B}	1.34^{D}	1.29^{D}	1.14^{E}	0.93^{E}	1.37^{F}	3.50±0.16	3.31±0.17	3.17±0.17	1.75±0.01	3.24±0.09	2.99^{D}	8.50±0.19	8.31±0.20	8.17±0.20	6.74±0.11	8.24±0.15	7.99^{C}
	R^{+}	5.35^{A}	1.52^{C}	1.47^{C}	1.26^{D}	1.04^{CD}	1.51^{D}	3.98±0.17	3.77±0.19	3.53±0.16	1.94±0.02	3.57±0.10	3.36^{C}	9.33±0.20	9.12±0.21	8.87±0.19	7.29±0.10	8.92±0.15	8.71^{A}
Mean		4.48	1.66	1.63	1.43	1.08	1.55	4.32^{a}	4.18^{b}	4.00^{c}	2.01^{e}	3.67^{d}		8.80^{A}	8.65^{B}	8.48^{C}	6.49^{E}	8.15^{D}	
LSD	CERM		CERM					CERM		WC		CERM*WC		CERM		WC		CERM*WC	
(*p=0.05*)	0.08		0.08	0.07	0.07	0.06	0.03	0.08		0.12		0.21		0.08		0.16		0.25	

Table 2.39 Soil microbial biomass carbon (SMBC) (µg C g^{-1} soil) as influenced by crop establishment and residue management (CERM) and winter crops under rainfed rice-fallow production system of eastern India (After 5 years of experimentation).

CERM		Soil microbial biomass carbon (SMBC) (µg C g^{-1} soil)					
		0-15 cm soil layer					
		R-C	R-L	R-SF	R-Li	R-M	Mean
ZTDSR	R^-	171.6±4.95	173.4±7.82	218.9±5.79	117.0±1.35	124.3±2.49	161.04^B
	R^+	213.7±4.27	295.8±7.44	241.2±7.37	167.4±5.38	186.8±2.85	220.98^A
CTDSR	R^-	99.5±1.52	165.6±4.78	168.3±5.14	82.5±2.65	86.3±2.77	120.44^D
	R^+	122.8±3.95	236.3±4.73	170.5±6.15	122.8±2.56	171.7±5.52	164.82^B
TPR	R^-	105.8±2.80	171.0±2.61	105.4±2.19	93.4±0.54	86.3±2.77	112.38^E
	R^+	123.3±3.26	206.1±6.63	128.9±1.97	99.0±3.18	110.5±1.69	133.56^C
Mean		139.45^C	208.03^A	172.2^B	113.68^E	127.65^D	
LSD (*p=0.05*)		CERM		WC		CERM* WC	
		6.30		4.68		11.47	
				15-30 cm soil layer			
ZTDSR	R^-	94.3±2.49	96.6±3.11	95.2±1.90	83.5±1.74	83.6±0.48	90.64^C
	R^+	112.9±5.09	127.9±3.38	115.0±1.76	111.2±1.70	131.9±4.24	119.78^A
CTDSR	R^-	65.3±1.64	98.6±3.01	57.4±1.85	73.0±0.84	51.0±1.02	69.06^E
	R^+	106.3±3.07	108.8±3.92	111.0±2.94	97.7±3.14	77.8±1.19	100.32^B
TPR	R^-	83.0±1.66	82.3±1.71	87.7±2.68	74.4±2.39	48.3±1.55	75.14^D
	R^+	86.7±1.32	99.8±2.88	104.8±3.78	82.2±1.71	77.8±2.50	90.26^C
Mean		91.42^C	102.33^A	95.18^B	87.00^D	78.40^E	
LSD (*p=0.05*)		CERM		WC		CERM* WC	
		3.82		2.77		7.17	
				30-45 cm soil layer			
ZTDSR	R^-	83.6±2.21	98.5±2.27	62.7±2.83	68.3±1.81	82.2±2.64	79.06^B
	R^+	131.9±4.03	100.3±1.00	62.6±1.58	62.7±1.92	85.1±2.74	88.52^A
CTDSR	R^-	51.0±1.84	78.5±4.32	54.8±1.58	61.5±2.22	46.7±0.97	58.50^E
	R^+	77.8±1.62	85.0±2.73	63.8±1.28	59.9±1.25	47.5±0.27	66.8^D
TPR	R^-	48.3±0.74	66.1±1.01	63.5±0.97	44.6±0.68	45.3±1.46	53.56^F
	R^+	77.8±0.90	86.3±2.28	77.8±2.50	62.2±0.72	50.3±1.01	70.88^C
Mean		78.40^B	85.78^A	64.20^C	59.87^D	59.52^D	
LSD (*p=0.05*)		CERM		WC		CERM* WC	
		2.88		2.36		5.91	

CERM: crop establishment-cum-residue management; WC: winter crops, ZTDSR: zero-till-direct seeded rice; CTDSR: conventional-till-direct seeded rice, TPR: transplanted puddled rice; R^+: residue retention (30% RT), R^-: control; R-C:Rice-Chickpea; R-L:Rice-Lentil; R-SF: Rice-Safflower; R-Li: Rice-Linseed; R-M: Rice-Mustard; Different capital letters (vertical) represents the significant variations in CERM; Different (horizontal) capital letters indicates the significant variations in different cropping sequences; Values with ± represent standard error of mean.

Table 2.40 Soil dehydrogenase activity (DHA) (µg TPF g^{-1} soil d^{-1}), fluoresceindiacetate activity (FDA) (mg fluorescein kg^{-1} soil hr^{-1}) and urease activity (mg N g^{-1} soil hr^{-1}) as influenced by crop establishment-cum-residue management (CERM) and winter crops under rainfed rice-fallow production system of eastern India (After 5 years of experimentation).

CERM		0-15 cm R-C	R-L	R-SF	R-Li	R-M	Mean	15-30 cm R-C	R-L	R-SF	R-Li	R-M	Mean	30-45 cm R-C	R-L	R-SF	R-Li	R-M	Mean
Dehydrogenase activity (DHA) (µg TPF g^{-1} soil d^{-1})																			
ZTDSR	R+	17.4±0.56	20.8±0.55	21.4±0.69	23.6±0.27	18.5±0.67	20.34^{B}	12.8±0.41	12.5±0.33	10.2±0.33	10.8±0.12	12.5±0.25	11.76^{B}	6.4±0.35	8.0±0.23	7.5±0.27	5.3±0.11	8.7±0.48	7.18^{B}
	R-	25.0±0.58	23.1±1.04	23.9±0.63	25.1±0.81	19.3±0.40	23.28^{A}	15.7±0.36	19.4±0.87	10.9±0.29	10.6±0.34	13.0±0.20	13.92^{A}	6.1±0.20	10.3±0.21	7.7±0.16	5.5±0.03	8.3±0.27	7.58^{A}
CTDSR	R+	19.1±0.19	17.4±0.44	18.2±0.56	7.4±0.24	14.3±0.22	15.28^{E}	5.7±0.06	9.0±0.23	6.2±0.19	6.1±0.20	5.8±0.19	6.56^{E}	4.1±0.06	3.4±0.05	3.3±0.05	5.7±0.18	2.5±0.04	3.80^{E}
	R-	20.2±1.11	21.5±0.62	22.6±0.81	12.6±0.26	15.4±0.18	18.46^{C}	6.5±0.36	14.6±0.42	8.0±0.29	8.3±0.17	7.6±0.24	9.00^{D}	4.3±0.11	4.3±0.14	3.8±0.04	5.4±0.11	2.6±0.07	4.08^{E}
TPR	R+	15.7±0.50	17.6±0.35	17.6±0.37	10.3±0.06	8.7±0.28	13.98^{F}	11.2±0.36	11.8±0.24	12.6±0.26	6.5±0.04	5.0±0.12	9.42^{D}	7.7±0.35	6.4±0.17	8.5±0.27	3.8±0.06	4.7±0.21	6.22^{D}
	R-	16.9±0.26	20.0±0.31	19.5±0.30	11.4±0.37	11.8±0.38	15.92^{D}	11.4±0.17	12.0±0.18	14.8±0.23	6.0±0.19	5.5±0.06	9.94^{C}	8.4±0.21	6.7±0.20	9.4±0.30	4.6±0.15	4.6±0.12	6.74^{C}
Mean		19.05^{B}	20.07^{A}	20.53^{A}	15.07^{C}	14.67^{C}		10.55^{B}	13.22^{A}	10.45^{B}	8.05^{C}	8.23^{C}		6.17^{B}	6.52^{A}	6.70^{A}	5.05^{C}	5.23^{C}	
LSD (p=0.05)		CERM		WC		CERM*WC		CERM		WC		CERM*WC		CERM		WC		CERM*WC	
		0.60		0.64		1.53		0.42		0.34		0.86		0.37		0.22		0.61	
Fluoresceindiacetate activity (FDA) (mg fluorescein kg^{-1} soil hr^{-1})																			
ZTDSR	R+	124.3±1.90	109.8±3.53	70.7±1.41	109.7±2.28	137.5±0.79	110.40^{BC}	51.3±1.65	51.2±1.02	39.6±1.00	50.0±1.53	41.7±1.34	46.76^{D}	33.1±1.06	29.4±0.95	22.3±0.59	38.7±1.24	38.9±0.45	32.48^{E}
	R-	130.5±4.19	122.5±1.87	94.2±1.44	125.4±1.92	141.8±4.56	122.88^{A}	68.6±1.05	65.5±1.00	49.4±1.43	56.6±1.73	56.0±1.80	59.22^{A}	38.6±0.77	31.3±0.72	24.4±1.10	45.9±1.21	43.0±1.38	36.64^{D}
CTDSR	R+	110.6±3.56	111.0±2.94	86.2±2.77	106.0±1.22	126.0±2.52	107.96^{C}	36.1±0.96	51.2±1.65	66.6±1.33	51.0±1.84	43.7±0.91	49.72^{C}	31.6±0.48	34.0±0.34	49.0±1.23	40.4±1.23	38.5±1.24	38.7^{C}
	R-	124.8±2.88	119.6±5.39	125.0±3.31	119.8±3.85	134.6±2.06	124.76^{A}	40.8±1.84	51.6±1.37	77.8±1.19	57.8±1.20	51.7±0.30	55.94^{B}	34.2±1.10	34.6±1.91	58.6±1.69	42.0±1.51	46.8±0.97	43.24^{B}
TPR	R+	114.5±1.15	96.0±2.42	127.2±3.89	101.9±3.28	60.9±1.96	100.10^{D}	50.3±1.27	50.0±1.32	53.3±1.71	49.5±0.76	51.2±1.65	50.86^{C}	31.0±1.00	40.2±1.29	43.6±0.87	38.6±0.80	39.0±0.23	38.48^{C}
	R-	115.4±6.36	119.4±3.45	135.4±4.88	114.8±2.39	78.5±4.32	112.70^{B}	64.5±1.86	62.5±2.82	68.8±1.82	51.0±0.59	53.3±1.07	60.02^{A}	42.9±1.38	44.1±0.67	52.5±0.80	46.3±0.71	41.9±1.35	45.54^{A}
Mean		120.02^{A}	113.05^{B}	106.45^{C}	112.93^{B}	113.22^{B}		51.93^{C}	55.33^{B}	59.25^{A}	52.65^{C}	49.60^{D}		35.23^{B}	35.60^{B}	41.73^{A}	41.98^{A}	41.35^{A}	
LSD		CERM		WC		CERM*		CERM		WC		CERM*		CERM		WC		CERM*	

(*p*=0.05)						WC						WC						WC	
		4.45		3.77		9.37		1.93		1.59		3.98		0.88		1.34		3.07	
	Urease activity (mg N g^{-1} soil hr^{-1})																		
ZTDSR	R^+	1.79±0.04	1.70±0.09	1.82±0.05	1.85±0.07	1.86±0.04	1.80^B	1.72±0.09	1.66±0.05	1.76±0.08	1.87±0.05	1.90±0.02	1.78^B	1.73±0.03	1.74±0.05	1.76±0.06	1.78±0.04	1.86±0.04	1.77^A
	R^-	1.84±0.03	1.81±0.06	1.86±0.04	1.92±0.04	1.93±0.01	1.87^A	1.79±0.06	1.76±0.04	1.81±0.05	1.92±0.06	2.02±0.06	1.86^A	1.75±0.03	1.71±0.08	1.80±0.05	1.84±0.03	1.88±0.03	1.80^A
CTDSR	R^+	1.79±0.06	1.73±0.03	1.74±0.03	1.85±0.03	1.37±0.04	1.70^C	1.74±0.03	1.68±0.03	1.69±0.05	1.73±0.05	1.47±0.05	1.66^C	1.75±0.06	1.76±0.04	1.71±0.05	1.79±0.06	1.48±0.02	1.70^B
	R^-	1.83±0.06	1.75±0.05	1.80±0.06	1.86±0.02	1.89±0.04	1.83^{AB}	1.73±0.05	1.70±0.05	1.78±0.04	1.79±0.06	1.90±0.04	1.78^B	1.78±0.06	1.81±0.05	1.76±0.06	1.78±0.05	1.84±0.06	1.79^A
TPR	R^+	1.59±0.04	1.35±0.06	1.23±0.03	1.22±0.04	1.32±0.02	1.34^E	1.53±0.07	1.21±0.03	1.23±0.02	1.24±0.03	1.20±0.01	1.28^E	1.76±0.06	1.19±0.02	1.35±0.03	1.26±0.04	1.16±0.04	1.34^C
	R^-	1.67±0.02	1.46±0.04	1.37±0.04	1.33±0.04	1.38±0.04	1.44^D	1.55±0.04	1.28±0.03	1.27±0.04	1.51±0.02	1.31±0.04	1.38^D	1.76±0.03	1.23±0.02	1.34±0.04	1.44±0.05	1.25±0.03	1.40^C
Mean		1.75^A	1.63^B	1.64^B	1.67^B	1.63^B		1.68^A	1.55^C	1.59^{BC}	1.68^A	1.63^{AB}		1.76^A	1.57^C	1.62^{BC}	1.65^B	1.58^C	
LSD (*p*=0.05)		CERM		WC		CERM*WC		CERM		WC		CERM*WC		CERM		WC		CERM*WC	
		0.05		0.05		0.13		0.08		0.05		0.14		0.07		0.05		0.13	

CERM: crop establishment-cum-residue management; WC: winter crops, ZTDSR: zero-till-direct seeded rice; CTDSR: conventional-till-direct seeded rice, TPR: transplanted puddled rice; R^+: residue retention (30% RT), R^-: control; R-C:Rice-Chickpea; R-L:Rice-Lentil; R-SF: Rice-Safflower; R-Li: Rice-Linseed; R-M: Rice-Mustard; Different capital letters (vertical) represents the significant variations in CERM; Different (horizontal) capital letters indicatesthe significant variations in different cropping sequences; Values with ± represent standard error of mean.

Table 2.41 Soil microbial counts as influenced by crop establishment-cum-residue management (CERM) and winter crops under rainfed rice-fallow production system of eastern India (After 5 years of experimentation).

CERM		Fungi counts (10^4)						Bacterial counts (10^7)					
		R-C	R-L	R-SF	R-Li	R-M	Mean	R-C	R-L	R-SF	R-Li	R-M	Mean
ZTDSR	R^+	6.50±0.21	4.55±0.10	5.00±0.08	2.40±0.05	2.65±0.11	4.22^{B}	2.00±0.16	2.80±0.09	5.00±0.31	9.20±0.26	1.60±0.05	4.12^{C}
	R^-	7.00±0.26	9.35±0.16	9.50±0.38	5.55±0.12	3.55±0.04	6.99^{A}	11.40±0.74	5.00±0.24	5.60±0.17	10.20±0.26	2.20±0.10	6.88^{A}
CTDSR	R^+	5.50±0.15	9.50±0.20	2.45±0.07	1.25±0.03	1.15±0.03	3.97^{C}	8.60±0.06	1.40±0.07	2.00±0.02	4.40±0.11	4.20±0.11	4.12^{C}
	R^-	8.50±0.45	1.20±0.04	5.00±0.16	5.00±0.20	1.45±0.03	4.23^{B}	9.40±0.01	4.00±0.10	3.20±0.30	6.00±0.01	4.80±0.10	5.48^{B}
TPR	R^+	1.00±0.03	1.50±0.02	1.15±0.03	1.00±0.01	1.00±0.03	1.13^{E}	5.00±0.23	0.44±0.00	1.40±0.10	0.40±0.00	1.00±0.05	1.65^{E}
	R^-	1.80±0.06	5.00±0.11	2.70±0.10	4.00±0.12	1.50±0.03	3.00^{D}	6.60±0.28	3.20±0.01	4.00±0.26	0.80±0.02	2.8±0.17	3.48^{D}
Mean		5.05^{A}	5.18^{A}	4.30^{B}	3.20^{C}	1.88^{D}		7.17^{A}	2.81^{D}	3.53^{C}	5.17^{B}	2.77^{D}	
LSD (p=0.05)		CERM		WC		CERM*WC		CERM		WC		CERM*WC	
		0.24		0.17		0.42		0.32		0.19		0.46	

CERM		Actinomycetes count (10^6)						Free living diazotrophs (10^6)					
		R-C	R-L	R-SF	R-Li	R-M	Mean	R-C	R-L	R-SF	R-Li	R-M	Mean
ZTDSR	R^+	3.60±0.10	4.60±0.16	6.20±0.16	3.60±0.11	4.00±0.10	4.40^{C}	1.20±0.03	2.20±0.07	1.20±0.03	1.40±0.03	1.60±0.05	1.52^{B}
	R^-	9.80±0.52	5.20±0.08	7.40±0.28	6.40±0.13	6.20±0.19	7.00^{A}	2.00±0.08	3.00±0.07	4.80±0.11	3.20±0.13	2.40±0.02	3.08^{A}
CTDSR	R^+	6.00±0.18	2.80±0.06	4.80±0.11	4.80±0.16	3.60±0.08	4.40^{C}	2.00±0.06	1.20±0.02	0.80±0.01	1.00±0.03	1.40±0.03	1.28^{C}
	R^-	6.80±0.23	4.60±0.07	5.60±0.12	6.00±0.12	4.80±0.12	5.56^{B}	1.60±0.03	0.20±0.00	2.20±0.04	1.80±0.05	0.80±0.03	1.32^{C}
TPR	R^+	2.40±0.05	1.60±0.06	4.20±0.09	3.20±0.08	2.00±0.04	2.68^{D}	0.60±0.01	0.20±0.00	0.40±0.01	1.40±0.05	1.80±0.06	0.88^{D}
	R^-	3.80±0.07	3.60±0.10	5.00±0.20	6.00±0.12	3.60±0.06	4.40^{C}	0.80±0.01	1.80±0.06	1.60±0.05	2.00±0.06	0.40±0.01	1.32^{C}
Mean		5.40^{A}	3.73^{D}	5.53^{A}	5.00^{B}	4.03^{C}		1.37^{B}	1.43^{B}	1.83^{A}	1.80^{A}	1.40^{B}	
LSD (p=0.05)		CERM		WC		CERM*WC		CERM		WC		CERM*WC	
		0.18		0.20		0.48		0.06		0.06		0.15	

CERM: crop establishment-cum-residue management; WC: winter crops, ZTDSR: zero-till-direct seeded rice; CTDSR: conventional-till-direct seeded rice, TPR: transplanted puddled rice; R^+: residue retention (30% RT), R^-: control; R-C: Rice-Chickpea; R-L: Rice-Lentil; R-SF: Rice-Safflower; R-Li: Rice-Linseed; R-M: Rice-Mustard; Different capital letters (vertical) represents the significant variations in CERM; Different (horizontal) capital letters indicatesthe significant variations in different cropping sequences; Values with ± represent standard error of mean.

Table 2.42 Earthworm counts their biomass and as influenced by crop establishment-cum-residue management (CERM) and winter crops under rainfed rice-fallow production system of eastern India (After 5 years of experimentation).

CERM		Earthworm populations (no. cft^{-1})					Mean	Earthworm biomass (g cft^{-1})					Mean
		R-C	R-L	R-SF	R-Li	R-M		R-C	R-L	R-SF	R-Li	R-M	
ZTDSR	R^-	128.0±3.9	134.0±4.3	126.0±4.1	54.0±0.8	92.0±1.4	106.8^{B}	3.9±0.1	4.5±0.2	3.8±0.1	4.7±0.0	7.0±0.2	4.8^{B}

	R^{+}	183.0±6.6	215.0±4.5	189.0±6.1	116.0±3.1	114.0±3.7	163.4^{A}	5.4±0.1	6.7±0.1	3.5±0.0	2.6±0.1	9.5±0.3	5.5^{A}
CTDSR	R^{-}	45.0±0.9	84.0±0.5	20.0±0.5	22.0±1.0	73.0±1.9	48.8^{E}	1.0±0.0	1.1±0.0	1.5±0.0	1.2±0.0	2.3±0.0	1.4^{E}
	R^{+}	79.0±1.2	126.0±4.1	33.0±0.3	30.0±0.8	101.0±2.7	73.8^{C}	1.5±0.0	1.8±0.0	1.9±0.0	1.9±0.0	2.5±0.0	1.9^{C}
TPR	R^{-}	69.0±0.8	18.0±0.4	15.0±0.8	10.0±0.3	19.0±0.9	26.2^{F}	1.1±0.0	0.5±0.0	0.4±0.0	0.4±0.0	0.6±0.0	0.6^{F}
	R^{+}	93.0±3.0	102.0±1.6	25.0±0.8	18.0±0.4	40.0±1.0	55.6^{D}	1.7±0.1	3.5±0.1	0.9±0.0	0.9±0.0	1.2±0.0	1.7^{D}
Mean		99.5^{B}	113.2^{A}	68.0^{D}	41.7^{E}	73.2^{C}		2.4^{C}	3.0^{B}	2.0^{D}	1.9^{D}	3.8^{A}	
LSD(p=0.05)		CERM		WC	CERM*WC			CERM		WC	CERM*WC		
		3.31		3.30	7.82			0.11		0.10	0.21		

Table 2.43 Soil organic C (SOC) stock on mass and volume basis as affected by crop establishment-cum-residue management (CERM) under rainfed rice-fallow production system of eastern India (After 5 years of experimentation)

CERM		SOC in volume basis (Mg ha^{-1})				SOC in mass basis (Mg ha^{-1})			
		0-15 cm	15-30 cm	30-45 cm	0-45 cm	~2419 Mg ha^{-1}	~2492 Mg ha^{-1}	~2496 Mg ha^{-1}	~7406 Mg ha^{-1}
ZTDSR	R-	16.4^{A}	11.9^{A}	11.7^{AB}	40.0^{AB}	18.3^{B}	12.1^{A}	12.0^{A}	42.4^{AB}
	R+	16.9^{A}	11.7^{A}	11.8^{A}	40.5^{A}	19.0^{A}	12.2^{A}	12.0^{A}	43.2^{A}
CTDSR	R-	15.5^{A}	11.9^{A}	10.1^{BC}	37.5^{BC}	17.6^{B}	11.8^{A}	10.6^{AB}	40.1^{B}
	R+	16.2^{A}	12.1^{A}	11.4^{AB}	39.7^{AB}	17.8^{B}	12.5^{A}	11.6^{A}	41.9^{AB}
TPR	R-	16.6^{A}	9.9^{B}	10.1^{ABC}	36.6^{C}	16.0$_{C}$	9.5^{B}	9.6^{B}	35.0^{C}
	R+	16.8^{A}	10.2^{B}	9.6^{C}	36.6^{C}	16.3^{C}	9.8^{B}	9.2^{B}	35.3^{C}
Mean		16.4	11.3	10.8	38.5	17.5	11.3	10.8	39.7

CERM: crop establishment-cum-residue management; WC: winter crops, ZTDSR: zero-till-direct seeded rice; CTDSR: conventional-till-direct seeded rice, TPR: transplanted puddled rice; R^{+}: residue retention (30% RT), R^{-}:control ; Different small letters (vertical) represent significant variations in CERM

Objective 3: Adapting and mainstreaming available best bet location specific CA practices for enhanced productivity and profitability in rainfed and irrigated eco-systems

1. IARI , New Delhi

The success of the CA based rice-wheat system was validated on farmers' fields in two districts of the north-western Indo-Gangetic plain *viz.* Bareilly and Karnal . The fields of ten farmers (five 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 (Table 3.1 and 3.2). In all the districts, zero till wheat exhibited higher yield than conventional tilled wheat while DSR yield was little lower but 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, CA based system gave approximately 18% higher net returns as compared to conventional system. The DSR-ZTW also performed better than TPR-CTW. 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 3.1 Crop and system productivity (t/ha) and net returns at farmers field Karnal (Haryana) 2020-21

Farmer Name	Village	District	Grain yield t/ha (CA)				Grain yield t/ha (CT)			
			Rice yield	Wheat yield	WEY (SP)	NR (Rs.)	Rice yield	Wheat yield	WEY (SP)	NR (Rs.)
Krishan Sharma	Kurlan	Karnal	4.80	5.60	10.26	176950	4.96	5.20	9.99	150228
Sadanand Sharma	Kurlan	Karnal	4.65	5.45	9.96	171646	4.80	5.20	9.83	144541
Mohan Kumar	Kurlan	Karnal	4.96	5.70	10.51	178057	4.85	5.42	10.10	145180
Jagmohan Singh	Thari	Karnal	5.20	5.56	10.61	180232	5.15	5.20	10.17	153532
Sukha Singh	Thari	Karnal	5.10	5.50	10.45	175509	5.30	5.35	10.47	152602

Table 3.2 Crop and system productivity (t/ha) and net returns at farmers field Bareilly (U..P) 2020-21

Farmer Name	Village	District	Grain yield t/ha (CA)				Grain yield t/ha (CT)			
			Rice yield	Wheat yield	WEY (SP)	NR (Rs.)	Rice yield	Wheat yield	WEY (SP)	NR (Rs.)
Omprakash	Rajpura	Bareilly	5.25	5.85	10.94	186894	5.10	5.20	10.12	157608
Chatarpal	Rajpura	Bareilly	4.75	5.80	10.41	177666	4.90	5.65	10.38	155245
Sumerilal	Rajpura	Bareilly	4.50	5.70	10.07	171571	4.65	5.50	9.99	149950
Bhagwandas	Rajpura	Bareilly	4.38	5.60	9.85	165954	4.56	5.20	9.60	140096
Satyadev	Rajpura	Bareilly	4.45	5.25	9.57	165932	4.60	5.10	9.54	143092

2. CSSRI, Karnal

2.1Demonstration at Farmers field in Bahupur village, Panipat in rice–wheat cropping system

The significant highest grain yield of rice and wheat were in PTR/CTW (4.50 t ha-1) and MSIS-RTDSR/ZTW+RM (6.54 t ha-1) treatment, respectively (Fig. 11). The grain yield of rice (t ha-1) followed the trend of PTR/CTW treatment (4.50)> PTR+RI/CTW+R M (3.67)>MSIS-RTDSR/ZTW+RM (3.66)>SIS-RTDSR/ZTW+RM (3.57).However, in wheat crop the trend for grain yield(tha-1)was MSIS-RTDSR/ZTW+RM (6.54)>SIS-RTDSR/ZTW+RM(6.40)> PTR+RI/CTW+RM (6.38) > PTR/CTW (5.46). In the system perspective (RWS), the system yield (t ha-1) followed the trendofMSISRTDSR/ZTW+RM(10.20)>PTR+RI/CTW+RM(10.05)>SISRTDSR/ZTW+RM(9.97)>PTR/CTW(9.96)

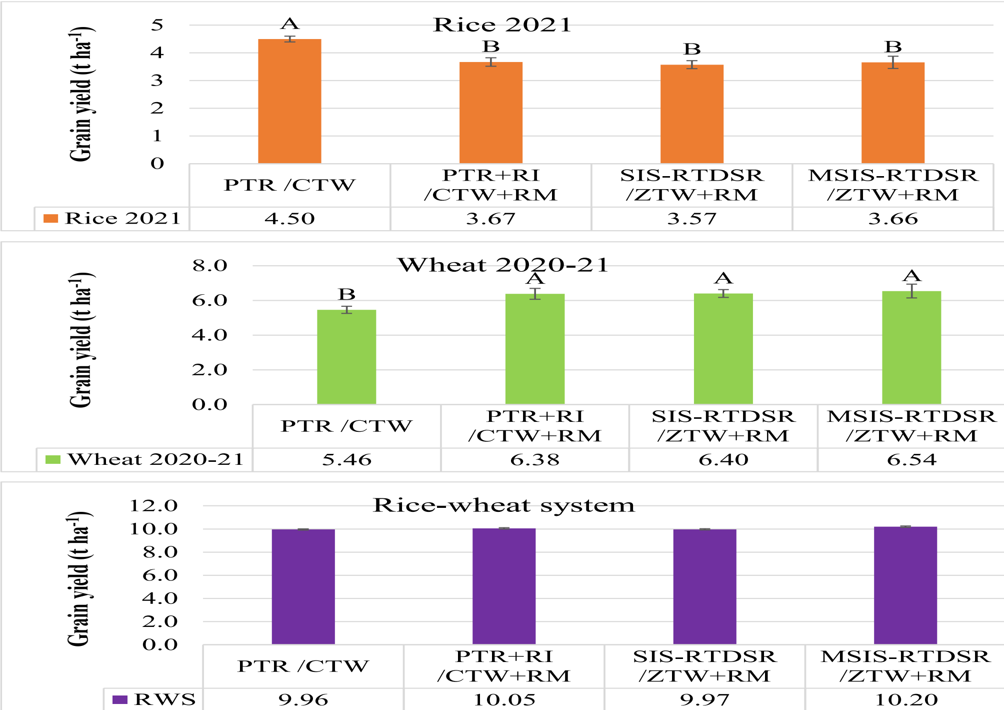

Fig 3.1 Crop productivity of rice (2021), wheat (2020-21) and RWS (2020-21) under different treatments at farmer field in Bahupur village, Panipat.
(**PTR** = Puddled transplanted rice; **CTW**= Conventional tilled wheat; **RTDSR**= Reduced tilled direct seeded rice; **ZTW**= Zero tillage wheat; **RI**= Residue incorporation; **RM**= Residue management; **SIS**= Surface irrigation system; **MSIS**= Mini sprinkler irrigation system)

2.2 Demonstration at Farmers field in Shambali village, Karnal

The highest grain yield of rice, wheat and RWS was in MSIS-RTDSR/ZTW+RM treatment (Fig. 12). The grain yield of rice (t ha^{-1}) followed the trend of MSIS-RTDSR/ZTW+RM (3.95)> PTR/CTW (3.84) > SIS-RTDSR/ZTW+RM (3.67) > PTR+RI/CTW+RM (3.42). Likewise, the grain yield of wheat and RWS (t ha^{-1}) followed the trend of MSIS-RTDSR/ZTW+RM (6.51; 10.45) > SIS-RTDSR/ZTW+RM (6.50; 10.17) > PTR+RI/CTW+RM (6.41; 9.84) > PTR/CTW (5.62; 9.46).

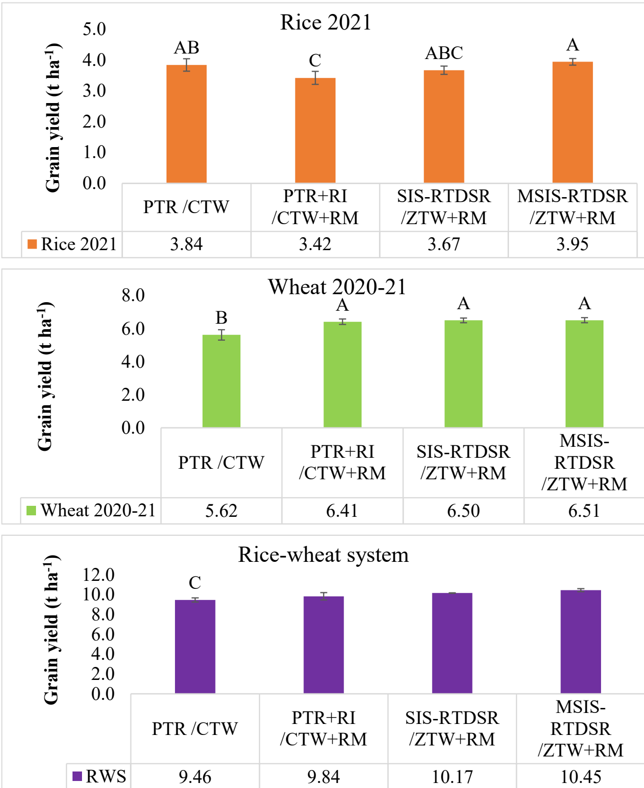

Fig 3.2 Crop productivity of rice (2021), wheat (2020-21) and RWS (2020-21) under different treatments at farmer field in Shambali village, Karnal.
(**PTR** = Puddled transplanted rice; **CTW**= Conventional tilled wheat; **RTDSR**= Reduced tilled direct seeded rice; **ZTW**= Zero tillage wheat; **RI**= Residue incorporation; **RM**= Residue management; **SIS**= Surface irrigation system; **MSIS**= Mini sprinkler irrigation system)

3. CRIDA, Hyderabad

In Bengal gram higher yield was recorded in raised bed and furrow system (1970 kg/ha) followed by paired row (1867 kg/ha) and farmer practice (1637 kg/ha) (Table.3.3 & Fig 3.3). Raised bed and furrow recorded higher gross income (95545 Rs/ha), net income (57670 kg/ha) and C:B ratio (2.52) whereas farmer practice recorded lower gross income (79394 kg/ha), net income (40018 kg/ha) and C:B ratio (2.01)

Table 3.3 Effect of Different Moisture Conservation Methods on yield and returns in Bengalgram

Observations	Yield kg/ha	Cost of Cultivation Rs/ha	Gross Income Rs/ha	Net Income Rs/ha	C:B ratio
1.FP (30x10 cm)	1637	39376	79394	40018	2.01
2. Row to row distance 30 cm. Formation of channel between two rows.	1867 (14.0%)	37875	90549	52674	2.40
3. Row to row distance 35 cm.,formation of channel after 3 rows.	1970 (20.3%)	37875	95545	57670	2.52

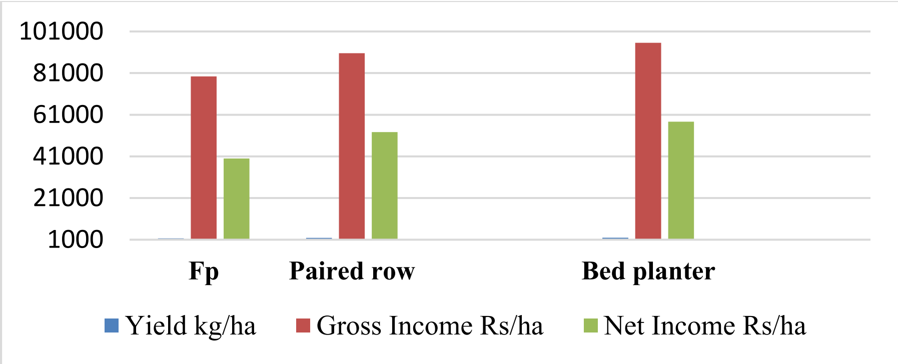

Fig 3.3 Effect of Different Moisture Conservation Methods as yield and income in Bengalgram

Fig 3.4 Crop growth of bengalgram under raised bed and permanent row method

Table 3.4 Cultivation of Bengal gram with minimum tillage after Redgram+setaria intercrop

Particulars	yield kg/ha	Cost of cultivation Rs/ha	Gross income Rs/ha	Net income Rs/ha	Additional income Rs/ha
Redgram+setaria - Bengalgram	712 (Bengal gram equivalent yield)	40370	101319	60949	20579
Redgram+Setaria	394.8 (setaria equivalent yield)	33450	73820	40370	

New cropping system was introduced in Kurnool district. In setaria + redgram system (8:2) row ratio after harvest of setaria bengalgram was sown in zero tillage. This system recorded higher equivalent yield, and an additional returns of Rs 20,759 /ha. (Table 3.4).

Fig 3.5 Crop growth under Redgram setaria inter crop

The traditional cropping system of the region was fallow- Bengal gram in black soil of Kurnool. Hence setaria was introduced in Kharif season with minimum tillage. The bengalgram equivalent yields and net monetary returns were higher in setaria-bengalgram system as compared to fallow-bengalgram system (Table 3.5).

Table 3.5 Setaria-Bengalgram cultivation with minimum tillage

Particulars	Equivalent yield kg/ha	Cost of cultivation Rs/ha	Gross income rs/ha	Net income Rs/ha	Additional income Rs/ha
Setaria	1623	48170	98969	50799	9216
Bengalgram (sole)	1531	32670	74253	41583	

Fig 3.6 Setaria-Bengalgram cultivation with minimum tillage

Minimum tillage treatment recorded higher blackgram equivalent yields over farmers practice after harvest of Seatria-Blackgram intercrop (Table 3.6). This practice recorded an additional return of Rs 14240/-.

Table 3.6 Cultivation of Setaria-Blackgram with minimum tillage

Particulars	**Eqivalent Yield kg/ha**	**Cost of cultivation Rs/ha**	**Gross Income Rs/ha**	**Net income Rs/ha**	**Additional Income Rs/ha**
Setaria	1397	48580	139730	91150	14240
Blackgram (sole)	1732	35670	112580	76910	

Fig 3.7 Cultivation of Setaria-Blackgram with minimum tillage

4. IIWBR, Karnal

Field demonstrations on *in-situ* rice residue management using different machines were done at farmers' field in Kaimla village of Karnal.CA wheat demonstrations were conducted in villages of Karnal district in rice-wheat system. Paddy was harvested using straw management system (SMS) fillted combine harvester which was followed by wheat seeding using Super Seeder. Wheat was sown using a seed rate of 125 kg/ha with the Turbo Happy Seeder. Results showed that rice residue can be managed by RDD and THS machines with a lesser energy requirement than that required for Super Seeder. The use of such resource conserving technologies can reduce the input cost as well as provide the yield advantage to crop due to timely completion of sowing operation. Due to Corona pandemic, wheat yield at farmers field could not be recorded. The reduced tillage cost in CA has resulted in economics in favour of CA system.

Fig 3.8 *In-situ* residue management option with various seeding

5. DWR, Jabalpur

5.1 On-farm research and demonstration of weed management technologies in rice-wheat greengram and maize-chickpea-greengram system under conservation agriculture (Patan and Bargi Locality at Jabalpur)

5.1.1 Rice (Direct-seeded) (*Kharif*, 2021)

Twelve OFR trials were undertaken on weed management in direct-seeded rice during *Kharif,* 2021. Weed management through herbicides with recommended dose of fertilizer was compared with the farmers practice. The major weed flora observed was *Cyperus rotundus, Cyperus iria, Echinochlo acolona, Dinebra retroflexa, Paspaladium* sp., *Phyllanthus niruri* and *Commelina communis.* 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-emergence at 18 DAS) was more effective (weed biomass 39.0 g/m^2; grain yield 4.16 t/ha; B: C 2.75) than farmers practice (weed dry weight, 63.9 g/m^2; grain yield 3.55 t/ha; B:C 2.21) (Table 3.7).

Table 3.7 Weed management, productivity and economics of OFR treatments in direct-seeded rice during *Kharif,* 2021

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Grain yield (t/ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C
RDF+CA+WM	37.9	39.0	74.2	4.16	77720	49474	2.75
FP	47.5	63.9	58.3	3.55	67770	37031	2.21
RDF+CA+Weedy	107.7	156.2		2.19	39322	13780	1.52
SEm±	1.39	3.91	2.10	0.05	1015	1013	0.04
LSD (p=0.05)	4.28	12.05	6.46	0.16	3127	3120	0.11

CA: Conservation agriculture; FP: Farmers Practice; RDF: Recommended dose of fertilizer; WCE: Weed control efficiency; WM: Weed management

Fig 3.9 Weed management in direct-seeded rice during *Kharif,* 2021

5.1.2 Maize (*Kharif,* 2021)

Seven OFR trials were conducted on weed management in maize during *Kharif,* 2021. The major weed flora was observed *Commelina benghalensis, Cyperus* spp., *Dinebraret roflexa, Echinochloa colona, Ecliptaalba* and *Euphorbia geniculata*. Lower weed density (22.5 no./m^2) and dry weight (32.05 g/m^2) in maize were observed 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 than farmers practice (Table 3.8). Grain yield of maize was observed as 7.37 t/ha in CA practice with improved weed management technique. Higher net return (Rs.136292/ha) and B: C (3.87) were recorded with the same treatment as compared to the farmer's practice.

Table 3.8 Weed management, productivity and economics of OFR treatments in maize during *Kharif,* 2021.

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Grain yield (t/ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B: C
RDF+CA+WM	34.8	29.7	82.6	7.37	136292	101470	3.87
FP	65.4	76.1	63.4	5.53	102384	64326	2.69
RDF+CA+Weedy	167.9	215.5		2.37	45752	22875	1.44

CA: Conservation agriculture; FP: Farmers Practice; RDF: Recommended dose of fertilizer; WCE: Weed control efficiency; WM: Weed management

Fig.3.10 Weed management in maize during *Kharif,* 2021.

6 NRRI, Cuttack

The yield attributes of different varieties under different management practices showed significant difference. Among different varieties CR Dhan 314 showed maximum yield under DSR-C and TPR-ZT practise whereas CR Dhan 312 (6.90 t/ha) and Cr Dhan 310 (6.90 t/ha) recorded highest yield under DSR-ZT and TPR-C, respectively.

Table 3.9 Yield and yield attributes of rice verities as influenced by treatments.

	Plant height (cm)	Panicle no.	mt^2 grain weight(kg)	mt^2 straw weight(kg)	100grain weight (gm)	Yield (t/ha)
DSR-C						

CR Dhan-310	112.1	374	0.661	0.812	2.07	6.61
CR Dhan-312	107.8	267	0.515	0.710	2.05	5.15
CR Dhan-314	118.1	314.7	0.675	0.741	3.03	6.75
DSR-ZT						
CR Dhan-310	110.7	319.3	0.555	0.750	2.10	5.55
CR Dhan-312	105.2	385.7	0.690	0.777	2.09	6.90
CR Dhan-314	128.6	303	0.612	0.758	2.93	6.12
TPR-C						
CR Dhan-310	114.7	382	0.690	0.806	2.08	6.90
CR Dhan-312	108.5	293	0.576	0.662	2.07	5.76
CR Dhan-314	120.6	339.3	0.656	0.791	2.99	6.56
TPR-ZT						
CR Dhan-310	117.3	339.3	0.656	0.791	2.99	6.56
CR Dhan-312	107.0	262.3	0.550	0.692	2.07	5.50
CR Dhan-314	122.0	347.3	0.683	0.820	3.03	6.83

3.2 Farmers' Training Programme On "Awareness regarding the conservation agriculture" for Balibhanda village On 31st August, 202l

Conducted a training programme for awareness regarding the Conservation agriculture" in Balibhanda village on 31st August, 2021. A total of 50 farmers attended the meeting including women farmers. Course Director of the Programme was Dr A. K. Nayak, Head, CPD, NRRI. The Programme was Co-ordinated by Dr Mohammad Shahid, Senior Scientist, CPD, NRRI. Dr Sushmita Munda, Scientist, CPD, NRRI and DrRubinaKhanam, Scientist, CPD, NRRI were the Co-Cordinator of the Programme. Mr. SatyabrataNayak, Head of Office, NRRI also attended the Programme.

Dr Mohammad Shahid, addressed the farmer on the topic major-nutrients management under CA. He explained the practices followed under conservation agriculture. He also explained about the SCSP scheme of Govt. of India. Dr Sushmita Munda delivered a lecture on Crop establishment methods, weed management, and cropping systems under CA. She explained the importance of timely weed management in CA. She also explained about proper use of herbicides for efficient control of weeds. Dr Rubina Khanam addressed the farmers on the topic micro-nutrients management under CA. She emphasized on the use of micronutrients particularly application of Zn in CA. Dr A.K. Nayak addressed the farmers and expressed keenness to do support the farmers in future.

Khurpi, Sickle, Storage Drum and Spade were distributed to 50 beneficiary farmers.

3.3 Farmers' Training Programme On "Awareness Regarding Conservation Agriculture, Farm Mechanization and Role of Women in Reducing Poverty" for Balibhanda village on 6th January, 2022

A training on Awareness regarding "conservation agriculture, farm mechanization and role of women in reducing poverty" at Balibhanda village, Rajkanika block on 6th January, 2022. A total of 30 farmers attended the meeting. Course Director and coordinator of the Programme was Dr A. K. Nayak, Head, CPD, NRRI. The other programme Coordinators were Dr Mohammad Shahid, Senior Scientist, CPD, and Dr Sushmita Munda, Scientist, CPD, NRRI. And Co-coordinator was Dr Rubina Khanam, Scientist, CPD, NRRI. Dr B.S. Satpathy, scientist, CPD, NRRI and Dr B. Mondal, Pr. scientist, SSD, NRRI were the expert for the programme.

7 sewing machines were distributed to the self help group and total of 325 kg of rice seeds were distributed to the farmers. Varieties are

1.Satabdi: 100kg
2. Swarnasriya: 30kg
3. CR Dhan 206: 70kg
4. CR Dhan 312: 30kg
5. CR Dhan 304: 25kg
6. I. lalat: 30kg
7. Bina.11: 40kg

Fig 3.11 Farmers' Training Programme at Balibhanda village On 31st August, 202l

7. ICAR-NIASM

7.1 Training and Extension activities under CRPCA-sugarcane at ICAR-NIASM

7.1.1 Training cum field demonstrations of MRD/SORF machines:

During year 2021, four one-day training program cum frontline demonstrations and 10 field trials of MRD/SORF machine were conducted at Gunawadi, Malad and Sangavi villages of Baramati and Phaltan Tehsils for creating awareness of benefits of conservation agriculture (CA) in ratoon sugarcane cropping system (Fig 3.12). Some of these training programs cum field demonstrations were organised in collaboration with KVK, Baramati and ATMA, Govt. of Maharashtra. More than

1000 sugarcane farmers, students, entrepreneurs, sugar factories and state agricultural department officials were benefited.

		
Frontline demonstration of CA machines- Krushik-2021 (18-24 January 2021)	Field demonstration-Gunwadi village (12.01.2021)	Field demonstration- Malad village (30.11.2021)
		
One day training of SORF/MRD Machine at Sagavi village, Phaltan, Satara		

Fig 3.12 Training cum field demonstrations, exhibition and kisan melas organised during 2020-21

7.2 Distribution of inputs to the SC women self help groups (SHG) under CRPCA Project

For the benefits of scheduled caste sugarcane farmers, women's and landless labours, drip irrigation system (5 acres), chilli powder making machine (2 No.) and sugarcane juice extractor machines (1 No.) were distributed. More than 45 farmers, women's and unemployed youths were benefited by scheme (Fig 3.13).

Fig 3.13 Distribution of inputs to the SC women shelf help groups (SHG) under CRPCA Project

7.3. HRD Activities

Dr G C Wakchaure, Senior Scientist (AS&PE) attended the international training "11th Advanced Course (Asia & North Africa) on Conservation Agriculture: Gateway for Sustainable Intensification of Smallholders Systems" organized by International Maize and Wheat Improvement Centre (CIMMYT) and ICAR-Central Soil Salinity Research Institute (CSSRI) and Borlaug Institute for

South Asia (BISA), with support from ICAR and CGIAR research Programs on Wheat, Maize and CCAFS at Karnal/Ludhiana, India (06-18 December 2021)

8. RCER, Patna

8.1 Evaluation of CA practices on productivity of rice in Jharkhand & Chhattisgarh

CA practices was evaluated during 2020-21 in farmer's field at two locations viz., Chene, Ranchi, Jharkhand and Kandora, Jaspur, Chhattisgarh. CA practices comprised of zero-tillage transplanted rice with mulch (ZTT-M), zero-tillage transplanted rice without mulch (ZTT-NM), zero-tillage direct seeded rice with mulch (ZTDSR-M), zero-tillage direct seeded rice without mulch (ZTDSR-NM) and farmer's practice without mulch (FP-NM) were evaluated on rice with genotypes *viz.* Naveen, Lalat, IR-64 and Sahbhagi. Rice grain yield was significantly higher of 5.12 t/ha in ZTT-M over all other CA and farmer's practices (Table 3.10). Farmer's practice registered grain yield of 4.2 t/ha. Among the genotypes, Naveen recorded the highest grain yield of 4.85 t/ha.

Table 3.10 Effect of CA practices on yield attributes of rice (Mean data of 2021)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)
CA practices			
FP	4.20	6.0	10.2
ZTDSR	4.69	5.9	10.59
ZT Transplant	5.12	6.5	11.62
LSD (p≤0.05)	0.276	0.396	0.510
Genotypes			
V1: Naveen	4.85	6.12	10.97
V2: Lalat	4.47	5.98	10.45
V3: IR 64	4.36	5.14	9.5
V4: Sahabhagi	3.89	5.71	9.6
LSD (p≤0.05)	0.355	0.457	0.607

8.2 Evaluation of CA practices on productivity of winter crops: Different winter crops like lentil, mustard and linseed were grown in rice-fallow under different CA practices. The yield attributes of mustard and linseed are described below:

8.2.1 Mustard: Significantly highest grain yield was 2.91 q/ha in ZTDSR-M followed by 2.55 q/ha in ZTT-M. CA practices of ZT-DSR-M, recorded highest grain yield over ZTT-M and farmer's practice (FP-NM) (Table 8). Mulched treatment of CA practices i.e., ZTDSR-M and ZTT-M recorded 23.8 and 8.51% increase in grain yield.

8.2.2 Linseed: Grain yield of linseed varied from 1.86 to 2.21 q/ha among different CA practices. CA practices (ZTT-M) registered highest grain yield (2.21 q/ha) followed by ZTDSR-M. It was observed that mulched treatment of CA *i.e.,* ZTT-M and ZTDSR-M recorded 3.31and18.8% increase in grain yield over their corresponding non-mulched CA practice (Table 3.11).

Table 3.11 Effect of different CA practices on yield attributes of mustard and linseed

CA practices	Mustard			Linseed		
	Grain yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Grain yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)
FP-NM	2.35	4.99	7.34	1.95	4.34	6.29
ZTDSR-M	2.91	5.65	8.56	2.19	4.45	6.64
ZTDSR-NM	2.35	6.35	8.70	2.12	5.45	7.57
ZTT-M	2.55	4.95	7.50	2.21	4.10	6.31
ZTT-NM	2.35	5.75	8.10	1.86	4.78	6.64

LSD ($p \leq 0.05$)	0.42	0.84	0.82	0.40	0.77	0.88

8.3 Evaluation of CA practices on productivity of summer crops: Different summer crops like black gram, green gram and cow pea were grown in rice-fallows under different CA practices. Yield attributes of black gram, green gram and cow pea are described below:

8.2.1 Green gram: Highest grain yield was 2.05 q/ha in ZTT-M followed by 1.95 q/ha in ZTDSR-M (Table 3.12). CA practices of ZTT-M, recorded highest grain yield over ZTT-NM and farmer's practice (FP-NM). ZTDSR-M and ZTT-M recorded 10.1 and 4.28% increase in grain yield over their corresponding non-mulched CA practices, respectively (Table 3.12).

8.2.2 Black gram: Grain yield of black gram varied from 2.31 to 2.65 q/ha among the different CA practices. CA practices (ZTT-M) registered significantly highest grain yield (2.65 q/ha) followed by ZTDSR-M. It was observed that mulched treatment of CA practice *i.e.,* ZTT-M and ZTDSR-M recorded 14.72and 10.6% increase in grain yield over their corresponding non-mulched CA practice i.e., ZTT-NM and ZTDSR-NM, respectively (Table 3.12).

8.2.3 Cow pea: Highest green pod yield was 94.8 q/ha in ZTT-M followed by 93.65 q/ha in ZTDSR-M. CA practices of ZTT-M, recorded highest green pod yield over ZTT-NM and farmer's practice (FP-NM). ZTDSR-M and ZTT-M recorded 1.45 and 1.13% increase in grain yield over their corresponding non-mulched practices (Table 3.12).

Table 3.12 Effect CA practices on yield attributes of green gram, black gram and cow pea

CA practices	**Green gram**			**Black gram**			**Cow pea**		
	Grain yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Grain yield, (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Green pod yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)
FP-NM	1.92	5.46	7.38	2.61	7.43	10.04	90.60	160.20	250.80
DSR-M	1.95	5.27	7.22	2.61	6.39	9.00	93.65	162.00	255.65
DSR-NM	1.87	6.26	8.13	2.36	7.08	9.44	92.60	144.00	236.60
ZTT-M	2.05	6.49	8.54	2.65	6.49	9.14	94.80	167.40	262.20
ZTT-NM	1.86	4.78	6.64	2.31	6.25	8.56	93.45	144.00	237.45
LSD ($p \leq 0.05$)	0.49	0.46	0.73	0.63	0.51	0.92	12.96	12.91	18.97

Rice equivalent yield (REY) obtained under rice-mustard-cowpea ranged between 8.2 to 9.3 t/ha while that for rice-linseed-green gram it ranged between 5.4 to 6.5 t/ha. Among different treatments the REY was found higher under CA and recorded higher (9.3 t/ha) under ZTT-M.

8.3 Post-harvest soil studies: Highest soil pH was 4.81 recorded in treatment T5: ZTTR. SOC content in T3, T4 and T5 showed significantly higher over T1, but when compared among them, showed non-significant. Highest SOC content was 0.62% in T4: ZT-DSR treatment. Available-N content was significantly highest of 175.9 kg/ha in T5: ZTTR treatment. Available-P content was highest of 17.35 kg/ha in T4: ZT-DSR treatment and found significantly higher over T1: Rice Fallow treatment. Available-K content in T2, T4 and T5 showed significantly higher over T1 treatments, but when compared among them, showed non-significant. Highest available-K content was 137.9 kg/ha in T4: ZT-DSR treatment (Table 3.13).

Table 3.13 Effect of CA practices on soil properties in post-harvest soils of kharif crops

Treatments	pH	SOC (%)	Available-N (kg/ha)	Available-P (kg/ha)	Available-K (kg/ha)
Rice Fallow	4.80	0.51	159.5	13.26	102.5
FPTR	4.68	0.58	168.9	14.85	124.0
CT-DSR	4.73	0.59	158.8	14.55	121.5
ZT-DSR	4.78	0.62	164.2	17.35	137.9
ZTTR	4.81	0.60	175.9	15.83	131.9
LSD ($p \leq 0.05$)	NS	0.075	10.51	3.30	19.41

9. CIAE, Bhopal

9.1 Development of Nine Row Mulcher -Cum -Seed Drill

It was observed from the experiments that a seed drill or planter can be used for sowing of seed in any level of wheat straw after using mulcher in combine harvested fields. Based on this experiment a nine row mulcher cum seed drill has been developed as depicted in (figure 3.14). The machine is capable to cut and shred the previous crop straw and sow the seeds of succeeding crop.

Fig 3.14 Nine row mulcher cum seed drill

This machine is found capable for working in full load of residue condition. The machine has inverted T type furrow opener used for sowing of seeds under residue condition and arrangement for adjustable row to row spacing. Fluted roller type metering mechanism is used for (control the seed and fertilizer rate) variety of seed sowing. Working width of the machine is 1800mm.The machine was used for sowing of soybean in the field of ICAR-IISS, Bhopal having 100% wheat straw and Kans (*Saccharum spontaneum L.*) of 1.2 to 1.8 m height as shown in figure-7. Crop germination and yield parameters were found comparable to happy seeder.

9.2 Adaptation and evaluation of slit till drill.

Institute developed slit till drill was tested and based on the feedback a ten row slit-till drill was developed and evaluated for sowing of crop directly into the uncultivated field just after the harvesting of previous crop.

Fig 3.15 Sowing of wheat and maize with slit till drill

The machine was fine tuned and used for sowing of wheat in farmer's field and maize at IISS, Bhopal as shown in (fig .3.15). Crop germination and yield parameters were found comparable to happy seeder for wheat and maize crops.

9.3 Evaluation of zero till planter with herbicide applicator as an attachment.

After modification (8 rows, 200l tank capacity and adjustable ground clearance) ICAR- CIAE developed tractor operated inclined plate planter with pre-emergence herbicide strip applicator was evaluated at farmers field (Fig 3.16).The developed machine is suitable for herbicide application and simultaneously planting of wide spaced crops like maize, soybean, pigeon pea etc. The planter is working satisfactorily for sowing of various crops but the inner surface of the tank is corroding due to chemical reaction with herbicide applicator as it is made of mild steel.

Fig 3.16 Inclined plate planter with pre-emergence herbicide strip applicator in farmer's field

9.4 Capacity building and knowledge management for accelerated adoption of conservation agriculture machinery

Various activities related to capacity building and knowledge management for accelerated adoption of conservation agriculture machinery were organized.

Field day

Consortia Research Platform on conservation agriculture. ICAR-Central Institute of Agriculture Engineering, Bhopal center organized field day for farmers on improved agricultural machinery/implements suitable for conservation agriculture on 16 March 2021. A total of (105) farmers from various villages, Kheri (54), Amipur (12), BadaKhedi (12), Amla (05), Kanda khedi (05), Bichholi (03), Mubrakpur (03), Nipaniya (02), Sehore (02), Echavar (01), Ragayal (01), Daulatpur (01), Vishankhedi (01), Suvakhedi (01), Astha (01) and Devkhedi (01), of Sehore district participated in the field day (fig 3.17). During the training, participates were briefed on conservation agriculture technologies and covered cultivation. They were given hands on training including demonstrations of improved conservation agricultural machinery (Mulcher, Broad bed former planter, pre-imergence herbicide applicator with inclined plate planter, Mulcher cum seeder, zero toll drill and strip till drill, Boom sprayer and other agricultural machinery (Display hall).

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Fig 3.17 Field day on conservation agriculture machinery

9.5 Training program for SCSP farmers and distribution of hand tools for the beneficiaries

Under this programme, resources/missing input in the form of hand tools were provided for filling the critical gaps in agricultural operations for economic development of SCs below the poverty line. Farmers were also given hands on training/knowledge for use of these tools for growing better crops (Fig 3.18). Farmers from various villages of Sehore districts were provided hand tools useful for agriculture practices.

Fig 3.18 Training program for SCSP farmers and distribution of hand tools for the beneficiaries

9.6 Promote Conservation Agriculture (CA) technology in Bundelkhand Region of Uttar Pradesh with the help of NGO

Efforts were made to promote use of conservation agriculture technologies in Bundelkhand region of Uttar Pradesh through Shri Ramchandra Anandam mission (NGO). Inverted T type furrow openers were provided to the NGO for promotion of conservation agriculture in Banda District of Uttar Pradesh. These furrow openers were fitted to locally available tractor drawn seed cum fertilizer drill in place of traditionally used furrow openers. These in the frame of local seed cum fertilizer drill as shown in (fig 3.19). Feedback on performance of these furrow opener in Bundelkhand region will be taken under this project.

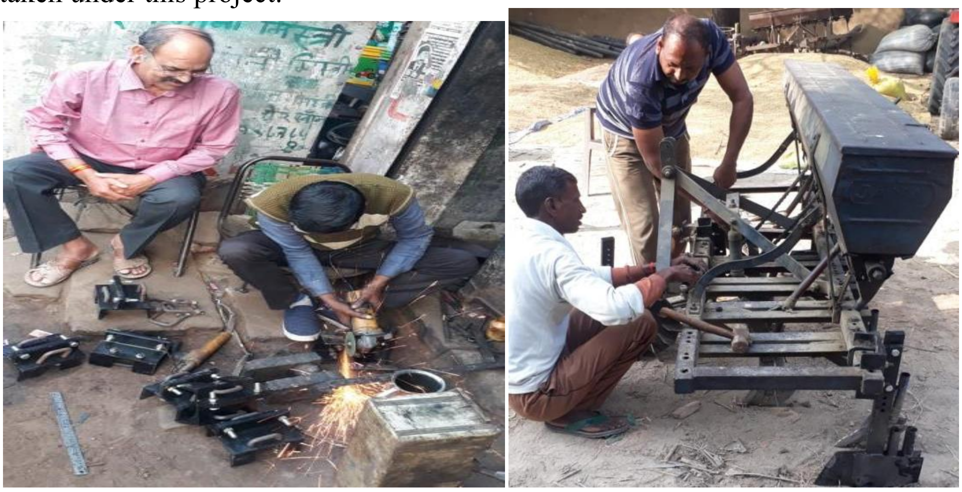

Fig 3.19 Fitting of inverted T type furrow openers in seed cum fertilizer drill

10. IISS, Bhopal

The best-bet conservation agriculture practices were demonstrated in the farmer's field during 2020-21. Farmer field experiments were conducted in a participatory mode in villages Khamkheda, Rasla Khedi, Raipur and Karod khurd under Bhopal sub-division of Madhya Pradesh. Data for various crop growth and yield attributes were recorded under no till, reduced tillage and compared with conventional tillage farmers practice.

10.1 Wheat

Twelve demonstrations with wheat crop in the farmer's field were conducted during the *rabi* season in 2020-21. A perusal of the data revealed that reduced tillage recorded higher seed yield of wheat (47.90 q/ha) as compared to conventional tillage (47.61q/ha) and zero tillage (47.31q/ha), however the differences in grain yield were not significant.

Table 3.14 Grain and straw yield of wheat crop during the *rabi* season in 2020-21

Wheat									
Name of Farmer	Straw yield (q/ha)	Grain yield (q/ha)	HI (%)	Straw yield (q/ha)	Grain yield (q/ha)	HI (%)	Straw yield (q/ha)	Grain yield (q/ha)	HI (%)
	ZT			**RT**			**CT**		
Nandlal Yadav	85.23	56.81	40.00	88.80	55.96	38.66	83.88	54.34	39.32
Parvat Yadav	85.36	54.34	38.90	79.48	49.40	38.33	80.00	51.87	39.33
Hemraj Yadav	94.55	52.85	35.85	78.75	51.37	39.48	78.25	50.63	39.28
Santosh Yadav	75.38	47.56	38.69	81.28	49.65	37.92	77.40	48.19	38.37
Karan singh Yadav	85.75	55.57	39.32	83.38	57.30	40.73	87.78	55.32	38.66
Deepak Yadav	77.68	50.88	39.58	77.58	48.16	38.30	78.10	50.14	39.10
Naval singhyadav	75.13	46.23	38.09	77.35	51.12	39.79	77.25	51.40	39.95
JagjeevanAhirwar	70.28	45.00	39.04	74.50	46.00	38.17	63.85	44.00	40.80

Himmat Singh Lodhi	61.55	37.05	37.58	62.00	40.20	39.33	72.45	40.45	35.83
Naval Singh Lodhi	70.20	39.20	35.83	71.55	39.90	35.80	66.00	41.25	38.46
Ram Singh Lodhi	69.60	43.58	38.51	76.50	45.23	37.16	66.00	42.12	38.96
Azad Singh	61.60	38.65	38.55	68.85	40.50	37.04	63.50	41.63	39.60
Mean	**76.02**	**47.31**	**38.36**	**76.67**	**47.90**	**38.45**	**74.54**	**47.61**	**38.98**

10.2 Chickpea

Eight demonstrations with chickpea crop were conducted during the *rabi* season of 2020-21. A perusal of the data revealed that conventional tillage recorded higher seed yield of chickpea (10.83 q/ha) as compared to zero tillage (10.11q/ha) and reduced tillage (10.04q/ha), however the differences in grain yield could not attain the level of significance.

Table 3.15 Grain and straw yield of Chickpea during the *rabi* season in 2020-21

Chickpea									
Name of Farmer	Straw yield (q/ha)	Grain yield (q/ha)	HI (%)	Straw yield (q/ha)	Grain yield (q/ha)	HI (%)	Straw yield (q/ha)	Grain yield (q/ha)	HI (%)
	ZT			**RT**			**CT**		
Jeevan Singh Jat	12.75	11.00	46.32	11.20	11.80	51.30	13.00	12.50	49.02
Badam Singh Jat	11. 00	9.00	45.00	13.33	8.30	38.38	12.60	9.20	42.20
Chain Singh Jat	11.75	9.50	44.71	11.80	8.70	42.44	11.70	9.80	45.58
Rajnarayan Yadav	11.63	9.63	45.29	11.60	8.40	42.00	12.00	9.00	42.86
Ram Singh Jat	13.80	11.20	44.80	11.20	11.80	51.30	14.15	12.60	47.10
Vijay Malviya	12.50	10.00	44.44	12.55	8.90	41.49	12.65	9.60	43.15
Phul Singh	10.98	10.40	48.65	10.85	10.90	50.11	10.78	11.60	51.84
Goverdhan	9.8	10.2	48.00	12.80	11.50	47.33	11.95	12.30	50.72
Mean	**11.15**	**10.11**	**45.88**	**11.92**	**10.04**	**45.72**	**12.35**	**10.83**	**46.70**

10.3 Soybean

Twenty field demonstrations under zero tillage and reduced tillage were conducted during the *kharif* season of 2021 with soybean crop. A perusal of the data revealed that zero tillage recorded higher seed yield of soybean (11.14 q/ha) as compared to reduced tillage (10.38q/ha) and conventional tillage (10.60q/ha), however the differences in seed yield could not attain the level of significance.

Table 3.16 Grain and straw yield of Soybean during the *kharif* season in 2021

S.No.	Name of Farmer's	**ZT**	**RT**	**CT**
1	Parvat Yadav	12.00	10.00	10.50
2	Nandlal Yadav	10.00	8.50	9.00
3	Karan singh Yadav	13.00	12.00	12.40
4	Hemraj Yadav	10.20	7.80	8.65
5	Naval singh yadav	10.50	11.00	9.60
6	Deepak Yadav	11.20	10.60	10.50
7	Rajnarayan Yadav	12.20	12.00	13.10
8	Santosh Yadav	11.50	10.90	11.30
9	Chain Singh Jat	13.30	11.80	12.20
10	Jeevan Singh Jat	9.65	7.29	6.96

11	Badam Singh Jat	8.68	9.36	8.20
12	Ram Singh Jat	11.80	11.25	11.40
13	Jagjeevan Ahirwar	10.47	10.24	10.00
14	Vijay Malviya	12.00	11.00	10.45
15	Ram Singh Lodhi	9.00	9.50	9.10
16	Himmat Singh Lodhi	11.00	10.00	9.65
17	Naval Singh Lodhi	10.85	9.20	11.60
18	Azad Singh	10.00	10.40	10.50
19	Phul Singh	13.00	12.25	13.65
20	Goverdhan	12.40	12.52	13.20
	Average	**11.14**	**10.38**	**10.60**

NIASM

Training, Extension and SCSP activities under CRPCA-sugarcane at ICAR-NIASM

1. Training cum field demonstrations of MRD/SORF machines:

During year 2021, four one-day training program cum frontline demonstrations and 10 field trials of MRD/SORF machine were conducted at Gunawadi, Malad and Sangavi villages of Baramati and Phaltan Tehsils for creating awareness of benefits of conservation agriculture (CA) in ratoon sugarcane cropping system (Fig 3.20). Some of these training programs cum field demonstrations were organised in collaboration with KVK, Baramati and ATMA, Govt. of Maharashtra. More than 1000 sugarcane farmers, students, entrepreneurs, sugar factories and state agricultural department officials were benefited.

Frontline demonstration of CA machines- Krushik-2021 (18-24 January 2021)

Field demonstration-Gunwadi village (12.01.2021)

Field demonstration- Malad village (30.11.2021)

One day training of SORF/MRD Machine at Sagavi village, Phaltan, Satara

Fig 3.20 Training cum field demonstrations, exhibition and kisan melas organised during 2020-21

2. CRPCA-SCSP activities:

For the benefits of scheduled caste sugarcane farmers, women's and landless labours, drip irrigation system (5 acres), chilli powder making machine (2 No.) and sugarcane juice extractor machines (1 No.) were distributed. More than 45 farmers, women's and unemployed youths were benefited by scheme (Fig 3.21).

Fig 3.21 Distribution of inputs to the SC women shelf help groups (SHG) under CRPCA Project

3. HRD activities

Dr GC Wakchaure, Senior Scientist (AS&PE) attended the international training "11th Advanced Course (Asia & North Africa) on Conservation Agriculture: Gateway for Sustainable Intensification of Smallholders Systems" organized by International Maize and Wheat Improvement Centre (CIMMYT) and ICAR-Central Soil Salinity Research Institute (CSSRI) and Borlaug Institute for South Asia (BISA), with support from ICAR and CGIAR research Programs on Wheat, Maize and CCAFS at Karnal/Ludhiana, India (06-18 December 2021)

11. IIFSR

11.1 SCSP related work under the CRP on CA

On-farm Participatory Research in Farming Systems Perspective under Schedule Caste Sub-plan (SCSP) in Laldhang cluster under Bahadrabad block, District Haridwar (Uttarakhand)

(**PI**: A.L. Meena; **Co-PI**: Dr. L.R. Meena; Dr. D.K. Singh; Dr. P.C. Jat; Dr. Sunil Kumar; Dr. JairamChoudhary)

The analysis of socio-economic pattern of the sampled farmers helps in providing an insight to the background and farm situation regarding the decision-making pattern of the farmers of selected village. Details of the economic and social characteristics of the farm households of selected village are given in (Table 3.17).

Table 3.17 Social and economic status of the sampled schedule caste farmers of Dalupuri village.

Particulars	**Landless farmers**	**Marginal farmers (<1 ha)**	**Small farmers (1-2 ha)**	**Medium and large farmers (>2 Ha)**	**Overall**
Farmers (No.)	76	88	22	14	200
Percent (%)	38	44	11	7	100
Average family size (Nos.)	5.07	4.50	5.09	5.43	5.0
Average age (Years)	42.7	44.7	49.9	49.6	46.7
Education (number of years of schooling)	5.3	6.7	8.8	9.7	7.6
Farming experience	-	32.0	35.3	33.0	33.4
Non-farm income					
Wage days	148	175	148	160	157.8
Wage rate	185	252	311	395	285.8
Non-farm income (Rs.)	49051	70633	88773	246789	113812
Mean land holding (ha)					

Owned land	-	0.306	0.871	1.637	0.938
Leased-in land	-	0.116	0.511	1.458	0.695
Leased-out land	-	-	-	0.964	0.964
Operational holding	-	0.423	1.383	3.095	1.634
Possession of Kisan Credit Cards (KCC %)	-	70.6	76.7	79.5	75.6
Membership in organizations					
Gram Panchayat (%)	30.2	31.3	22.1	22.5	26.53
Co-operative society (%)	12.3	40.5	38.7	38.3	32.45
Marketing society (%)	5.1	34.3	44.2	41.8	31.35
SHG's (%)	66.3	55.6	36.3	22.9	45.28
Adoption of micro-irrigation (%)	-	-	5.6	11.4	8.50
Adoption of crop insurance (%)	-	-	9.8	17.9	13.85
Cropping intensity (%)	-	157.9	162.7	171.3	164.0

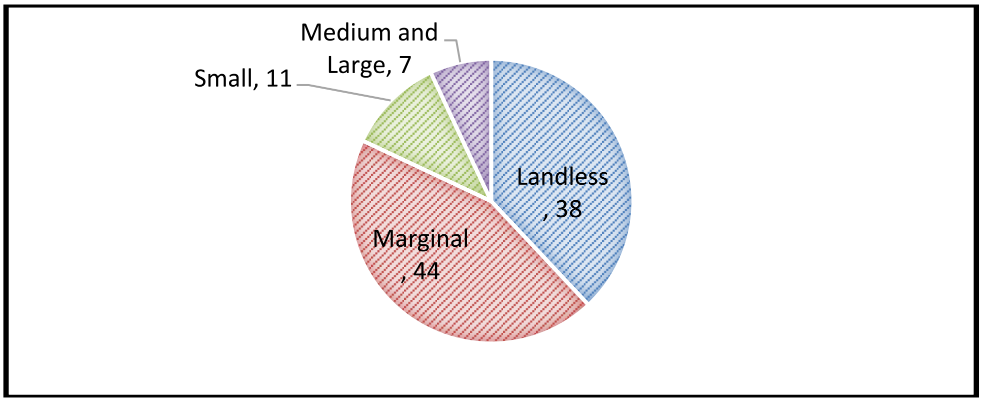

Fig 3.22 Percent distribution of different farmers' category among the sampled farmers of Dalupuri village

As per the above mentioned table, the selected village is dominated by the marginal farmers' category (44%) owning <1ha land followed by landless farmers (38%) and small farmers (11%) (fig. 1). The mean age of farmers belonging to different category is in the range of 42.7 to 49.9 years and the average family size ranged from 4.5 to 5.43 members in all the categories. The mean number of education years is 7.6 among all the sampled farmers, indicating a junior high school education level among most of the farming community. Thus, the sampled farmers can be targeted for application of integrated farming system approaches along with adoption of modern farming practices. The average number of years of farming experience is about 32 years in case of marginal farmers and 33 years in case of medium and large farmers.

The average operational land holding among the marginal farmers is 0.423 ha, 1.383 ha for small farmers and 3.095 ha for medium and large farmers. On an average, 75.6% farmers availed the Kisan Credit Card (KCC) scheme once or twice during their farming experiences. The landless and small farmers are numerically more in membership of gram Panchayat and co-operative societies. In adoption of crop insurance scheme, 17.9% of medium and large farmers have adopted this scheme, at the same time 11.4% medium and large farmers have adopted the micro-irrigation facilities in the sampled farm families. Most of women of the adopted village have registered them with different self-help groups and among the different categories of the farming communities the members of self-help group are in the order of 66.3% landless > 55.6%marginal > 36.3% small farmers > 22.9% medium and large farmers. The mean level of cropping intensity in Dalupuri village is 164%, with the medium and large farmers with a significantly higher level.