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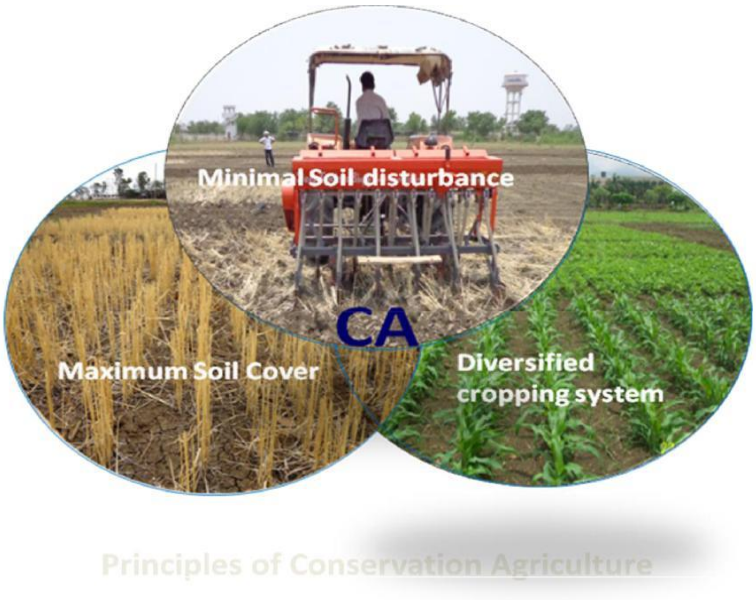
INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Consortia Research Platform
on
Conservation Agriculture

ANNUAL REPORT 2023



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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 332.22 million tonnes during 2023-24, 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 greenhouse 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 effect 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 greenhouse 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 greenhouse 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 equipment's 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 (2023)

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

A. Tillage and Residue Management Practices

1. Rice-Wheat Cropping System

IARI

Wheat yield, system productivity, and net returns were superior for a long-term (13 years) triple zero-till cropping system (TZT) involving ZT DSR with summer mungbean (SMB) residue (MBR)- ZT wheat (ZTW) with rice residue (RR)– ZT summer mungbean (ZTSMB) with wheat residue (WR) compared to other CA systems and puddled transplanted rice (PTR) - conventional till wheat (CTW) system (Fig. 1.1). Notably, ~24% higher wheat yield, ~18% higher system productivity and ~20% lower rice yield than TPR-CTW system. This led to sustainable intensification of the R-W system with a legume mungbean, which proved to be a superior alternative and an important adaptation and mitigation strategy to climate change.

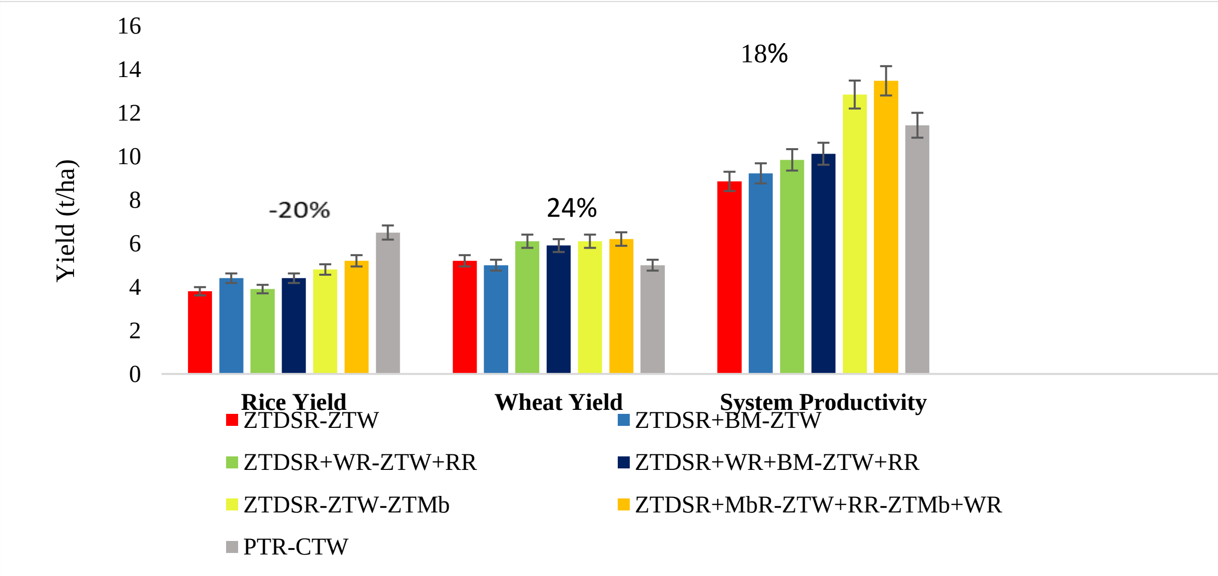


Fig 1.1: Effect of CA on rice yield, wheat yield, and system productivity under rice-wheat system

CSSRI

Rice crop during *Kharif* 2023

a) Puddled Transplanted Rice (PTR)

Higher grain yield (7.16tha^{-1}) was recorded under conventional puddled transplanted rice with wheat residue incorporation (PTR+RI) than without residue incorporation (PTR; 6.94tha^{-1}). So, residue incorporation in conventional PTR rice increased the grain yield by 3.21% (Fig. 1.2).

Plate 1: Experimental view of the puddled transplanted rice with wheat residue incorporation

Plate 2: 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 6.24 tha^{-1}, which was 11.11% lower in comparison to PTR (6.94 tha^{-1}) and 6.81% lower in comparison to direct seeded rice under reduced tillage without wheat residue (RTDSR; 6.70t ha^{-1}), respectively (Fig. 1.2).

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

Grain yield under zero tilled DSR with anchored wheat residue (ZTDSR+RR) was 5.95t ha^{-1} which was 14.23% lower than the PTR (6.94 t ha^{-1}) and 4.03% lower than the direct seeded rice in zero tillage without wheat residue incorporation (ZTDSR; 6.20 t ha^{-1}) (Fig. 1.2). The lower yield in the ZTDSR+RR was mainly because of the higher weed population, and lower plant density as compared to the PTR.

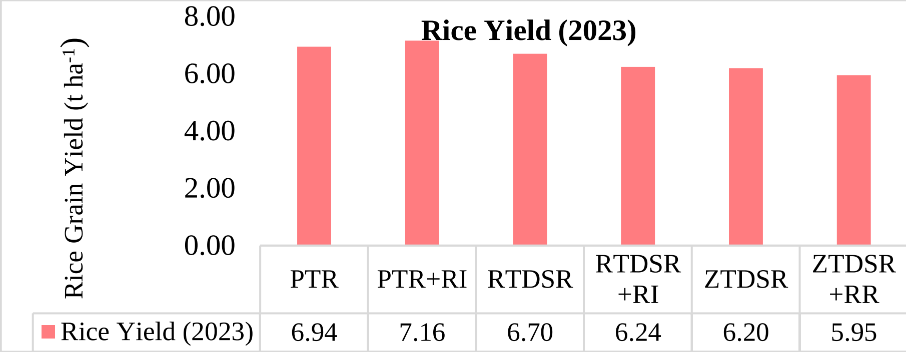


Fig 1.2: Effects of different tillage and residue management practices on rice grain yield during kharif 2023

(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)

1.1.1 Details of wheat crop during *rabi* 2022-23

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

a) Conventional **tilled wheat (CTW)**

Higher grain yield (5.48 t ha^{-1}) was recorded under conventional tilled wheat with residue incorporation (CTW+RI) than without residue addition (CTW) (5.34 tha^{-1}). So, residue incorporation in CTW enhanced the grain yield by 2.69% (Fig 1.3).

b) Reduced tilled wheat with rice residue

Reduced tilled wheat without rice residue (RTW)produced grain yield of 5.87 t ha^{-1}, which was 9.95and 6.22% higher in comparison to CTW (5.34 t ha^{-1}) and reduced tilled wheat residue with rice residue (RTW+RI) (5.53 t ha^{-1}), respectively (Fig 1.3).

c) Zero tilled wheat with anchored rice residue

Zero tilled wheat with anchored rice residue (ZTW+RR) produced wheat yield of5.91 t ha^{-1} which was 10.66% higher in comparison to CTW (5.34 t ha^{-1}) and 1.05% lower in comparison to zero tilled wheat without rice residue retention (ZTW; 5.97 t ha^{-1}) (Fig 1.3). The lower yield in the ZTW+RR was mainly because of the higher weed population, lower plant density as compared to the CTW. 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 saves from deterioration of soil physical properties. However, the residue retention under both the conservation tillage treatments, i.e., reduced tillage and zero tillage leads to considerable lose in wheat yield.

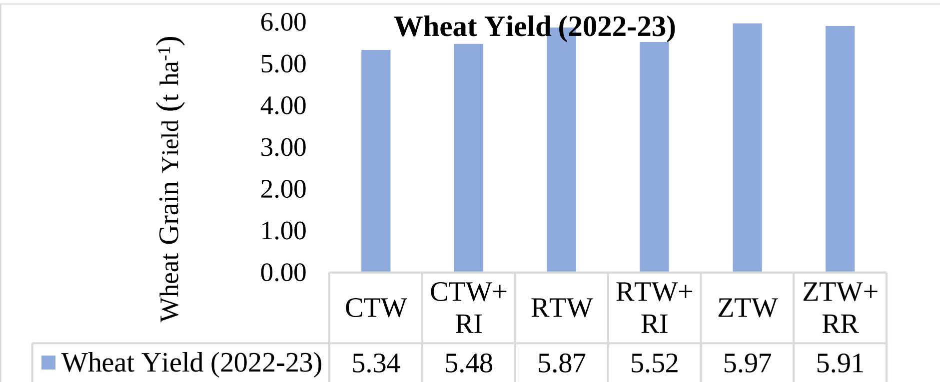


Fig 1.3: Effects of tillage and residue management practices on wheat grain yield during rabi2022-23

(**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)

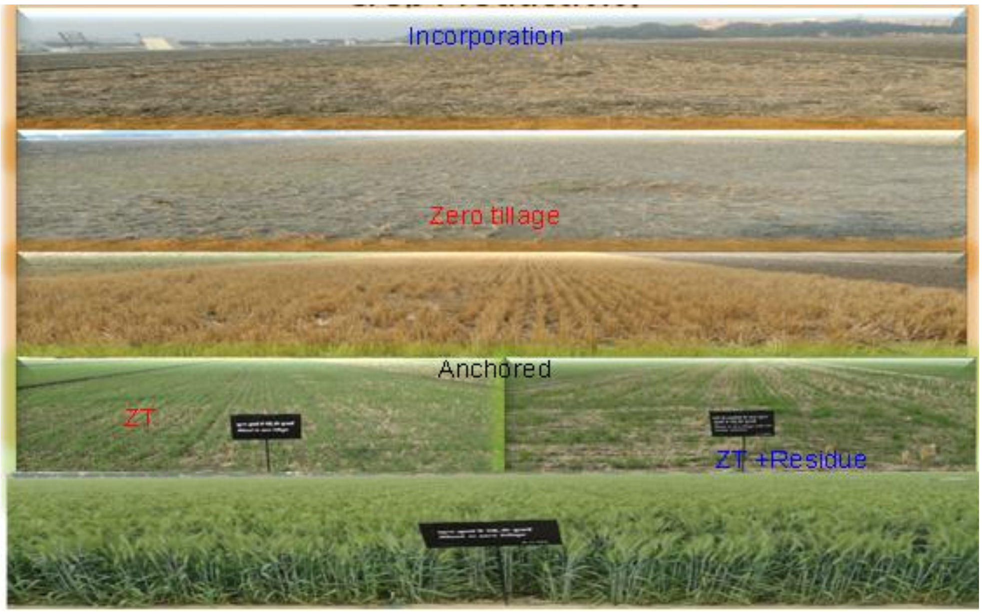


Plate 3: Experimental view of wheat germination under rice residue incorporation/anchored and zero tillage conditions

1.1.2 Details of rice-wheat cropping system during 2022-23

a) PTR/CTW

Higher grain yield (12.64 t ha^{-1}) was recorded under conventional puddled transplanted rice/ conventional tilled wheat with residue incorporation (PTR+RI/CTW+RI) and12.28 t ha^{-1} in PTR/CTW without residue incorporation. So, residue incorporation in conventional PTR rice enhanced the grain yield by 2.98% (Fig 1.4).

b) RTDSR+RI/RTW+RI

Direct seeded rice under reduced tillage/reduced tilled wheat with residue incorporation (RTDSR+RI/RTW+RI) produced grain yield of 11.77 t ha^{-1}, which was 4.30 and 6.80% lower in comparison to PTR/CTW (12.28 t ha^{-1}) and direct seeded rice under reduced tillage/ reduced tilled wheat without residue incorporation (RTDSR/RTW) (12.57 t ha^{-1}), respectively (Fig 1.4).

c) ZTDSR+RR/ZTW+RR

Grain yield under zero tillage direct seeded rice/zero tilled wheat with anchored wheat residue (ZTDSR+RR/ZTW+RR) was 11.86 t ha^{-1} which was 3.53% lower than the PTR/CTW (12.28 t ha^{-1}) and 2.64% lower than the direct seeded rice in zero tillage without wheat residue incorporation (ZTDSR/ZTW; 12.17 t ha^{-1}) (Fig 1.4).

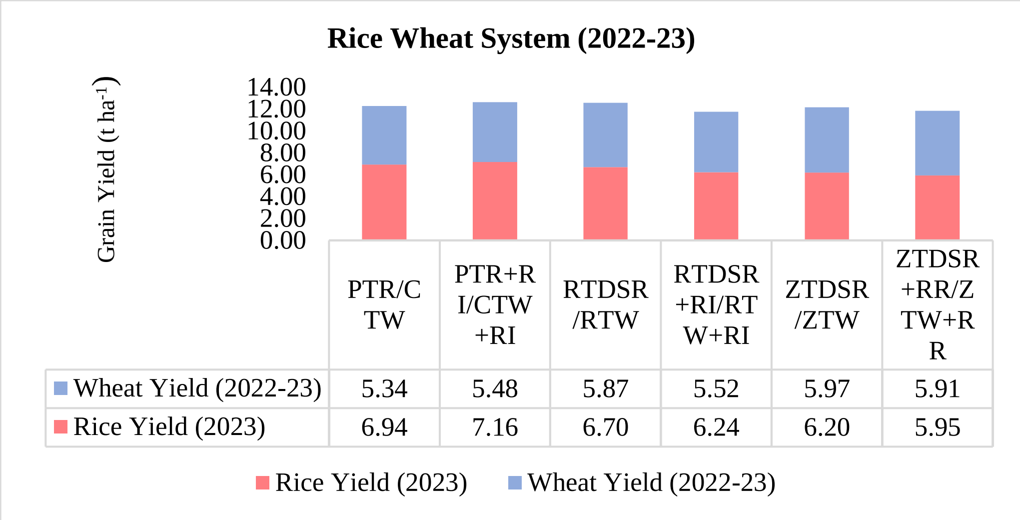


Fig 1.4: Effects of tillage and residue management practices on rice-wheat cropping system grain yield during 2022-23

(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)

IIFSR

The direct seeded rice (DSR) recorded 25.9% and 14.8% lower yields over the puddled transplanted rice (PTR) in R-W and R-W-GG cropping systems, respectively. At the same time the zero tilled wheat (ZT) recorded 7.8% and 7.1% higher yield over the conventionally tilled (CT) wheat in these cropping systems. Interestingly, the ZT maize and ZT mustard recorded 7.8% and 9.2% higher yield over the CT maize and CT mustard in CA based M-M-GG cropping system (Table 1.1). Similarly, the sugarcane crop grown in reduced tillage (RT) had 6.0% lower yield over the conventionally grown sugarcane crop.

Table 1.1: Crop yields and system productivity in diverse cropping systems with CA based management practices (2022-23)

Cropping Systems	Tillage	Yield data of different crops (t ha^{-1})				
		Kharif	**Rabi**	**SP-SEY (t ha^{-1})**		
R-W	PTR-CT	5.45	5.01		CA	CP
R-W	ZTDSR-ZT	4.04	5.40	R-W	55.71	62.20
R-W-GG	PTR-CT-CT	5.75	5.39	R-W-GG	56.34	66.24
R-W-GG	ZTDSR-ZT-ZT	4.90	5.77	M-M-GG	74.92	69.50
M-M-GG	CT-CT-CT	5.13	2.62	S-R-W	158.8	166.0
M-M-GG	ZT-ZT-ZT	5.53	2.86	Sem (±)	1.356	0.959
S-R-W	CT-CT-CT	135.3	5.04	C.D.	4.154	2.937
S+GG-R-W	RT-ZT-ZT	127.2	5.21			

* SP-SEY=system productivity in terms of sugarcane equivalent yield (t ha^{-1}); CT=Conventional tillage; ZT-Zero tillage; PTR=puddled transplanted rice; RT=reduced tillage

IIWBR

Performance of CA and CT rice-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, greengram) and two weed control options (weedy check and weed free) in cropping systems i.e. rice-wheat (R-W). The experiment was started in 2020 with crop. For rice, the cultivar grown was PR 131. For wheat, in rice-wheat system, timely sown wheat variety DBW 222 was sown during the first week of November. 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. Wheat was sown using the Turbo Happy Seeder. Whereas, one month old rice seedlings were transplanted at 20 cm row to row spacing and 15 cm plant to plant spacing after ponding of water for two days in ZT and CT conditions. 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 slightly better under ZT (54.55 q/ha) compared to CT system (52.52 q/ha) due to lower infestations of weeds in CA system. The effect of manuring on wheat was not distinctly visible and lon term continuation may result some desirable effect on system productivity. In case of rice, the grain yields were lower in CA transplanted system compared to CT (Puddled transplanted system). The average rice yield in puddle transplanting was 77.38 q/ha and in CA was 66.23 q/ha. It means that rice is less suitable under CA system than CT system.

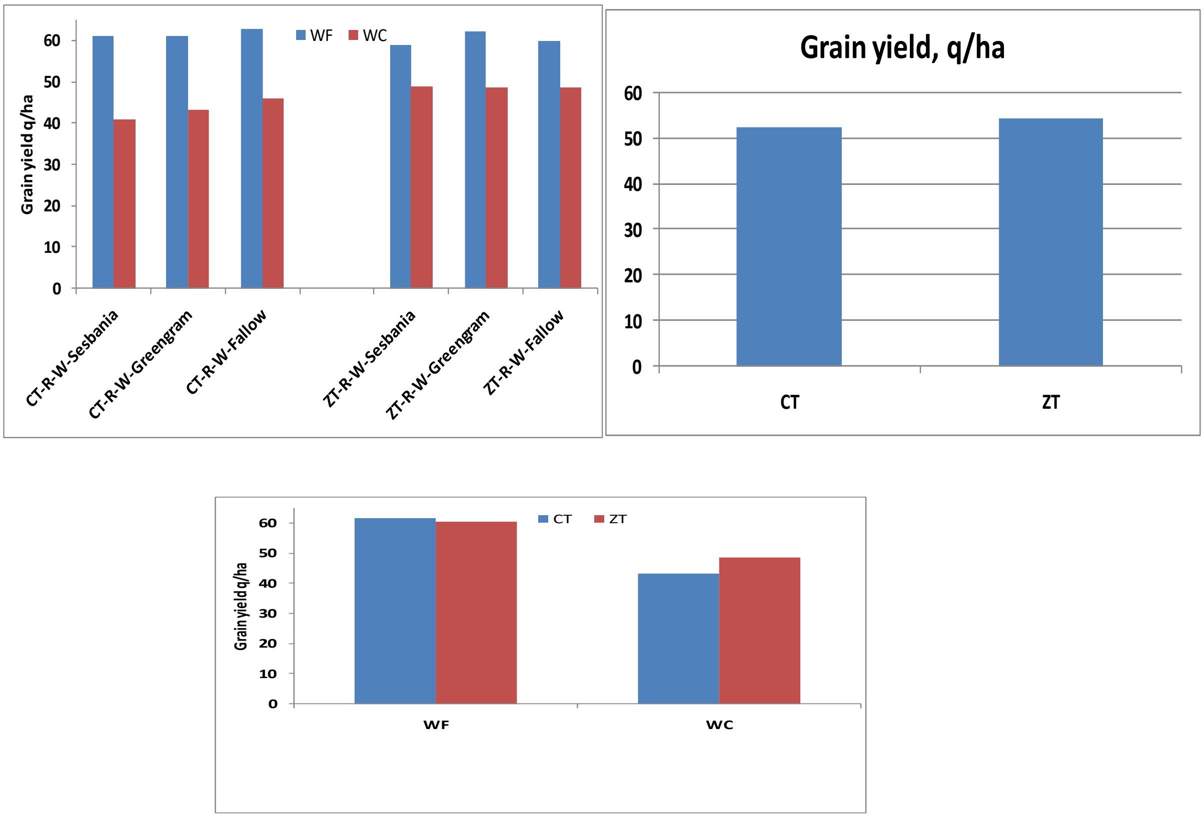


Fig 1.5: Effect of tillage and manuring on wheat yield in rice-wheat system

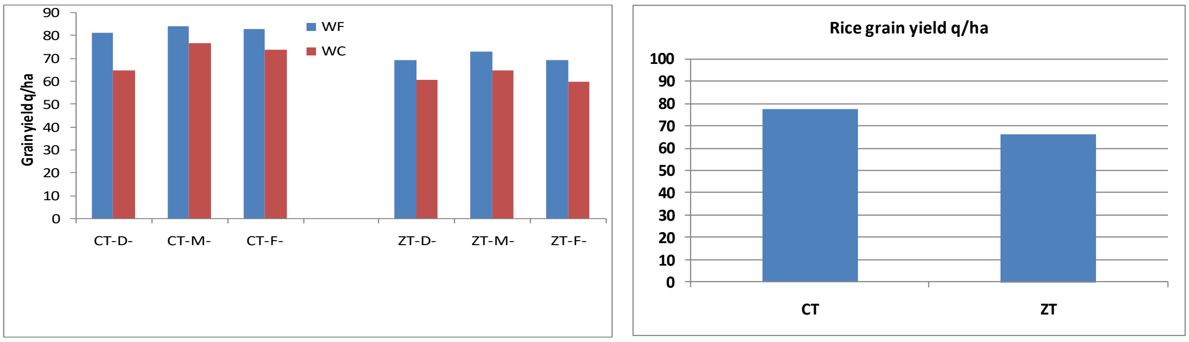


Fig 1.6: Effect of tillage and manuring on rice yield in rice-wheat system

Plate 4: Rice transplanting under ZT and puddle conditions

2. Rice- Fellow cropping system

RCER

Field trials were initiated during the rainy season of 2016 at the ICAR Research Complex for Eastern Region in Patna, Bihar (25°35' N, 85°05' E, and 51 m above mean sea level), situated in a sub-tropical humid region. Average annual precipitation for region is 1213 mm. The monthly distribution of rainfall, evaporation, and minimum and maximum temperatures during the experiment is provided in. The mean precipitation during winter season (November to April) was 49 mm, categorizing it as a 'dry' period. In contrast, mean precipitation during rainy season (June to October) was 936 mm, classifying it as a 'wet' period for cropping season. Average pan evaporation (Epan) varied between 46.4 mm in January (the lowest) and 187.6 mm in May (highest). Soil at the experimental site exhibited a silty-clay loamy texture (with sand: 10.7%, silt: 53.3%, and clay: 36%) and was slightly alkaline in nature (pH: 7.58). In upper soil layer (0-15 cm), bulk density was 1.63 g cm^{-3}, and soil organic carbon (SOC) content was 5.6 g kg^{-1}. Experimentation was conducted in split-plot with treatment of crop establishment-cum-residue management (CERM) as main-plot & post-rainy crops as sub-plots (13 m × 4.5 m). Droughts-tolerant short duration rice cultivars "*Swarna Shreya*" (115-120 day) was taken in rainy cropping. In winter season, main plot was divided into sub-plot, wherein treatment of post-rainy crops was imposed. Six CERM treatment [zero-till-direct-seeded rice (ZTDSR), conventional-till-DSR(CTDSR), transplanted puddled rice (TPR), ZTDSR with residue retention ($ZTDSR_{R+}$), CTDSR with residue retention ($CT\text{-}DSR_{R+}$) & TPR with residue retention (TPR_{R+})] were laid out in main-plot, while five potential winter crops [chickpea, lentil, safflower, linseed, mustard] were in sub-plots. In treatment having residue retention ($ZTDSR_{R+}$, $CTDSR_{R+}$, TPR_{R+}), crops harvested manually by leaving~20 cm crop stubble, while crops harvested close to ground level in treatment without residue (ZTDSR, CTDSR, TPR).

CERM management markedly influenced system productivity in TPR compared to ZTDSR/CA and CTDSR/pCA-based systems. Among CERM, TPR had 28.9 and 15.4% higher grain yield in comparison to CA and pCA-based systems, respectively (Table 1.2). In general, rice-oilseed sequences (4.68 Mg ha^{-1}) had higher crop yield than that of rice-pulses system (4.66 Mg ha^{-1}). Among the cropping systems, rice-linseed (4.99 Mg ha^{-1}) had the highest rice yield followed by rice-safflower sequences (4.99 Mg ha^{-1}). Post-rainy crops following CA/pCA-management performed better in grain yield. Crop yields of all winter crops reduced markedly sown after TPR and the reductions in crop yields were 21.2, 89.7, 44.1, 44.4 and 25.3% in chickpea, lentil, safflower, linseed and mustard in comparison to CA-based systems. Similar trends were followed in pCA-based system also, where yields of all post-rainy crops increased to the tunes of 7.34, 520.7, 48.3, 22.5 and 19.5%, respectively compared to TPR. The effect of CERM on crop yield was more intense in safflower and lentil in comparison to the rest of the treatments. Irrespective of CERM practices, post-rainy crops i.e., chickpea (1.82 Mg ha^{-1}) & mustard (1.03 Mg ha^{-1}) had maximum crop yield. System productivity was enhanced from 5.44 to 9.54 Mg ha^{-1} by including winter crops in the fallow period. Irrespective of CERM-based management, pulse-based cropping systems had markedly higher REYs for winter crop & system productivity (3.14 and 8.12 Mg ha^{-1}) than oilseed-based sequences (2.77 &7.91 Mg ha^{-1}). Among the cropping systems, rice-chickpea rotation had maximum REY for winter crop & system productivity (4.97 and 9.54 Mg ha^{-1}) in comparison to the rest of the treatments.

Plate 5: Diverse crop-establishment-cum-residue management (CERM) in rice fallows system

Table 1.2: Yield parameters of rice as affected by diverse crop-establishment-cum-residue management (CERM) in rice fallows system of eastern India

CERM		Rice yield (Mg ha^{-1})					Mean	Winter crop yield (Mg ha^{-1})				
		R-C	**R-L**	**R-S**	**R-Li**	**R-M**		**R-C**	**R-L**	**R-S**	**R-Li**	**R-M**
[ZTDSR-ZT] R-	CA	3.67	3.57	4.09	4.18	3.39	3.78^{D}	2.02^{AB}	1.33^{AB}	0.95^{AB}	0.74^{B}	1.06^{B}
[ZTDSR-ZT] R+		4.04	4.39	4.47	4.42	3.57	4.18^{CD}	2.13^{A}	1.49^{A}	1.16^{A}	0.86^{A}	1.27^{A}
[CTDSR-ZT] R-	pCA	4.41	4.61	4.78	4.93	4.51	4.65^{BC}	1.66^{BC}	0.77^{C}	0.8^{BC}	0.5^{CD}	0.96^{BC}
[CTDSR-ZT] R+		4.66	4.74	4.90	5.10	4.74	4.83^{B}	1.85^{ABC}	1.03^{BC}	0.95^{AB}	0.59^{C}	1.12^{AB}
[TPR-ZT] R-	FP	5.18	5.59	5.44	5.4	5.58	5.44^{A}	1.53^{C}	0.19^{D}	0.51^{D}	0.4^{D}	0.82^{C}
[TPR-ZT] R+		5.46	5.78	5.77	5.88	5.9	5.76^{A}	1.74^{ABC}	0.1^{D}	0.67^{CD}	0.49^{CD}	0.92^{BC}
Mean		4.57^{A}	4.78^{A}	4.91^{A}	4.99^{A}	4.62^{A}						
P Value		CERM		WC		CERM* WC						
		<0.0001		0.0269		0.8921		0.0055	<.0001	<.0001	<.0001	0.0001

CERM		WCREY (Mg ha^{-1})					Mean	System productivity/SREY (Mg ha^{-1})					Mean
		R-C	R-L	R-SF	R-Li	R-M		R-C	R-L	R-SF	R-Li	R-M	
[ZTDSR-ZT] R-	CA	5.51	3.63	2.70	1.59	2.64	3.21^{B}	9.18	7.20	6.79	5.77	6.03	6.99^{B}
[ZTDSR-ZT] R+		5.81	4.07	3.32	1.83	3.16	3.64^{A}	9.85	8.46	7.79	6.25	6.73	7.82^{A}
[CTDSR-ZT] R-	pCA	4.53	2.10	2.30	1.07	2.38	2.48^{C}	8.94	6.71	7.08	6.00	6.89	7.12^{B}
[CTDSR-ZT] R+		5.05	2.80	2.70	1.27	2.78	2.92^{B}	9.71	7.54	7.60	6.37	7.52	7.75^{A}
[TPR-ZT] R-	FP	4.17	0.52	1.44	0.85	2.04	1.80^{D}	9.35	6.11	6.88	6.25	7.62	7.24^{AB}
[TPR-ZT] R+		4.75	0.27	1.91	1.04	2.28	2.05^{D}	10.21	6.05	7.68	6.92	8.18	7.81^{A}
Mean		4.97^{A}	2.23^{C}	2.40^{BC}	1.28^{D}	2.55^{B}		9.54^{A}	7.01^{B}	7.3^{B}	6.26^{C}	7.16^{B}	
P Value		CERM		WC		CERM*WC		CERM		WC		CERM*WC	
		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0003	

CERM: crop-establishment-cum-residue management; WC: winter crops; FP: Farmers practices; pCA: partial conservation agriculture; CA: conservation agriculture; ZT: zero-tillage; ZTDSR: zero-till-direct seeded rice; CTDSR: conventional-till-direct seeded rice; TPR: transplanted puddle rice; R+: crop residue with 30% retention; R-: without residue; R-C: rice-chickpea; R-L: rice-lentil; R-S: rice-safflower; R-Li: rice-linseed; R-M: rice-mustard; Different capital letters (vertical) indicate significant variations in different CERM; Different capital letters (horizontal) indicate significant variations in different cropping systems; Values after ± symbol represent standard error of mean; Values in parentheses are means of three replications before performing square root transformation (√x+0.5).

Rice-fallow management through climate resilient agricultural practices: A flagship program in form of umbrella project entitles “Rice-fallow management through climate resilient agricultural practices” has been initiated during *Kharif* 2023 at Guleriyachak village, Tekari Block of Gaya district of Bihar. As these activities has given by the Council to ICAR Research Complex for Eastern Region Patna to improve the productivity of rice fallow system in eastern India. The project has the following objectives.

- Assessing & characterising rice-fallow area for identifying possible interventions & their management based on the soil, climate, soil moistures, natural resources, and spatio-temporal variations.
- To study the socio-economic constraints & farmers perception about rice-fallow system
- Development of location specific rice-fallow management strategy through interdisciplinary approach

In first year, targeted area has been selected and basic information collected from rice-fallow farming community. Major issues for fallowing land during rabi due to lack of irrigation facilities. Collective team efforts by the ICAR RCER have been implemented for greening rice fallow through suitable intervention, integrated crop management (ICM) and conservation agricultural (CA) management practices. During *kharif*, large area was remained fallow due to inadequate rainfall and their distribution. For managing this, selected farmers in the village have been given arhar seed cv. IPA 203 for more than 15 farmers as demonstration through proper awareness. This intervention was adopted by farming community in their upland fields and bunds. Performance of this crop in rainfed condition is better and it will give better results. Similarly, seed of pulses/oilseeds was demonstrated in rabi to farming community (100 no.) for greening rice fallow area for more than 100 acres through ICM and CA-based practices. Details of supplied inputs for demonstrated at rice fallow community as mentioned below:

Table 1.3: Details of supplied inputs for demonstrated at rice fallow community

S. No.	Crop	Variety	Quantity (kg)	Farmers (no.)	Area (acre
1.	Arhar	IPA 203	100	15	12.5
2.	Lentil (ZT)	IPL 220	384	24	24
3.	Chickpea (ZT)	GNG 2299	896	28	28
4.	Mustard (ZT)	DRMR-150-35	50	25	25
5.	Mustard-FLD*	DRMR-150-35	30	15	15
Total			**1460**	**107**	**104.5**

*The frontline demonstration seed for mustard was given for demonstration at the project site by ICAR Directorate of Rapeseed and Mustard Research (DRMR), Bharatpur, Rajasthan. Crop was raised on residual soil moisture and fertility levels. Performance of all rabi crop was wonderful and farmers are ready to accept our interventions in the village.



Plate 6: Rice-fallow management through climate resilient agricultural practices

Activities in Jharkhand & Chhattisgarh

Evaluation of CA practices in rice-fallows: CA practices was evaluated during 2023-24 in farmer's field at two locations *viz.* Chene, Ranchi, Jharkhand and Kandora, Jashpur, Chhattisgarh. CA practices comprised of zero-tillage transplanted rice (ZTTR), ZT direct seeded rice (ZTDSR), conventional tillage direct seeded rice (CTDSR), farmer's puddled transplanted rice (FPTR) and rice fallow were evaluated on winter crops i.e. lentil (KLS-218), mustard (Pusa-26) and linseed (BAU 06-03) after harvesting of rice.

Experimental Site 1: Chene, Namkum, Ranchi, Jharkhand

Evaluation of CA practices on productivity of kharif crop rice: CA practices was evaluated during 2023-24 in farmer's field at Chene, Ranchi. CA practices comprised of zero-tillage transplanted rice (ZTTR), zero-tillage direct seeded rice (ZTDSR), conventional tillage direct seeded rice (CTDSR), farmer's puddled transplanted rice (FPTR) and rice-fallow were evaluated on winter crops i.e., lentil (KLS-218), mustard (Pusa-26) and linseed (BAU 06-03) after harvesting of rice. Rice grain yield was significantly higher of 4.8 t/ha in ZTDSR compared to other CA and farmer's practices (Table 1.4).

Table 1.4: Yields of kharif and rabi crops at Jharkhand and Chhattisgarh sites

Treatments	Jharkhand			Chhattisgarh			
	Rice, (t/ha)	Mustard (q/ha)	Linseed (q/ha)	Rice (t/ha)	Lentil (q/ha)	Mustard (q/ha)	Linseed (q/ha)
Rice-fallow	4.56^{b*}	-	-	5.01^{a}	-	-	-
ZTDSR	4.80^{a}	5.98^{a}	3.12^{a}	5.21^{a}	2.35^{a}	6.53^{a}	3.22^{a}
CTDSR	4.10^{c}	5.35^{c}	2.91^{a}	4.44^{b}	1.96^{b}	5.86^{b}	2.85^{b}
ZTTR	4.70^{a}	5.56^{b}	2.96^{a}	5.12^{a}	2.13^{a}	6.36^{a}	3.16^{a}
FPTR	4.33^{b}	5.15^{c}	2.68^{b}	4.62^{b}	1.76^{b}	5.36^{c}	2.75^{b}

*Values in a column having different superscripts are significantly different from each other DMRT

Evaluation of CA practices on productivity of winter crops: The winter crops mustard and linseed were grown in rice-fallow under different CA practices. Significantly highest grain yield was 5.98 q/ha in ZTDSR followed by 5.56 q/ha in ZTTR. CA practices, ZTDSR recorded highest grain yield over ZTTR and farmer's practice (FPTR). Similarly, grain yield of linseed varied from 2.91 to 3.12 q/ha among different CA practices. CA practices (ZTDSR) registered highest grain yield (3.12 q/ha) followed by ZTTR. Rice equivalent yield (REY) obtained under winter crops ranged between 0.98 to 1.90 t/ha. Among different treatments REY was higher in CA and recorded higher in ZTDSR treatment

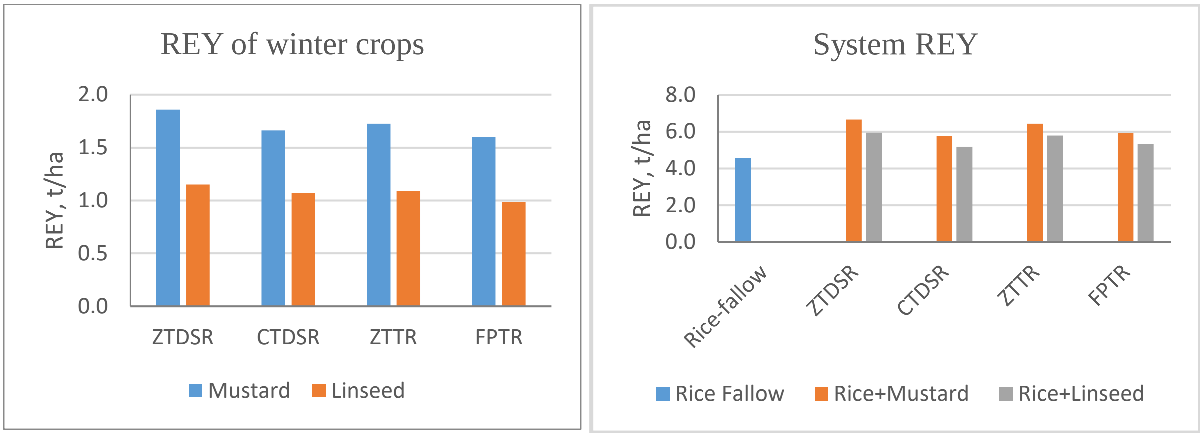


Fig 1.7: Rice equivalent yields of crops and cropping systems at Jharkhand

System REY of cropping sequences were also evaluated under different CA practices. REY of rice + mustard (6.7 t/ha) in ZTDSR was significantly. Higher REY of all these sequences were observed under plots having CA practices as depicted in Fig 1.7.

Experimental Site 2 (Kandora village, Block: Kunkuri, Distt: Jashpur (Chhattisgarh)

Evaluation of CA practices on productivity of rice: Highest rice yield was recorded of 5.21 t/ha in ZTDSR and followed by ZTTR (5.12 t/ha) (Table 1.4).

Evaluation of CA practices on productivity of winter crops: Different winter crops like lentil, mustard and linseed were grown under different CA practices. Grain yield of lentil was significantly highest of 2.35 q/ha in ZTDSR compared to other CA and farmer's practices (Table 1.4). Similarly, highest linseed grain yield was 3.22 q/ha in ZTDSR followed by ZTTR and was better than other practices. Grain yield of mustard was significantly influenced by different CA practices. Highest grain yield was 6.53 q/ha in ZTDSR and was followed by 6.36 q/ha in ZTTR with a significant difference between two practices. REY of winter crops were evaluated under different CA. It was observed that REY of mustard (2 t/ha) in ZTDSR was significantly better over other two crop. Higher REY of all these sequences were observed in plots having CA practices (ZTDSR and ZTTR) as depicted in Fig 1.8.

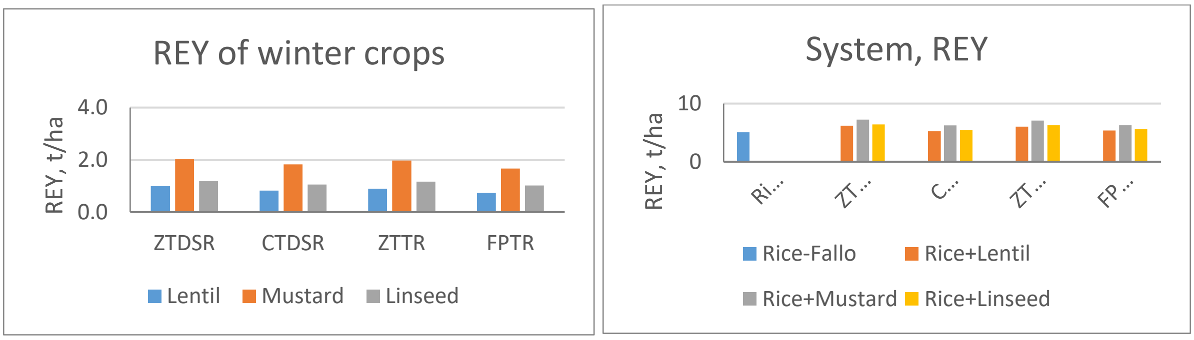


Fig 1.8: Rice equivalent yields of crops and cropping systems at Chhattisgarh

System REY of cropping sequences were also evaluated under different CA practices. It was observed that the REY of rice+mustard (7.2 t/ha) in ZTDSR was significantly better over other two cropping sequences of rice+lentil and rice+ linseed. Higher REY of all these sequences were observed under plots having CA practices as depicted in Fig 1.8.

3. Maize-Wheat cropping system (MWS)

IARI

Under the CA-based maize-wheat system (after 12 years), 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 conventional tillage (CT) system (Fig 1.9). In contrast to previous years, ZT permanent broad bed with 100% N had a higher maize yield by ~46%, wheat yield by ~10%, and system productivity by ~23% than CT system. However, 75% N was comparable with 100% N, this leads to 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.

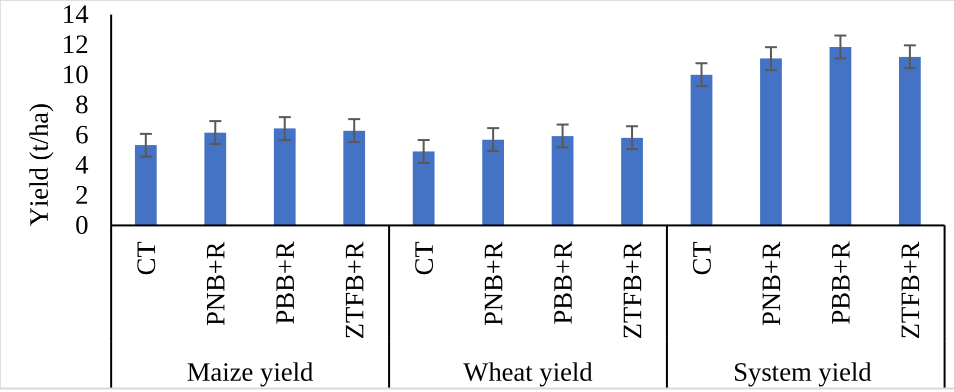


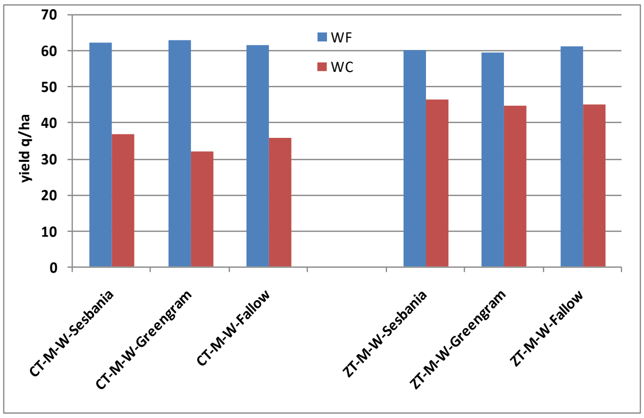
Fig 1.9: Effect of CA on maize yield, wheat yield, and system productivity under maize-wheat cropping system

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, greengram) and two weed control options (weedy check and weed free) in maize-wheat cropping systems. The experiment was started in 2020 with maize crop. 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 1.10). Whereas, in presence of weeds the yield advantage was observed under CA system.



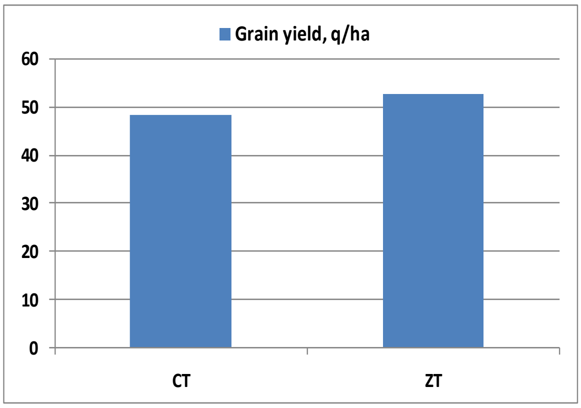


Fig 1.10: Effect of tillage and manuring on wheat yield in maize-wheat system

The maize yield was higher in CA system both in the presence and absence of weeds (Fig 1.11). The higher 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.

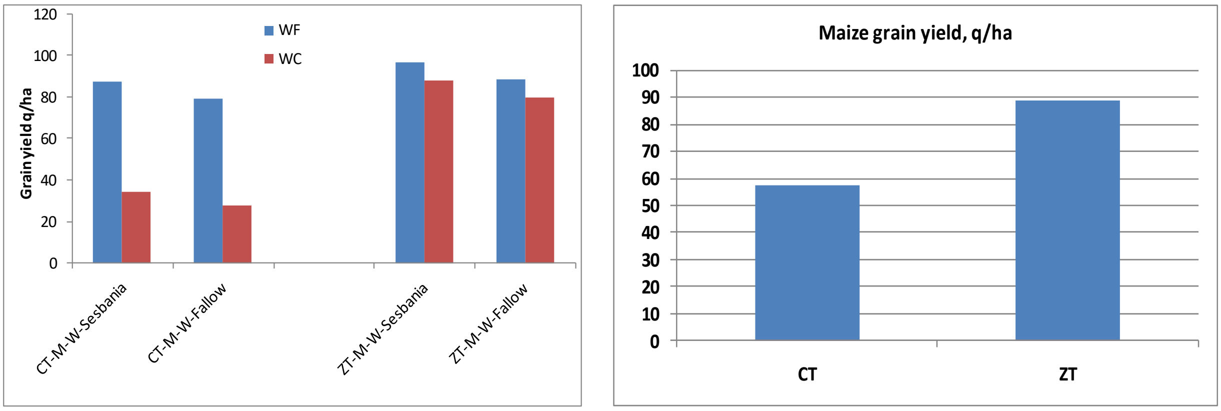


Fig 1.11: Effect of tillage and manuring on maize yield in maize-wheat system

4. Maize-Wheat-Green gram cropping system
IIWBR

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 (2022-23) was sown on November21, 2022at 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 Smart 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 fbmetsulfuron 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 1.5 revealed that the effect of tillage and residue management, nutrient management and their interactions were for grain yield. Among four nutrient management options minimum yield was recorded in unfertilized control plots having a mean yield of16.10 q/ha. The poor yield in this treatment was due to lesser yield attributes mainly the effective tillers. The wheat grain yield was maximum (66.90 q/ha) when FYM @ 10t/ha was applied along with Rec. NPK and it was significantly superior to all other nutrient management options including 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 1.5: Effect of tillage, residue and nutrient management in wheat under Maize-wheat system during 2022-23

Tillage and residue management	Plant height, cm	Earhead length, cm	Tillers/m^2	Yield q/ha	1000 grain weight, g	Protein (%)
ZT	87.8	8.9	405.4	44.36	37.04	10.6
ZT+R*	94.8	9.9	419.4	49.55	37.84	10.6
CT	85.5	8.9	387.9	44.78	36.56	10.3
CT+RI*	89.4	9.5	417.7	49.09	38.60	10.4
CD at 5%	2.75	0.26	NS	3.29	0.95	NS
Nutrient management						
Control	67.1	7.0	333.5	16.10	35.49	9.4
N Alone	87.6	9.7	384.0	43.66	39.58	11.8
Rec. NPK	100.2	10.2	448.5	61.12	37.57	10.1

Rec. NPK+ FYM 10t/ha	102.6	10.3	464.4	66.90	37.41	10.7
CD at 5%	3.79	0.53	26.38	3.57	1.25	0.35
FactorB at same level of A	7.74	NS	NS	7.38	NS	0.71
FactorA at same level of B	7.10	NS	NS	6.99	NS	0.65

*R=Residue Retention and RI= Residue incorporation

Plate 7: Long term maize-wheat experiment's treatments

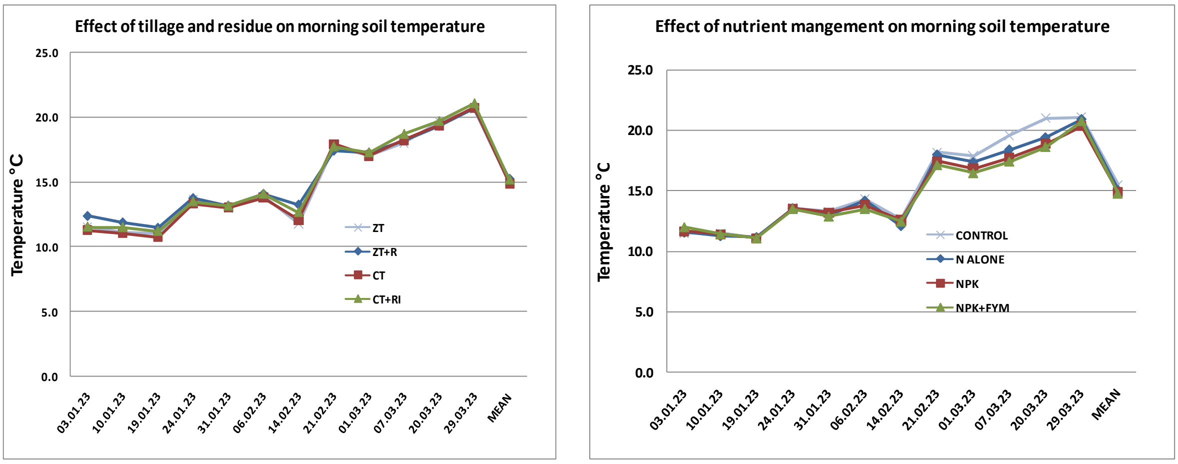


Fig 1.12: Effect of tillage, residue and nutrient management on morning soil temperature in long term maize-wheat-greengram experiment

Observations were also taken on soil temperature in the morning and noon on different dates (Fig 1.13). The morning temperatures were on slightly higher in CA system where as reverse in the noon, where the temperatures were on lower side. The noon temperatures in the control plots were higher than different nutrient management treatments.

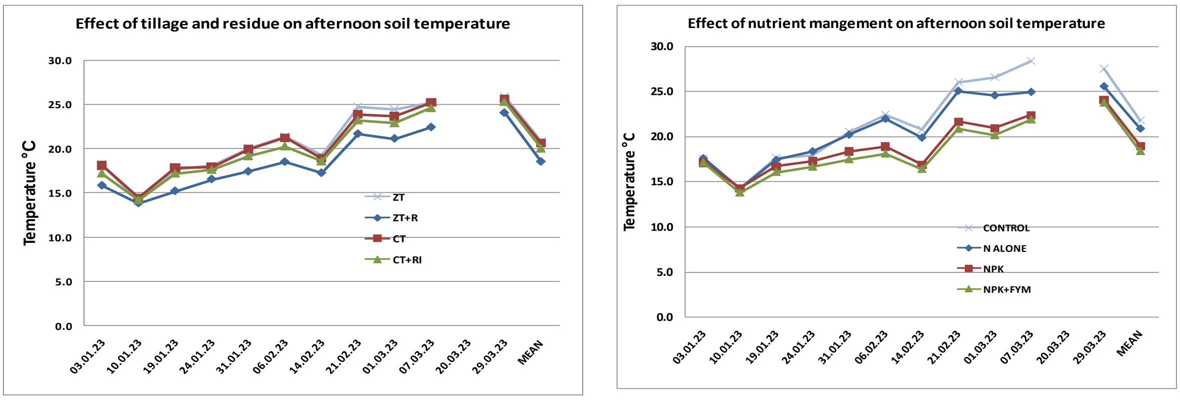


Fig 1.13: Effect of tillage, residue management and nutrient management on afternoon soil temperature during different crop seasons in long term maize-wheat-greengram experiment.

Canopy temperature as measured by LT300 Infrared Thermometer was higher in unfertilized control plots. Whereas the Normalized Difference Vegetation Index (NDVI) values recorded using hand held green seeker, a direct indicator of the crop growth was drastically less in unfertilized control plots, which was reflected in lower crop yields N application alone also had lower NDVI compared to Rec. NPK and NPK + FYM treatments. The lowest SPAD values were recorded in unfertilized control plots (Fig 1.14).

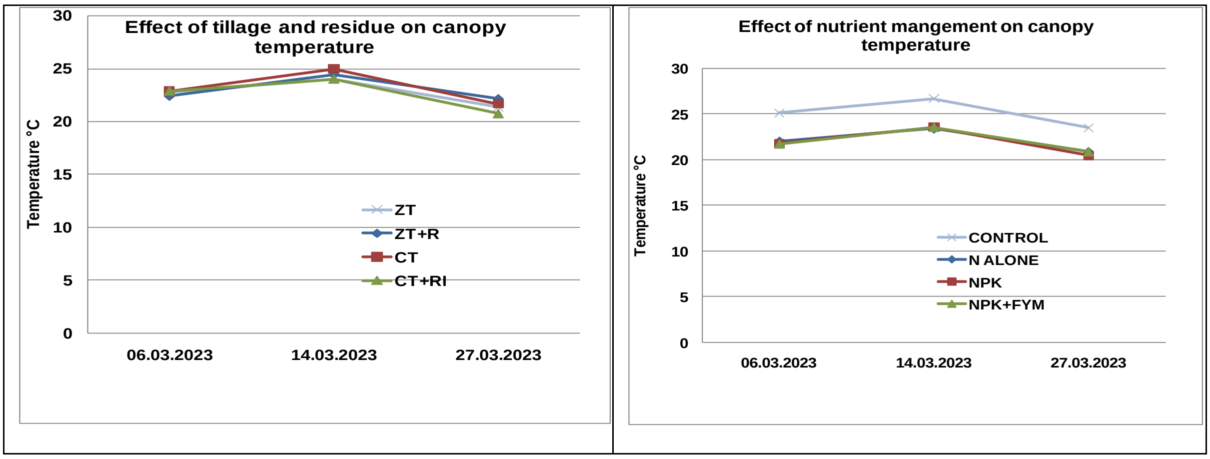


Fig 1.14: Effect of tillage, residue and nutrient management on canopy temperature during different crop seasons in long term maize-wheat-greengram experiment

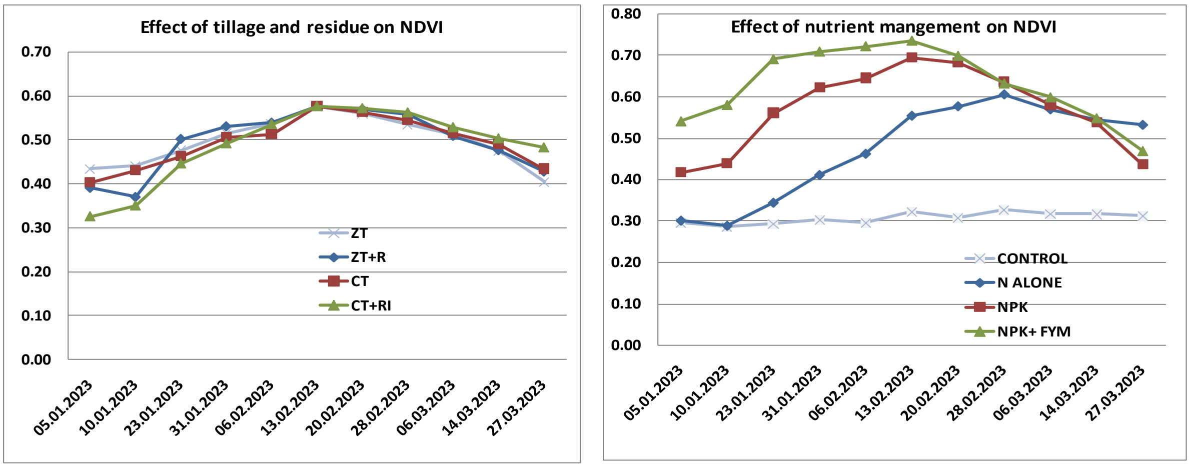


Fig 1.15: Effect of tillage, residue and nutrient management on NDVI in long term maize-wheat-greengram experiment

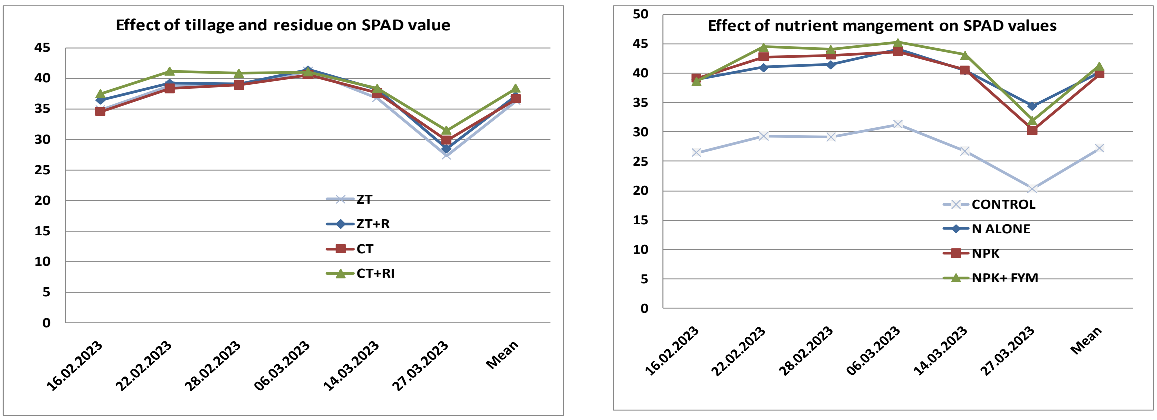


Fig 1.16: Effect of tillage, residue and nutrient management on SPAD values in long term maize-wheat-greengram experiment.

Using Dualex sensor nitrogen balance index (NBI), chlorophyll, flavonoids and anthocyanins content in wheat leaves were recorded on 15.02.2023 and 02.03.2023. The NBI and CHL values were highest in CA (ZT+R) treatment followed by CT+RI. Whereas, flavonoids were the lowest in CA treatment. Among nutrient management options, the NBI and CHL were maximum in NPK+FYM treatment and it was followed by application of recommended doses of NPK, N alone and control.

Table 1.17: Effect of tillage, residue and nutrient management on NBI, chlorophyll, flavonoids and anthocyanins

		15.02.2023				02.03.2023		
	NBI	**CHL**	**Flav**	**Antho**	**NBI**	**CHL**	**Flav**	**Antho**
ZT	46.0	28.5	0.69	0.0	49.41	27.68	0.64	0.00
ZT+R	53.5	31.0	0.62	0.0	56.52	30.93	0.59	0.00
CT	45.8	28.5	0.68	0.0	53.10	28.82	0.62	0.00
CT+RI	52.0	29.9	0.64	0.0	54.57	30.10	0.62	0.00
CONTROL	22.7	20.0	0.87	0.0	22.36	19.68	0.90	0.0
N ALONE	45.4	30.5	0.70	0.0	53.79	32.05	0.60	0.0
NPK	60.4	33.3	0.56	0.0	66.26	32.70	0.50	0.0
NPK+ FYM	68.8	34.1	0.50	0.0	71.19	33.10	0.47	0.0

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 or retained or incorporated as per treatment. In ZT and CA pre-planting glyphosate + paraquat were also applied at 1.5 + 0.5 kg/ha. 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 (86.59 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. The yield recorded in CT plots were 73.04 q/ha. Among nutrient management treatments, unfertilized plots recorded significantly lowest yield (43.96 q/ha).

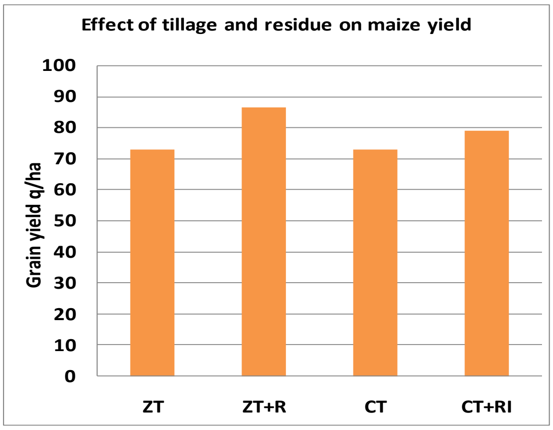


Fig 1.18: Effect of tillage and residue on maize yield

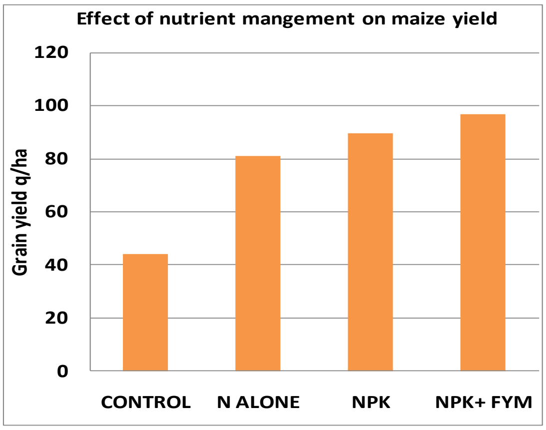


Fig 1.19: Effect of nutrient management on maize yield

Plate 10: Lesser adverse effect of heavy rainfall in CA maize

5. Cotton-Wheat cropping system (CW)

IARI

In CA-based cotton-wheat system (after 12 years), 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 conventional tillage (CT) system (Fig 1.20). In contrast to previous years, ZT permanent broad bed was superior than ZT flat bed with residue with 100% N in terms of cotton yield (~54%), wheat yield (~22%), and system productivity (~37%) than CT system. However, 75% N was comparable with 100% N, this leads to saving of 25% N. The cotton-wheat system under PFB+R led to 65% increase in net returns compared to CT. 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.

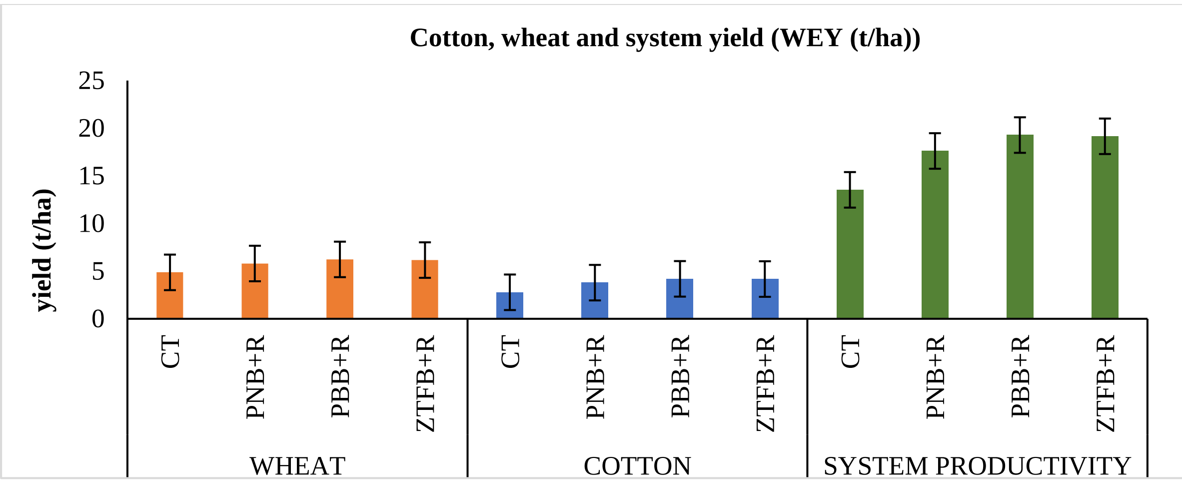


Fig 1.20: Effect of CA on cotton yield, wheat yield, and system productivity under cotton-wheat cropping system

Plate 11: Effect of CA on cotton-wheat cropping system

6. Pigeon pea-Wheat System (PWS)

IARI

Pigeon pea-wheat cropping system is a promising cropping system to achieve the food and nutritional security of the country. Under the CA-based pigeon pea-wheat system, all the CA-based treatments resulted in significantly higher yields of pigeon pea, wheat and system productivity than conventional tillage (CT) system (Table 1.7). The pigeon pea with 50% wheat residue, wheat sown with 50% pigeon pea residue resulted in ~21% higher pigeon pea yield, ~24% higher wheat yield and ~23% higher system productivity than conventional till pigeon pea-conventional till wheat system. This CA-based pigeon pea-wheat system could be a promising crop diversification option for rice-wheat system to meet out the sustainable development goals of UN and an important adaptation and mitigation strategy to climate change.

Table 1.7: Effect of tillage and crop residues on grain yield of pigeonpea, wheat and system under pigeonpea-wheat system

Treatment	Pigeon pea yield (t/ha)	Wheat yield (t/ha)	System productivity (PEY) (t/ha)
CT pigeonpea-CT wheat	1.17^{b}	4.46^{c}	2.60^{c}
ZT pigeonpea + 25 WR (wheat residue)-ZT wheat + 25 PR (pigeonpea residue)	1.33^{a}	4.61^{bc}	2.81^{bc}
ZT pigeonpea + 50 WR-ZT wheat + 50PR	1.42^{a}	5.53^{a}	3.20^{a}
ZT pigeonpea + 75 WR-ZT wheat + 75PR	1.35^{a}	5.08^{ab}	2.99^{ab}

Economic analysis of CA-based rice-wheat system carried out under this project, it was found that Triple ZT+R treatment was significantly recorded higher net returns (277.28 x10^{3} INR/ha) and net BC ratio (2.90) compared to other ZT treatments and PTR-CTW (191.65 x10^{3} INR/ha and 1.95 of NR & B:C, respectively). Next highest NR (248.70 10^{3} INR/ha) and B:C (2.65) was fetched from Triple ZT treatment. Notably, net returns were increased by 45% and 13% respectively with and without mungbean (Table 1.8).

Table 1.8: Effect of tillage and crop residues on economics of CA-based RWS

Treatment	NR (x10^{3} INR/ha)	Net B:C
ZTDSR-ZTW	208.26	2.84
ZTDSR-ZTW-ZTMb	248.70 (194.91)*	2.65 (2.66)*
ZTDSR+ MbR-ZTW+RR-ZTMb+WR	277.28 (216.69)*	2.90 (2.88)*
PTR-ZTW	205.80	2.25
PTR-CTW	191.65	1.95

*Net returns increased by 45% & 13% resp with and without mungbean.

7. Maize (Mz)-mustard (Ms) system

IARI

The CA based maize-mustard system revealed that zero-tillage maize with 50% mustard residue resulted in significantly higher yield of maize than other treatment and it was remained similar to 75% residue treatment. Whereas, mustard yield was significantly higher under zero-tillage mustard with 50% or 25% residue of maize over other treatments. Similarly, ZT maize + 50% MsR- ZT mustard+50%MzR resulted in 20% higher system productivity over CT (Table 1.9).

A comparative study was done for maize-mustard system with pigeonpea-wheat system with same tillage and crop residue treatments and results revealed that maize-mustard cropping system resulted in ~44% higher SP as compared to pigeonpea-wheat system. Among the tillage and crop residue practices, zero-tillage with 50% residue of both *kharif* (maize/pigeonpea) and *rabi* (mustard/wheat) crops had highest SP than CT and other ZT treatments (Fig 1.21).

Table 1.9: Effect of tillage and crop residues on grain yield of maize, mustard and system under maize-mustard cropping system

Treatment	Maize yield (t/ha)	Mustard yield (t/ha)	System productivity (SP) (MEY) (t/ha)
CT maize-CT mustard	5.94[c]	2.44[c]	12.70[c]
ZT maize+25% MsR (mustard residue)-ZT mustard+25%MzR (maize residue)	6.46[b]	2.77[ab]	14.16[b]
ZT maize + 50% MsR-ZT mustard+50%MzR	7.03[a]	2.98[a]	15.30[a]
ZT maize + 75% MsR-ZT mustard+75%MzR	6.81[ab]	2.70[b]	14.32[b]

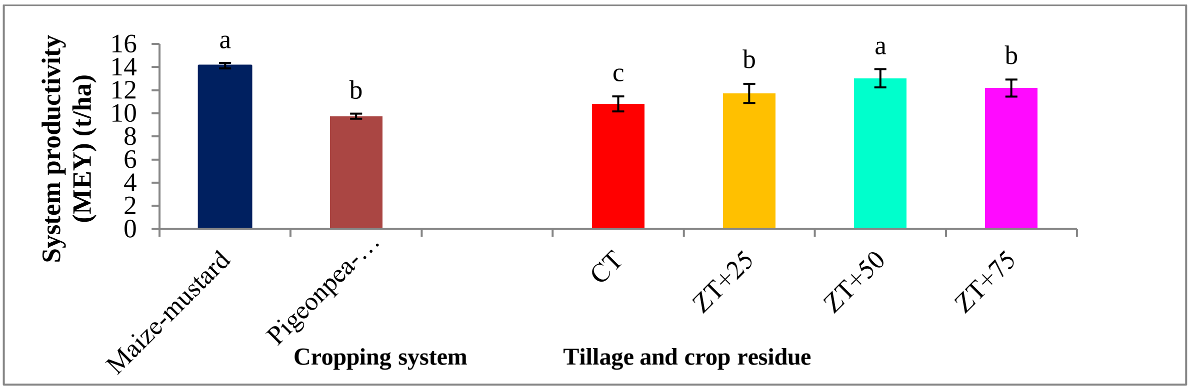


Fig 1.21: Combined effect of cropping systems and tillage and crop residues on system productivity (maize equivalent yield) (t/ha)

8. Rice-Lentil, Rice-Mustard, Rice-Linseed System

RCER

Effect of different CA practices on crop yield of different cropping system in EPHR

Field experiments were conducted during kharif season 2023-24 at ICAR-RCER, FSRCHPR, Plandu, Ranchi. Different cropping systems viz., Rice-Lentil, Rice-Mustard, Rice-Linseed were evaluated under different rice establishment methods of ZTDSR, ZTTR and CTDSR. ZTDSR Rice-mustard system showed highest kharif rice yield of 4.47 t/ha and winter mustard yield, REY of 4.65 t/ha. System REY was significantly highest of 9.12 t/ha compared to other treatments except ZTTR rice-mustard and CTDSR rice-mustard treatments (Fig 1.22).

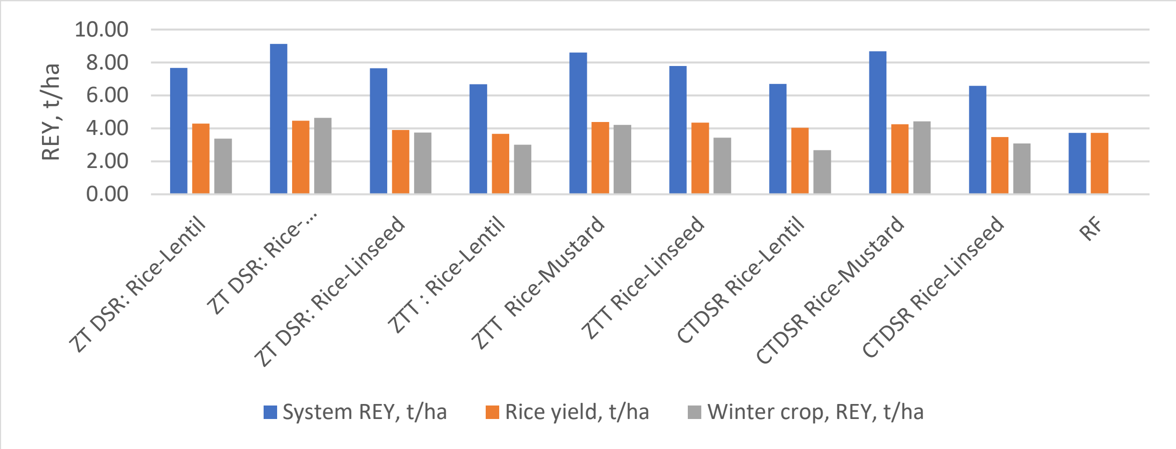


Fig 1.22: Rice equivalent yields of crops and cropping systems at ICAR-RCER, FSRCHPR,

After harvest of kharif crops, winter crops were grown under different conservation and conventional agricultural practices *viz.*, ZTDSR, ZTTR and CTDSR. Winter crops of lentil and linseed performed better in ZTDSR and ZTTR and followed trend as, ZTDSR>ZTTR> CTDSR. Highest lentil REY was 3.38 t/ha in ZTDSR. Similarly highest linseed REY was 3.76 t/ha in ZTTR. In mustard, highest REY was 4.65 t/ha in ZTDSR, which was followed by CTDSR and ZTTR. In all winter crops, ZTDSR was better for the growth and yield of crops.

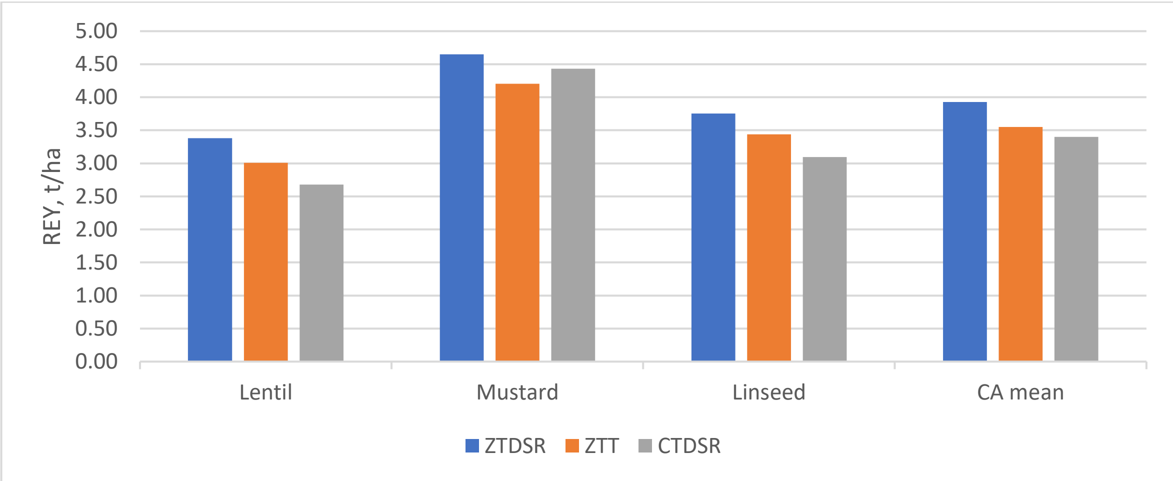


Fig 1.23: Rice equivalent yields of crops and cropping systems at ICAR-RCER, FSRCHPR,

Plate 12: Effect of CA practices on Crops at Chene, Ranchi, Jharkhand



Plate 13: Effect of CA practices on crops at Kandora, Chhattisgarh

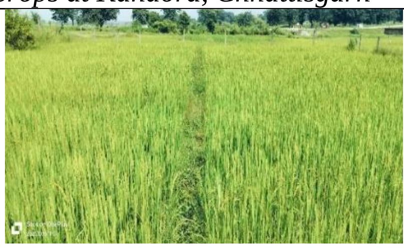




		
Plate 14: Lentil	Mustard	Linseed

9. Sugarcane Cropping System
NIASM

Long-term assessment of tillage, surface trash retention and fertigation strategies on productivity and water-energy-carbon nexus in drip irrigated sugarcane

A long term (six-year) impact of tillage, surface trash retention and fertigation strategies on productivity and water-energy-carbon nexus in drip irrigated sugarcane was assessed. The plant crop included three treatments of tillage (CT: Conventional tillage + 10% RDF basal and 90% fertigation; RT_1: Reduced tillage (RT) + 10% RDF basal and 90% fertigation, and RT_2: RT+10% RDF basal, 40% band placement and 50% fertigation) in main plots and (ii) soil surface trash retention practices, namely mulching (M) and non-mulching (NM), in subplots. The sub-plots were further divided to sub-sub plots to adjust three nutrient levels (N_1: 25% RDF as basal and rest through fertigation, N_2: 50% RDF as basal using multifunctional SORF (stubble shaving, off-barring, root pruning and band placement of fertilisers) drill and rest 50% through fertigation, and N_3: SORF with 75% RDF as basal using SORF drill and rest 25% through fertigation). RT_2+M+N_2 significantly improved tillers, cane weight, size matrices, juice quality indices, and ratoon cane yield by 45.4% compared to conventional practice (CT + NM + N_1). This narrated the yield gap between plant and ratoon crops from 38% to 8%. RT_2+M+N_2 also showed superior water productivity (16.4 kg m^{-3}), partial factor productivity (518.1 kg N kg^{-1}), and reduced water footprint (54.0 kg^{-1}), with favourable soil properties. Notably, the plant crop exhibited higher GHG loss (9.0–10.4 Mg CO_2-eq ha^{-1}) and lower energy use efficiency (EUE, 22.8–33.5) than the ratoon crop (6.5–7.7 Mg CO_2-eq ha^{-1} and 24.7–56.5). Over six years, these practices enhanced carbon sequestration (65.5–73.1%), consequently reducing the carbon footprint (72–88%). Overall, integrated CA practices hold promise in minimizing yield gaps, maximizing productivity, ensuring profitability, and sustaining environmental quality in sugarcane production, particularly in semi-arid regions.

Effect of deficit irrigation (DI) and plant growth regulators (PGRs) on ratoon cane yield under varied conservation agriculture practices in semi-arid regions

In 2023–24, after the harvest of the plant crop, a field trial was established to evaluate the effects of deficit irrigation (DI), foliar application of PGRs and surface trash retention on the ratoon crop (Co–86032) with existing tillage practices. The experiment was replicated thrice with three levels of deficit irrigation *viz.*, DI_1: 50% ETc; DI_2: 75% ETc and DI_3: 100% ETc (full irrigation) were applied using a drip system in main plots and four plant growth regulators (PGRs) namely thio-urea (TU, 1800 ppm), irradiated chitosan (IC, 5 ml/L), nano-urea (NU, 4 ml/L), salicylic acid (SA, 25 μM) and no PGRs (control) were applied exogenously with interval of two months after ratoon crop establishment (60 days) as subplot treatments. Further, two soil surface trash retention practices (S1: trash mulch and S2: without trash mulch) were maintained as subplots treatments. The highest ratoon cane yields of 140 t ha^{-1} was obtained in DI_2+ IC +S_1 i.e. when irrigated at 75% ETc with irradiated chitosan (5 ml/ litre) in trash retained (S_1) plots under reduced tillage practices. Surface trash retention (S_1) improved ratoon cane yields by 9.4, 21.0, and 36.4% in full (100% ETc), 75% ETc and 50% ETc when compared control (S_2). PGRs improved ratoon cane yields by 5.0–12.0%, 9.9–25.4% and 15.9–35.4% under full (100% ETc), 75%ETc and 50% ETc, water deficit levels, respectively. When compared with previous results of plant crop (2022–23), combined practice of 75%ETc, IC (5ml/L), and surface trash retention reduced the yield gaps between plant and ratoon crops up to 7.6% along with 25% water saving over farmers' practice.

IIFSR

The sugarcane crop grown in reduced tillage (RT) had 6.0% lower yield over the conventionally grown sugarcane crop. The yield attributes of sugarcane were also influenced by the different tillage practices. The maximum values of millable cane (126.2), cane height (4.71 m), cane weight (1.66 kg), cane girth (23.82) and number of internodes per cane (17.73) were found in CT based tillage practices as compared to RT based practices. Interestingly, the treatment comprised of reduced tillage in sugarcane recorded 8.43% higher sugar recovery over the CT based.

Table 1.10: Effect of tillage, and crop diversification on yield attributes of sugarcane

Cropping Systems	Tillage	cane height (m)	Millable cane (1000 ha^{-1})	Brix%	No. of internodes (per cane)	Girth (mm)	Single Cane weight (kg)		
							Cane weight	Stalk weight	Total weight
S-R-W	CT-CT-CT	4.71	126.2	19.20	17.73	23.82	1.43	0.230	1.66
S+GG-R-W	RT-ZT-ZT	4.53	124.1	20.82	17.13	22.99	1.39	0.236	1.63

CT=Conventional tillage; RT=reduced tillage; ZT=zero tillage

B. Weed Management Practices in Conservation Agriculture

1. Rice Wheat Cropping System

IARI

Weed dynamics in CA-based cropping systems

Weed dynamics in CA-based pigeon pea-wheat cropping system was studied and results revealed that the ZTFBR75N treatment significantly reduced total weed density (2.2) compared to CT (6.5). Whereas, the total weed dry weight found significantly lower in ZTFBR100N (0.93 g/m^2) in comparison with CT (1.57 g/m^2). (Table 1.11). Weed control efficiency (89.7%) and weed control index (81.6%) were found significantly higher in ZTFBR75N and ZTFBR100N treatments respectively as compared to other treatments under CA-based cropping system (Fig 1.24). The year-wise density of weed species in 2010-11, 2015-16, and 2021-22, respectively in wheat under pigeon pea-wheat system are illustrated in the Fig 1.25. The weed diversity and similarity in wheat under CA-based pigeon pea-wheat system was also studied and Sørenson similarity index was reduced gradually from 1.0 in 2010-11 to 0.62 in 2021-22 (Table 1.12).

Table 1.11: Weed density and dry weight across treatments in CA-based pigeon pea-wheat cropping system

Treatments	Total weed density (no./m^2)	Total weed dry weight (g/m^2)
CT	6.5 (42)[a]	1.57 (1.96)[a]
PNBR75N	3.2 (10)[b]	1.13 (0.78)[b]
PNBR100N	3.0 (8.3)[bc]	1.02 (0.54)[b]
PBBR75N	2.9 (8)[bc]	1.1 (0.71)[b]
PBBR100N	2.8 (7.7)[bc]	1.1(0.71)[b]
ZTFBR75N	2.2 (4.3)[c]	0.95 (0.4)[b]
ZTFBR100N	2.4 (5.3)[c]	0.93 (0.36)[b]

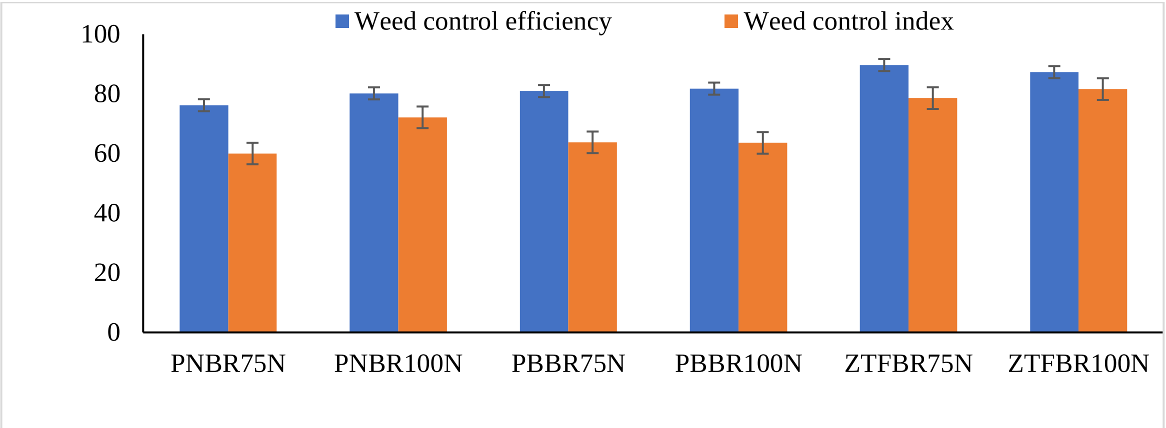


Fig 1.24: Weed control efficiency and weed control index in CA based pigeon pea-wheat cropping system

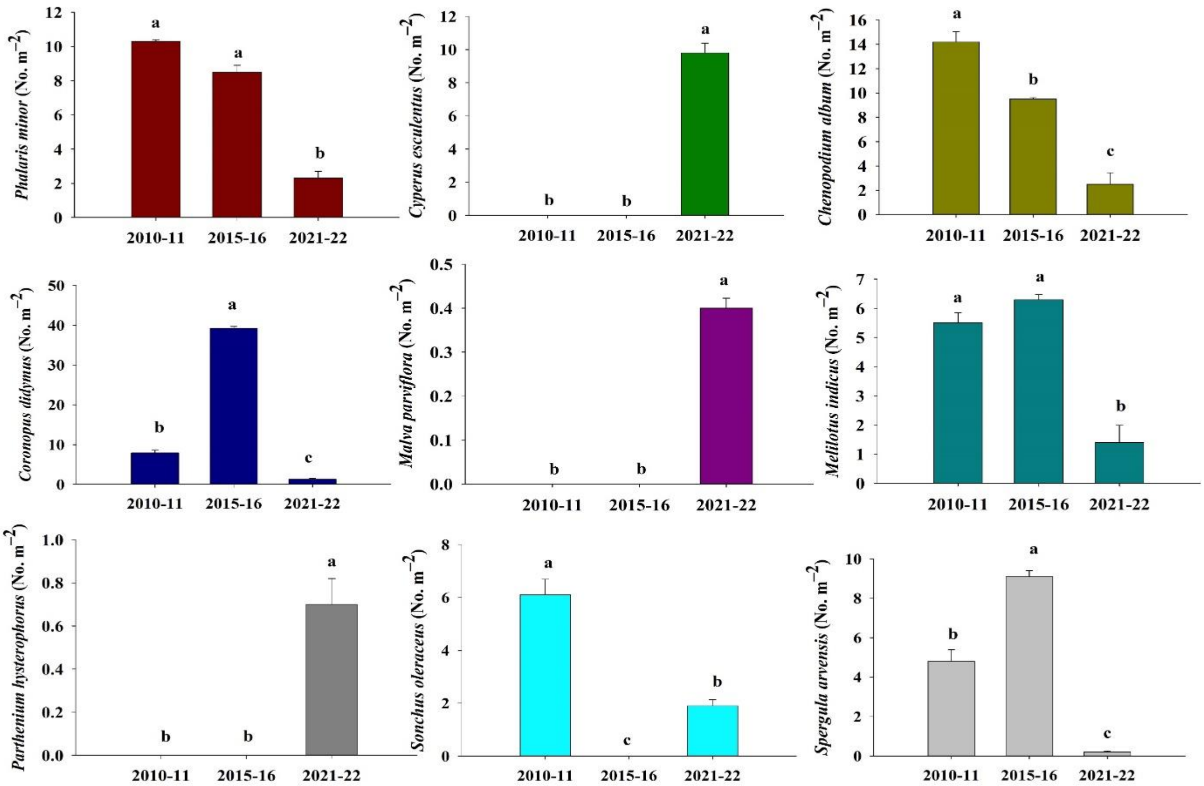


Fig 1.25: Year-wise density of weed species in 2010-11, 2015-16, and 2021-22, respectively in wheat under pigeon pea-wheat system

Table 1.12: Weed diversity and similarity in wheat under CA-based pigeon pea-wheat system

Index	2010-11		2015-16		2021-22	
	CT	CA	CT	CA	CT	CA
Shannon-Weiner index	1.66	1.75	1.37	0.92	1.48	1.85
Sørenson similarity index	1.00		0.89		0.62	

IIWBR

Efficacy of pre-emergence herbicides in conservation tillage wheat

Pot studies were conducted to determine the effect of residue retention on efficacy of pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin against *P minor*. The soil for filling pots (of size 4.5 kg soil capacity) was taken from field having no previous infestation of *P. minor*. The soil after passing through 2 mm sieve was filled in pots. Hundred seeds/pot were sown at about 2 cm. depth. After sowing pots were heavy irrigated for seed germination and thereafter half of the pots were covered with chopped rice residue @ 8t/ha. Two days after sowing graded doses of herbicides (pyroxasulfone 6.25, 12.5,25,50,100, 200 g/ha; pendimethalin 62.5, 125,250,500,1000 and 2000 g/ha; and pyroxasulfone + pendimethalin 6.25 + 62.5, 12.5+ 125, 25+250, 50+500, 100+1000, 200+2000 g/ha) were applied. The herbicides were sprayed with knap sack sprayer fitted with flat fan nozzles delivering 450 lit/ha of spray solution. One month after herbicide application, fresh weight/pot of *P. minor* was taken and based on which per cent *P. minor* biomass reduction compared to control was worked out and which was further used for calculating GR90 values using probit analysis (Finney, 1971). The experiment was conducted twice with four replications

The effect of residue retention on efficacy of pre-emergence herbicides was studied in pot experiment. Based on the fresh biomass reductions, GR90 values were calculated and results showed differential response under with (+R) and without (-R) residue retention conditions. Under the residue retention system, the dose of pyroxasulfone needed to suppress 90% of *P. minor* biomasswas increased by a factor of 6.29 times compared to the system without residue. GR_{90} values recorded for pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin under rice residue retention condition were 62.85, 226.41 and 291.11 g/ha, respectively, whereas without residue retention the respective values were 10.00, 184.09 and 97.18 g/ha. There were 528.5, 23.0 and 199.6%higher doses requirement of pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin, respectively with residue retention compared to without residue retention conditions. The rice residue retention reduced the efficacy of pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin against *P. minor*. The higher reduction was observed for pyroxasulfone efficacy.

Table 1.13: Effect of rice residue management on GR_{90} values of *P. minor* for pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin in a pot study

Residue management	Herbicide	GR_{90} values (g/ha)
Residue retention (+R)	Pyroxasulfone	62.85
	Pendimethalin	226.41
	Pyroxasulfone + Pendimethalin (1:10)	291.11
Without residue (-R)	Pyroxasulfone	10.00
	Pendimethalin	184.09
	Pyroxasulfone + Pendimethalin (1:10)	97.18

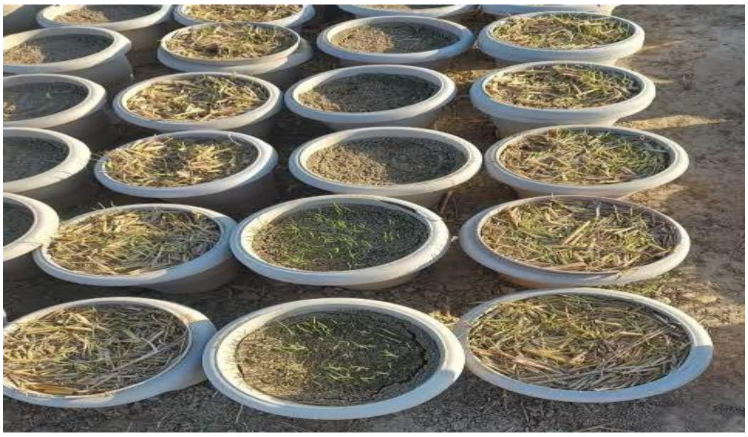


Plate 15: Efficacy of pre-emergence herbicides affected by residue retention

DWR

Wheat 2022-23

Relative weed density and biomass in wheat under rice-wheat-greengram system

At 60 days after sowing (DAS), the wheat field was comprised of weeds, i.e.*Medicago denticulata* (92%), whereas the rest of the weeds, like *Convolvulus arvensis* (3%), *Avena ludoviciana* (3%) *Chenopodium album* (2%), *Cynodon dactylon* (1%) were minor weeds present (Fig 1.26). The relative weed biomass followed the trend of relative density and recorded the highest with *Medicago denticulata* (93%) and the rest were minor weeds in wheat.

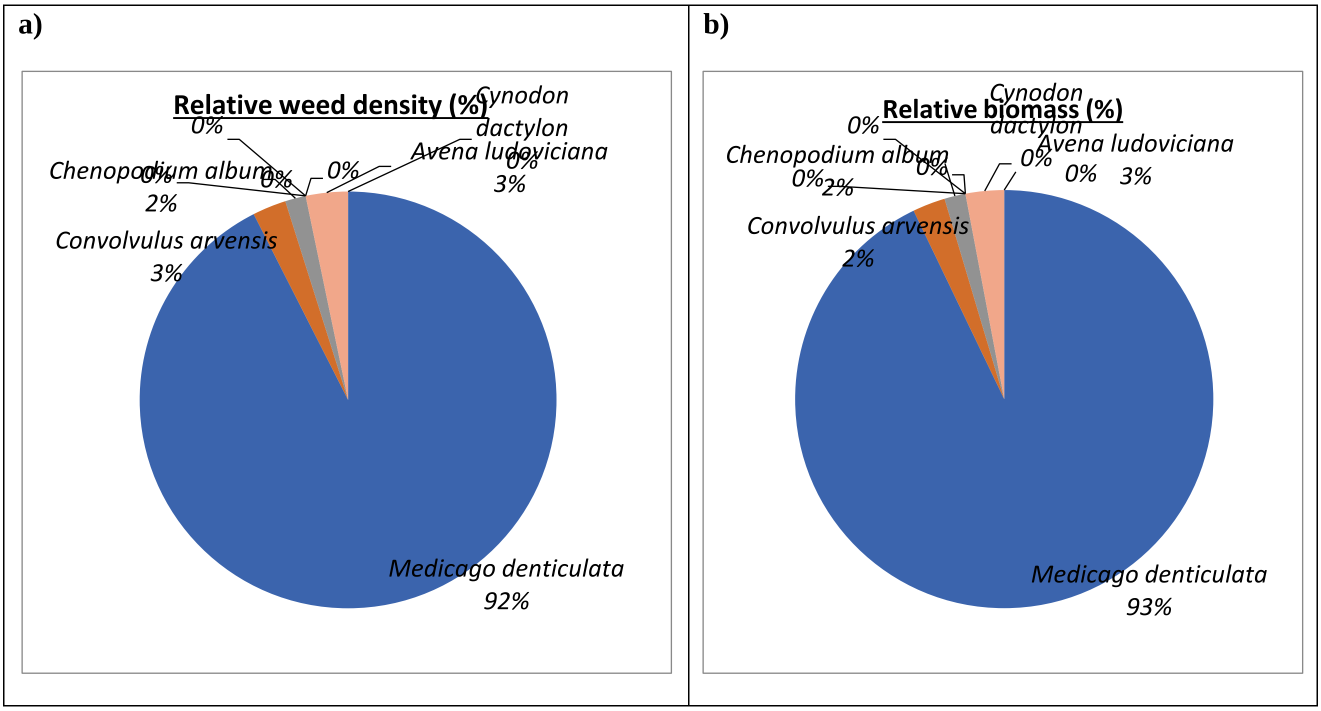


Fig 1.26: Relative weed density (a) and biomass (b) at 60 DAS in wheat under rice-wheat-greengram system

Weed density and biomass at 60 DAS in wheat under rice-wheat-greengram system

At 60 DAS, under crop establishment methods, the total weed density and biomass were recorded higher in the conventional system (CT-CT-CT) with 83.0 no./m^2 and 49.09 g/m^2, respectively. The lowest total weed density and biomass were measured in ZTR-ZTR-ZTRwith 79.67 no./m^2 and 41.00 g/m^2, respectively. In general, ZTR systems have more grassy weeds and CT systems have more broadleaf weeds.

Among weed management practices, weedy check recorded the highest total weed density and biomass with 284.00 no./m^2 and 168.61 g/m^2, respectively and the lowest in integrated weed management [IWM, clodinafop propargyl + metsulfuron-methyl at 60+4 g/ha (pre-mix) followed by (*fb*) hand weeding] followed by herbicide rotation (arylex+ fluroxypyr+ clodinafop at 200+60 g/ha) (Table 1.14). Likewise, weed control efficiency was recorded as being highest with ZTR-ZTR-ZTR (4.02%) over CT-CT-CT system. Likewise, the weed control index followed the trend of the WCE and recorded the highest with ZTR-ZTR-ZTR (16.49%) over the CT-CT-CT system. Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 96.30 and 98.89%, respectively, followed by herbicide rotation and recommended herbicide over weedy check.

Table 1.14: Effect of crop establishment methods and weed management practices on density and biomass of different weed species on wheat at 60 DAS under rice-wheat-greengram system

Treatment	Broadleaf weeds			Grassy weeds	
	Medicago denticulata	***Convolvulus arvensis***	***Chenopodium album***	***Avena ludoviciana***	***Cynodon dactylon***
	Weed density (no./m^2)				
Crop establishment methods (C)					
CT-CT-CT	6.70(76)	1.35(2.17)	1.17(1.42)	1.33(2.50)	1.06(0.92)
ZTR-ZTR-ZTR	6.47(70.92)	1.82(4.17)	1.04(0.92)	1.32(2.25)	1.25(1.42)
SEm±	0.33	0.28	0.07	0.06	0.1

CD (p=0.05)	NS	NS	NS	NS	NS
Weed management practices (W)					
W1	16.06(259.67)	2.68(7.33)	2.21(4.50)	3.05(9.17)	1.89(3.33)
W2	3.62(12.67)	1.41(2.67)	0.79(0.17)	0.71(0)	1.08(0.83)
W3	3.14(9.5)	1.01(1.00)	0.71(0)	0.71(0)	0.71(0)
W4	3.53(12)	1.22(1.67)	0.71(0)	0.85(0.33)	0.94(0.50)
SEm±	0.38	0.4	0.08	0.18	0.17
CD (p=0.05)	1.20	1.23	0.24	0.57	0.53
C X W	NS	NS	NS	NS	NS
	Weed biomass (g/m^2)				
Crop establishment methods (C)					
CT-CT-CT	4.59(45.37)	1.12(1.19)	1.04(0.88)	1.15(1.44)	0.82(0.22)
ZTR-ZTR-ZTR	4.17(36.21)	1.55(2.8)	0.94(0.54)	1.08(1.09)	0.9(0.36)
SEm±	0.24	0.27	0.06	0.05	0.03
CD (p=0.05)	NS	NS	NS	NS	NS
Weed management practices (W)					
W1	12.43(155.81)	2.1(4.24)	1.78(2.74)	2.29(4.99)	1.13(0.82)
W2	1.92(3.19)	1.25(2.07)	0.77(0.10)	0.71(0)	0.83(0.21)
W3	1.37(1.40)	0.89(0.47)	0.71(0)	0.71(0)	0.71(0)
W4	1.8(2.77)	1.08(1.18)	0.71(0)	0.75(0.07)	0.78(0.12)
SEm±	0.28	0.3	0.06	0.12	0.06
CD (p=0.05)	0.88	NS	0.19	0.38	0.19
C X W	NS	NS	NS	NS	NS

W1: control (weedy check); W2: recommended herbicide (mesosulfuron + iodosulfuron 12 + 2.4 g/ha); W3: integrated weed management [clodinafop+metsulfuron 60 +4 g/ha *fb* hand weeding (45 DAS)]; W4: herbicide rotation (Arylex+fluroxypyr+clodinafop 200+60 g/ha)

Table 1.15: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 60 DAS in wheat under rice-wheat-greengram cropping system

Treatment	Total grassy	Total broadleaf	Total weeds	WCE (%)
	Weed density (no./m^2)			
Crop establishment methods (C)				
CT-CT-CT	1.51(3.42)	6.87(79.58)	6.99(83.00)	0.00
ZTR-ZTR-ZTR	1.69(3.67)	6.85(76.00)	7.03(79.67)	4.02
SEm±	0.06	0.43	0.41	
CD (p=0.05)	NS	NS	NS	
Weed management practices (W)				
W1	3.56(12.50)	16.42(271.5)	16.81(284.00)	0.00
W2	1.08(0.83)	3.97(15.50)	4.07(16.33)	94.25
W3	0.71(0)	3.3(10.5)	3.3(10.50)	96.30
W4	1.05(0.83)	3.75(13.67)	3.86(14.50)	94.89
SEm±	0.21	0.39	0.38	
CD (p=0.05)	0.64	1.22	1.2	
C X W	NS	NS	NS	
	Weed biomass (g/m^2)			WCI (%)
Crop establishment methods (C)				
CT-CT-CT	1.21(1.66)	4.71(47.43)	4.78(49.09)	0.00
ZTR-ZTR-ZTR	1.21(1.44)	4.59(39.55)	4.68(41)	16.49
SEm±	0.04	0.4	0.39	
CD (p=0.05)	NS	NS	NS	
Weed management practices (W)				

W1	2.47(5.81)	12.71(162.79)	12.94(168.61)	0.00
W2	0.83(0.21)	2.31(5.36)	2.36(5.56)	96.70
W3	0.71(0)	1.52(1.87)	1.52(1.87)	98.89
W4	0.81(0.19)	2.06(3.95)	2.10(4.14)	97.54
SEm±	0.12	0.33	0.32	
CD (p=0.05)	0.37	1.03	1.01	
C X W	NS	NS	NS	

Crop growth and yield parameters of wheat under rice-wheat-greengram system

During the experimentation, between the crop establishment methods, the population of wheat plants at 15 DAS was comparable, whereas plant height and grains/spike at harvest was more with ZTR-ZTR-ZTR. The spikes per meter running length, spike length, spike weight, plant dry biomass and test weight were comparatively more in ZTR-ZTR-ZTR but was statistically similar to CT-CT-CT (Table 1.16). Among weed management practices, plant height, spikes per meter running length, spike length, dry biomass of plant, spike weight and grains/spike were highest with IWM followed by herbicide rotation and recommended herbicides. The lowest growth and yield parameters were recorded with weedy check (Table 1.17). The interaction between crop establishment methods and weed management practices was non-significant except for plant biomass.

Table 1.16: Effect of crop establishment methods and weed management practices on growth and yield parameters of wheat under rice-wheat-greengram cropping system

Treatment	Plant population at 15 DAS	Plant height (cm)	No. of spike per meter row	Spike length (cm)	Plant biomass at harvest (g/m^2)	Spike weight (g)	No. of grain/spike	Test weight (g)
Crop establishment methods (C)								
CT-CT-CT	26.25	95.33	86.77	16.35	819.24	3.09	57.38	1.63
ZTR-ZTR-ZTR	25.98	104.93	94.65	17.05	919.59	3.39	61.83	1.70
SEm±	0.21	1.31	2.33	0.30	16.77	0.11	0.56	0.03
CD (p=0.05)	NS	8.56	NS	NS	NS	NS	3.68	NS
Weed management practices (W)								
W1	25.30	89.16	45.12	14.75	447.70	2.51	39.75	1.32
W2	25.88	101.22	102.36	17.15	999.79	3.37	63.17	1.74
W3	26.88	106.45	108.82	17.57	1016.75	3.58	69.67	1.78
W4	26.38	103.71	106.53	17.34	1013.41	3.50	65.83	1.82
SEm±	0.76	1.40	2.10	0.22	16.57	0.14	1.79	0.02
CD (p=0.05)	NS	4.37	6.49	0.70	51.61	0.44	5.57	0.06
C X W	NS	NS	NS	NS	105.67	NS	NS	NS

Grain and straw yield of wheat under rice-wheat-greengram system

Lower weed density and biomass, and higher WCE helped in harvesting a higher grain yield in ZTR-ZTR-ZTR (4058 kg/ha) which was comparatively higher over the CT-CT-CT system (3606 kg/ha). The straw yield and biological yields were statistically at par between the crop establishment methods. The fact that the harvest index was highest in ZTR-ZTR-ZTR might be due to better accumulation of photosynthates in grains over the CT-CT-CT system (Table 1.17). Among weed management practices, weedy check has the lowest grain, straw and biological yields (1793, 2685 and 4477 kg/ha, respectively). The highest crop yields were obtained under IWM (4624, 5544 and 10168 kg/ha, respectively), followed by herbicide rotation and recommended herbicides. The harvest index was highest with IWM, followed by herbicide rotation and recommended herbicides. The interaction between crop establishment methods and weed management practices was found to be significant for grain, and biological yield, but the straw yield and harvest index was non-significant.

Table 1.17: Effect of crop establishment methods and weed management practices on yields of wheat under rice-wheat-greengram cropping system

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Crop establishment methods (C)				
CT-CT-CT	3606	4586	8192	43.3
ZTR-ZTR-ZTR	4058	5137	9141	43.7
SEm±	75	126	168	0.63
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	1793	2685	4477	39.9
W2	4362	5636	9888	43.6
W3	4624	5544	10168	45.5
W4	4551	5583	10134	45.0
SEm±	72	155	166	0.9
CD (p=0.05)	225	482	516	2.8
C X W	464	NS	1057	NS

C. Water Management Practices in Conservation Agriculture

Rice Wheat Cropping System

CSSRI

1.1.3 Detail of rice crop during *kharif*2023

The experimental results have been divided into three aspects and discussed below

d) Puddled transplanted rice (PTR)

Higher grain yield (7.16tha^{-1}) was recorded under conventional puddled transplanted rice with wheat residue incorporation (PTR+RI) than without residue incorporation (PTR; 6.94tha^{-1}). So, residue incorporation in conventional PTR rice increased the grain yield by 3.21% (Plate 16).

Plate 16: Experimental view of the puddled transplanted rice with wheat residue incorporation

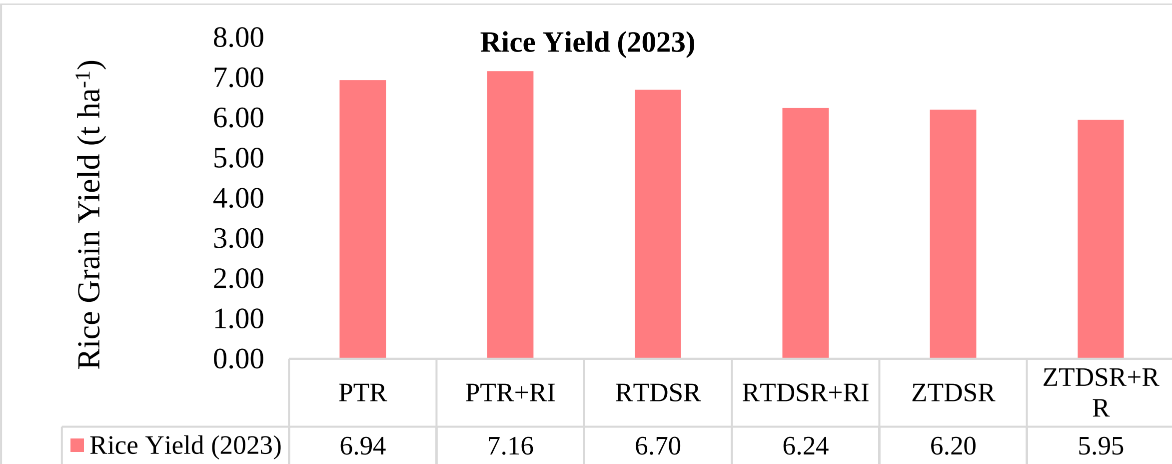
Plate 17: Experimental view of DSR in reduced tillage (residue incorporation, sowing and germination) and DSR in zero tillage with wheat residue, germination in anchored residue and rice performance)

e) Direct seeded rice under reduced tillage with wheat residue

Direct seeded rice under reduced tillage with wheat residue (RTDSR+RI) produced grain yield of 6.24 tha^{-1}, which was 11.11% lower in comparison to PTR (6.94 tha^{-1}) and 6.81% lower in comparison to direct seeded rice under reduced tillage without wheat residue (RTDSR; 6.70t ha^{-1}), respectively (Fig 1.25).

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

Grain yield under zero tilled DSR with anchored wheat residue (ZTDSR+RR) was 5.95t ha^{-1} which was 14.23% lower than the PTR (6.94 t ha^{-1}) and 4.03% lower than the direct seeded rice in zero tillage without wheat residue incorporation (ZTDSR; 6.20 t ha^{-1}) (Fig 1.27). The lower yield in the ZTDSR+RR was mainly because of the higher weed population, and lower plant density as compared to the PTR.



	PTR	PTR+RI	RTDSR	RTDSR+RI	ZTDSR	ZTDSR+RR
Rice Yield (2023)	6.94	7.16	6.70	6.24	6.20	5.95

Fig 1.27: Effects of different tillage and residue management practices on rice grain yield during kharif 2023.

(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)

1.1.4 Details of wheat crop during *rabi*2022-23

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

d) Conventional tilled wheat (CTW)

Higher grain yield (5.48 t ha^{-1}) was recorded under conventional tilled wheat with residue incorporation (CTW+RI) than without residue addition (CTW) (5.34 tha^{-1}). So, residue incorporation in CTW enhanced the grain yield by 2.69% (Fig. 1.28).

e) Reduced tilled wheat with rice residue

Reduced tilled wheat without rice residue (RTW) produced grain yield of 5.87 t ha^{-1}, which was 9.95and 6.22% higher in comparison to CTW (5.34 t ha^{-1}) and reduced tilled wheat residue with rice residue (RTW+RI) (5.53 t ha^{-1}), respectively (Fig. 1.28).

f) Zero tilled wheat with anchored rice residue

Zero tilled wheat with anchored rice residue (ZTW+RR) produced wheat yield of5.91 t ha^{-1} which was 10.66% higher in comparison to CTW (5.34 t ha^{-1}) and 1.05% lower in comparison to zero tilled wheat without rice residue retention (ZTW; 5.97 t ha^{-1}) (Fig. 1.28). The lower yield in the ZTW+RR was mainly because of the higher weed population, lower plant density as compared to the CTW. 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 saves from deterioration of soil physical properties. However, the residue retention under both the conservation tillage treatments, i.e., reduced tillage and zero tillage leads to considerable lose in wheat yield.

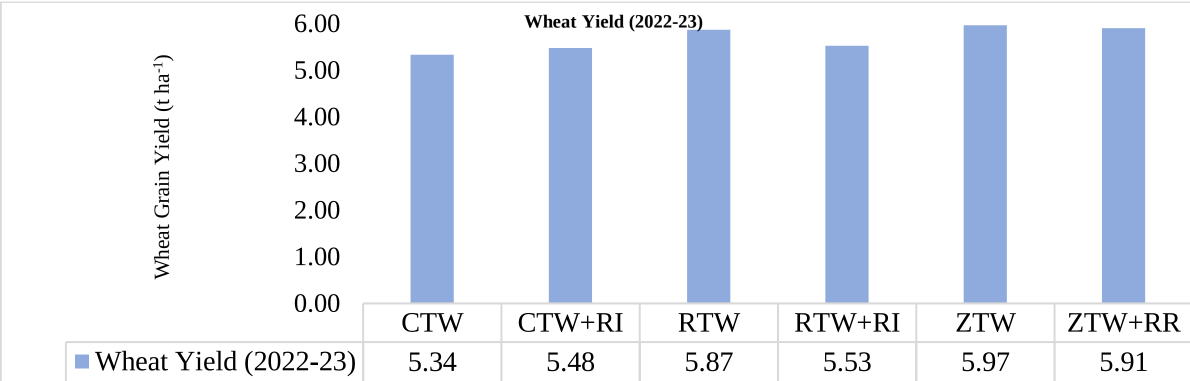


Fig 1.28: Effects of tillage and residue management practiceson wheat grain yield during rabi2022-23

(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)

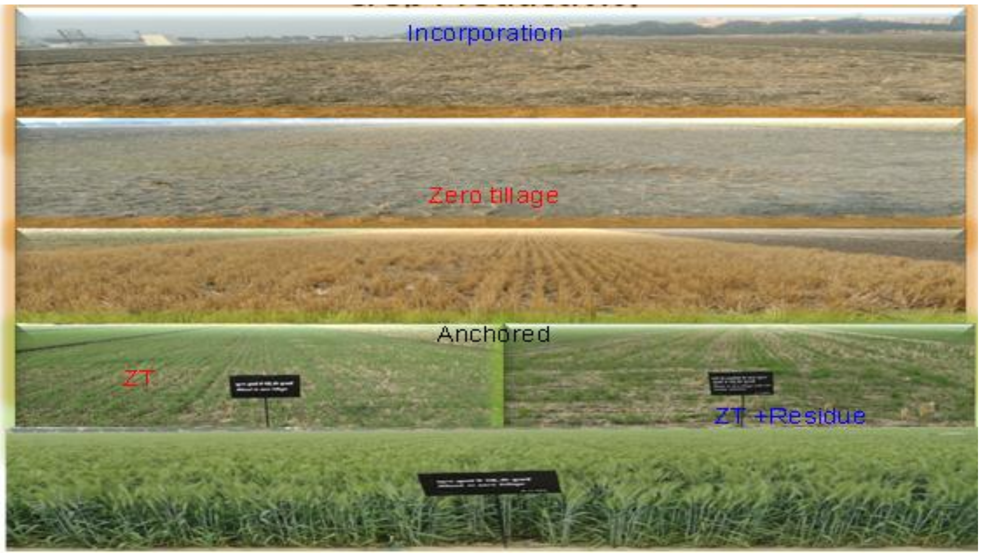


Plate 18: Experimental view of wheat germination under rice residue incorporation/anchored and zero tillage conditions.

1.1.5 Details of rice-wheat cropping system during 2022-23

d) PTR/CTW

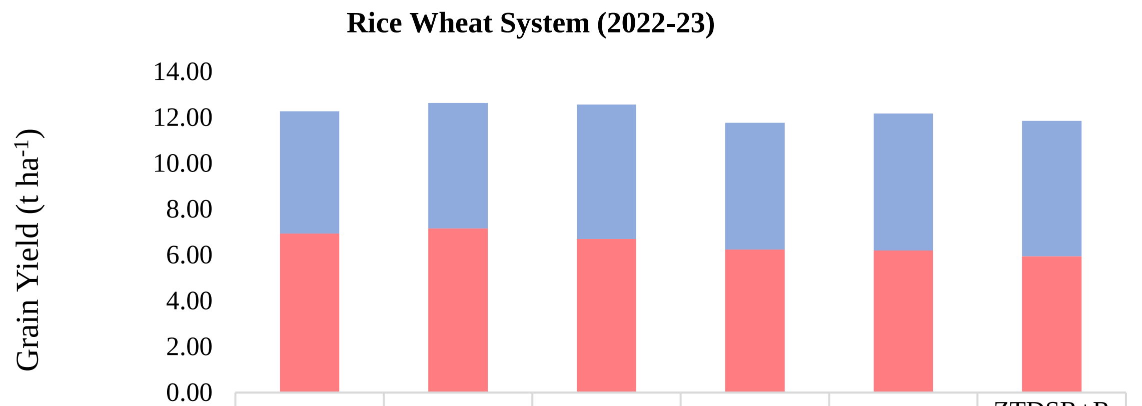
Higher grain yield (12.64 t ha^{-1}) was recorded under conventional puddled transplanted rice/ conventional tilled wheat with residue incorporation (PTR+RI/CTW+RI) and12.28 t ha^{-1} in PTR/CTW without residue incorporation. So, residue incorporation in conventional PTR rice enhanced the grain yield by 2.98% (Fig. 1.27).

e) RTDSR+RI/RTW+RI

Direct seeded rice under reduced tillage/reduced tilled wheat with residue incorporation (RTDSR+RI/RTW+RI) produced grain yield of 11.77 t ha^{-1}, which was 4.30 and 6.80% lower in comparison to PTR/CTW (12.28 t ha^{-1}) and direct seeded rice under reduced tillage/ reduced tilled wheat without residue incorporation (RTDSR/RTW) (12.57 t ha^{-1}), respectively (Fig. 1.27).

f) ZTDSR+RR/ZTW+RR

Grain yield under zero tillage direct seeded rice/zero tilled wheat with anchored wheat residue (ZTDSR+RR/ZTW+RR) was 11.86 t ha^{-1} which was 3.53% lower than the PTR/CTW (12.28 t ha^{-1}) and 2.64% lower than the direct seeded rice in zero tillage without wheat residue incorporation (ZTDSR/ZTW; 12.17 t ha^{-1}) (Fig. 1.29).



	PTR/CTW	PTR+RI/CTW+RI	RTDSR/RTW	RTDSR+RI/RTW+RI	ZTDSR/ZTW	ZTDSR+RR/ZTW+RR
Wheat Yield (2022-23)	5.34	5.48	5.87	5.53	5.97	5.91
Rice Yield (2023)	6.94	7.16	6.70	6.24	6.20	5.95

Rice Yield (2023) Wheat Yield (2022-23)

Fig 1.29: Effects of tillage and residue management practices on rice-wheat cropping system grain yield during 2022-23

(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)

1.2 Micro-irrigation methods

1.2.1 Detail of rice crop during *kharif* 2023

Data are given in Fig. 1.28 for the comparison of different irrigation systems in rice crop during *kharif* 2023. Results of micro-irrigation systems and surface irrigation systems are discussed below as:

a) **Drip irrigation system in rice crop**
During *kharif*2023, 6.72 t ha^{-1} rice yield was reported under drip irrigation system with DSR in reduced tillage (DRIP-RTDSR) (Fig 1.28). Rice yield under DRIP-RTDSR was 3.15% lower than the conventional PTR (6.94 t ha^{-1}). Whereas, it was 3.46% higher than the RTDSR under surface irrigation system (SIS-RTDSR) (6.49 t ha-1).

b) **Surface irrigation in rice crop**
DSR with reduced tillage under surface irrigation method (SIS-RTDSR) produced grain yield of 6.49 t ha^{-1} (Fig 1.28). Grain yield in DSR under surface irrigation method (SIS-RTDSR) was

6.40% lower than conventional PTR and3.08-5.76% higher compared to different micro sprinkler irrigation method.

c) **Mini sprinkler irrigation system in rice crop**

Results on irrigation system through mini sprinkler irrigation systemshowed that 6.12 and 6.29tha^{-1} grain yield was obtained in DSR with reduce tillage (RTDSR) and RTDSR with 33% wheat residue incorporation (RTDSR+RI) during *kharif* 2023 (Fig 1.30). During 2023, 11.78 and 9.28% lower yield of DSR was reported in RTDSR and RTDSR+RI, respectively under mini sprinkler irrigation system as compared to PTR (6.94 t ha^{-1}). Lowergrain yield of direct seeded rice under mini-sprinkler irrigation was recorded in comparison to DSR in surface irrigation method (SIS-RTDSR; 6.49 t ha^{-1}), which was about 5.76 and 3.08% lower in MSIS-RTDSR and MSIS-RTDSR+RI treatments, respectively.

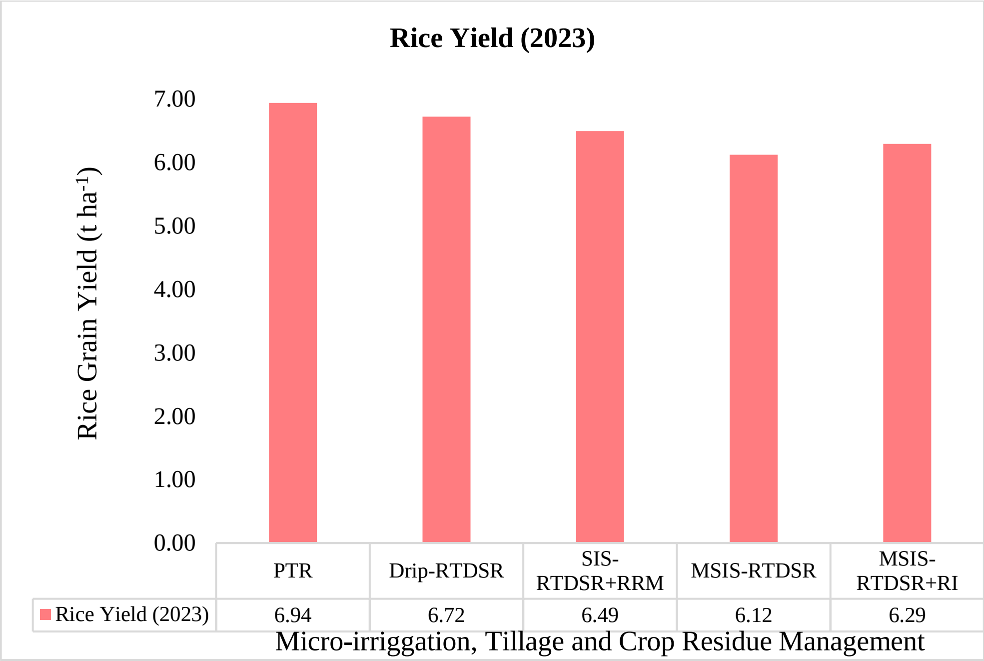


Fig 1.30: Effects of different micro-irrigation methods, tillage and crop residue management on rice grain yield during kharif2023

(Note: PTR- Puddled transplanted rice; RTDSR- Direct seeded rice in reduced tillage; RI- Residue incorporation; DRIP- Drip irrigation system; SIS- Surface irrigation system; MSIS- Sprinkler irrigation system)

Plate 19: Zero tilled wheat sowing using happy seeder in rice residue under mini sprinkler irrigation method.

1.2.2 Detail of wheat crop during *rabi* 2022-23

The results of micro-irrigation systems (drip and minisprinkler) in zero tilled wheat with rice residue mulch (ZTW+RM) during 2022-23is given in Fig 1.29 as given below:

a) **Drip irrigation system in wheat**

The grain yield of zero tilled wheat under drip irrigation (DRIP-ZTW+RM) was 6.31 t ha^{-1}, which was 18.15% higher in comparison to CTW (5.34 t ha^{-1}) and 12.61% higher in comparison tosurface irrigation system in wheat with 100% rice residue mulch (SIS-ZTW+RM) (5.60 t ha^{-1}) (Fig 1.29).

b) **Surface irrigation system in wheat**

Surface irrigation system in wheat with 100% rice residue mulch (SIS-ZTW+RM) produced grain yield of 5.60 t ha^{-1}. Grain yield in SIS-ZTW+RM was 4.92% higher to that of CTW (5.34 t ha^{-1}), whereas lowest among the different micro irrigation applied (3.93-12.61%). It is observed that retention of 100% rice residue mulch in wheat crop with different irrigation methods maintained the favorable 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 100% rice residue mulch in wheat crop with different irrigation methods showed that 100% rice residue mulch with turbo happy seed drill machine for wheat sowing is feasible as rice residue is hassle free which is good for plant stand, higher crop growth and crop yield.

c) **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 5.82 t ha^{-1} (T9) to 6.02 t ha^{-1} (T10) which was almost similar to conventional tilled wheat (CTW; 5.22 t ha^{-1}). Thus, the mini-sprinkler method may be feasible for wheat production. During 2022-2023, 7.71 and 4.56% lower yield of wheat recorded under zero tilled wheat with 100% rice straw mulch under mini sprinkler irrigation system (MSIS-ZTW+RM) i.e., T9 and T10, respectively as compared to DRIP-ZTW+RM (6.31 t ha^{-1}). Higher grain yield of wheat in zero tilled wheat with 100% rice straw mulch under mini sprinkler irrigation system (MSIS-ZTW+RM) i.e., T9 and T10 was recorded in comparison to surface irrigation system in wheat with 100% rice residue mulch (SIS-ZTW+RM; 5.60 t ha^{-1}), which was about 3.93 and 7.71% higher, respectively.

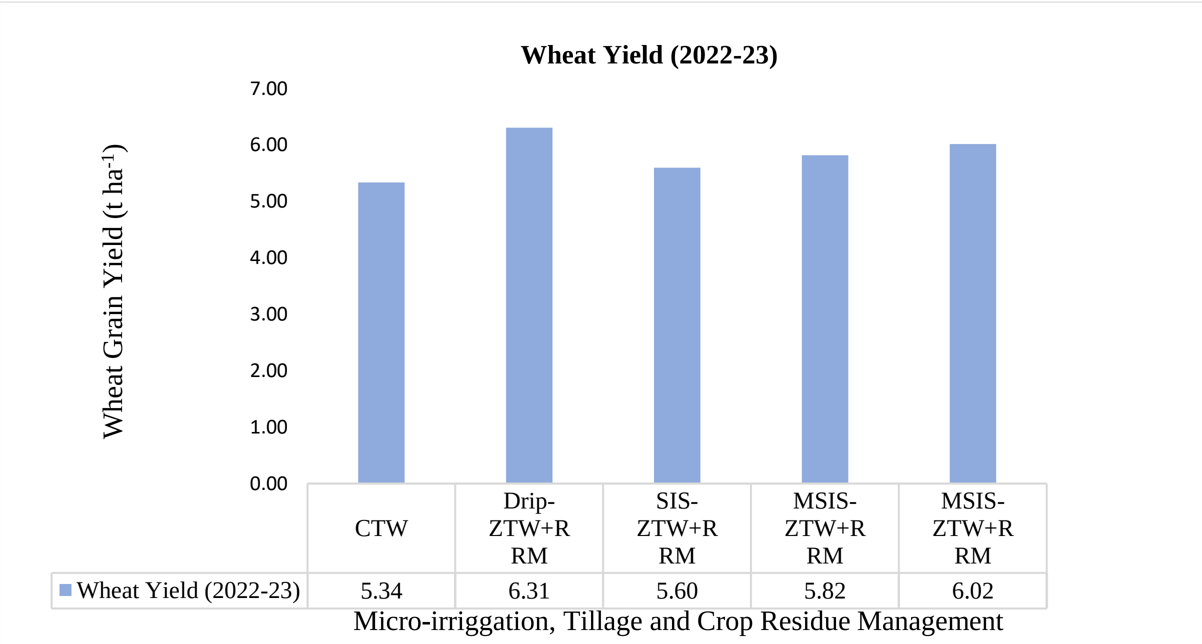


Fig 1.31: Effects of different micro-irrigation methods,tillage and crop residue management on wheat grain yield during rabi 2022-2023

(Note: CTW- Conventional tilled wheat; ZTW- Zero tilled wheat; RM- Residue mulch; DRIP- Drip irrigation system; SIS- Surface irrigation system; MSIS- Sprinkler irrigation system)

Details of rice-wheat cropping system during 2022-23

a) DRIP-RTDSR/ZTW+RM

Higher grain yield (13.03 t ha^{-1}) was recorded under drip irrigation system with DSR in reduced tillage/ zero tilled wheat under drip irrigation (DRIP-RTDSR/ZTW+RM) than PTR/CTW (12.28 t ha^{-1}) (Fig

1.32). So, the drip irrigation system leads to 6.11% increase in the grain yield of rice and wheat cropping system during 2022-2023.

b) SIS-RTDSR/ZTW+RM

DSR with reduced tillage under surface irrigation method/ Surface irrigation system in wheat with 100% rice residue mulch (SIS-RTDSR/SIS-ZTW+RM) produced grain yield of 12.09 t ha^{-1} (Fig 1.32). Grain yield in SIS-RTDSR/SIS-ZTW+RM was 7.70% lower than DRIP-RTDSR/ZTW+RM and 1.81% lower than MSIS-RTDSR+RI/ MSIS-ZTW+RM.

c) MSIS-RTDSR+RI/ZTW+RM

Results on irrigation system through mini sprinkler irrigation system showed that 11.94 and 12.31 t ha^{-1} grain yield was obtained in DSR with reduce tillage/ Zero tilled wheat with 100% rice straw mulch under mini sprinkler irrigation system (MSIS-RTDSR/ MSIS-ZTW+RM) and RTDSR with 33% wheat residue incorporation (MSIS-RTDSR+RI/ MSIS-ZTW+RM), respectively. During 2022-23, almost similar yield was reported in MSIS-RTDSR/ MSIS-ZTW+RM and MSIS-RTDSR+RI/MSIS-ZTW+RM to PTR/CTW (12.28 t ha^{-1}). DRIP-RTDSR/ZTW+RM system (13.03 t ha^{-1}) showed an advantage of 9.09 and 5.79% over MSIS-RTDSR/ MSIS-ZTW+RM and MSIS-RTDSR+RI/ MSIS-ZTW+RM treatments, respectively. 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 than CTW method of wheat sowing. It may be due to optimum soil moisture and favourable temperature regulation under residue management to facilitate better seed germination and crop growth as compared to non-residue practice.

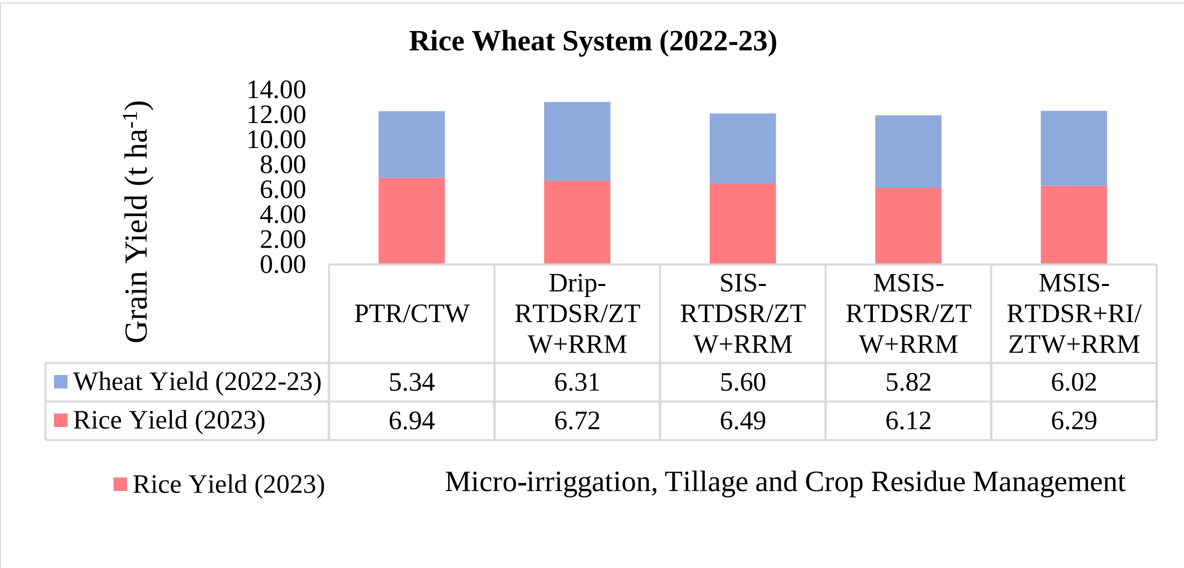


Fig 1.32: Effects of micro-irrigation methods, tillage and crop residue management on rice-wheat cropping system grain yield during 2022-23

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

1.3 Rotational System

A new experiment was initiated with the sowing of rice in Kharif 2022 season with the objective to examine the impact of the rotation-based (DSR)-ZTW-Moong/Green manure system on productivity, profitability, and weed dynamics under the rotation based (DSR/PTR) system in reclaimed sodic soils. The primary objectives were to investigate the productivity, profitability, and resource use efficiency of the rotation-based (DSR)-ZTW-Moong/Green manure system in partially reclaimed soils and to assess its influence on soil health. Furthermore, the study aimed to comprehend the weed flora dynamics in the rotation-based (DSR)-ZTW system. The research involved the evaluation of three combinations of rotation-based (DSR)-ZTW-Moong/Green manure systems in comparison to the conventional practice of rice/wheat (PTR/CTW), which is presented in Table 1.18.

Table 1.18: Detail of experiment of rotation based DSR-ZTW-Moong system going on at CSSRI, Karnal

Treatment's detail						Kharif	Rabi	Summer
			Tillage	Residue	Irrigation	Rice	Wheat	
T11	Sc 1	R-W-F	Conventional tillage	-	Surface	PTR	CTW	Fallow
T12	Sc 2	R-W-M/GM	1-year rotation ZT-CT-ZT-CT	100 % or maximum		DSR-PTR-DSR-PTR	ZTW	Moong/Green manure
T13	Sc 3	R-W-M/GM	2-year rotation ZT-ZT-CT-ZT			DSR-DSR-PTR-DSR	ZTW	
T14	Sc 4	R-W-M/GM	3-year rotation ZT-ZT-ZT-CT			DSR- DSR-DSR-PTR	ZTW	

1.3.1 Detail of rice crop during *kharif*2023

Data is presented in Fig 1.33 for the comparison of different rotational (DSR-PTR) systems in rice crop during kharif 2023. Results of rotational cropping systems are discussed below as:

a) One-year rotation

In one-year rotation system i.e., DSR-PTR-DSR (Sc 2) cultivation was done through puddled transplanted rice (PTR)for the year 2023 and produced a grain yield of 8.60 t ha^{-1}, which was 8.40% higher in comparison to the convention tilled rice (Sc 1; 7.93 t ha^{-1}) (Fig. 1.31).

b) Two-year rotation

Intwo-year rotation system i.e., DSR-DSR-PTR (Sc 3) thecultivationwas done through direct seeded rice for the year 2023 and produced a grain yield of 7.78 t ha^{-1} which was1.92% lower than the conventional tilled rice (Sc 1; 7.93 t ha^{-1}) and 9.52% lower than the one-year rotation (Sc 2; 8.60 t ha^{-1}) (Fig 1.31).

c) Three-year rotation

In three-year rotation i.e., DSR-DSR-DSR-PTR (Sc 4) wascultivation was done through direct seeded rice for the year 2023 and recorded the lowest grain yield of7.34 t ha^{-1}among the rotational system. The three-year rotation system i.e., DSR-DSR-DSR-PTR (Sc 4) observed 7.48, 14.65 and 5.67% lower yield in comparison to PTR (Sc 1), one-year rotation i.e., DSR-PTR-DSR (Sc 2) and two-year rotation i.e., DSR-DSR-PTR (Sc 3), respectively.

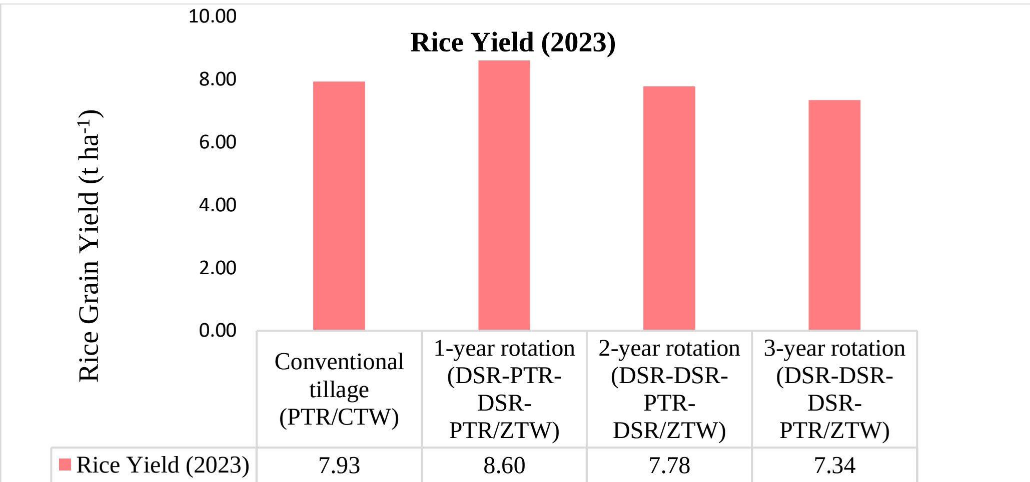


Fig 1.33: Effects of different rotation system on rice grain yield during kharif 2023.

(Note: Sc 1- Conventional tilled rice; Sc 2- one-year rotation; Sc 3- two-year rotation; Sc 4- three-year rotation)

1.3.2 Detail of wheat crop during *rabi* 2022-23

Data are given in Fig. 1.34 for the comparison of different rotational systems in wheat crop during *rabi* 2022-23. Results of rotation cropping systems are discussed below as:

a) One-year rotation

The one-year rotation wheat with zero tillage (Sc 2) produced a grain yield of 5.82 t ha^{-1}, which was almost similar to the conventional tilled wheat (Sc 1; 5.78 t ha^{-1}) (Fig 1.34).

b) Two-year rotation

Grain yield under two-year rotation with zero tillage (Sc 3) was recorded 5.73 t ha^{-1}, lowest among all the rotational system. Two-year rotation system (Sc 2) recorded 0.89, 1.53 and 4.00% lower yield in comparison to PTR (Sc 1), one-year rotation i.e., DSR-PTR-DSR (Sc 2) and three-year rotation i.e., DSR-DSR-DSR-PTR (Sc 4), respectively.

c) Three-year rotation

Grain yield under three-year rotation with zero tillage (Sc 4) was 5.97 t ha^{-1}which was highest among all the rotational system. The three-year rotation system i.e., DSR-DSR-DSR-PTR (Sc 4) observed 3.24, 2.58 and 4.17% lower yield in comparison to PTR (Sc 1), one-year rotation i.e., DSR-PTR-DSR (Sc 2) and two-year rotation i.e., DSR-DSR-PTR (Sc 3), respectively.

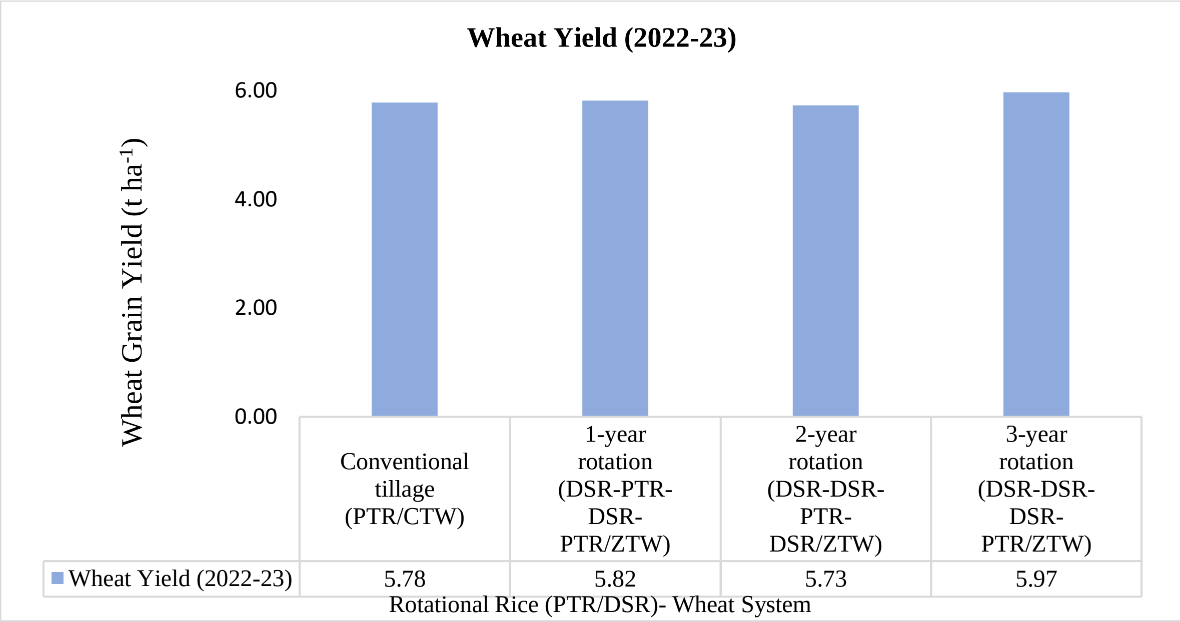


Fig 1.34: Effects of different rotation system on wheat grain yield during rabi 2022-23.
(Note: Sc 1- Conventional tilled wheat; Sc 2- one-year rotation; Sc 3- two-year rotation; Sc 4- three-year rotation)

1.3.3 Detail of rice-wheat cropping system during 2022-23

Data are given in Fig. 1.35 for the comparison of different rotational systems in rice-wheat cropping system during 2022-23. Results of rotation cropping systems are discussed below as:

a) One-year rotation

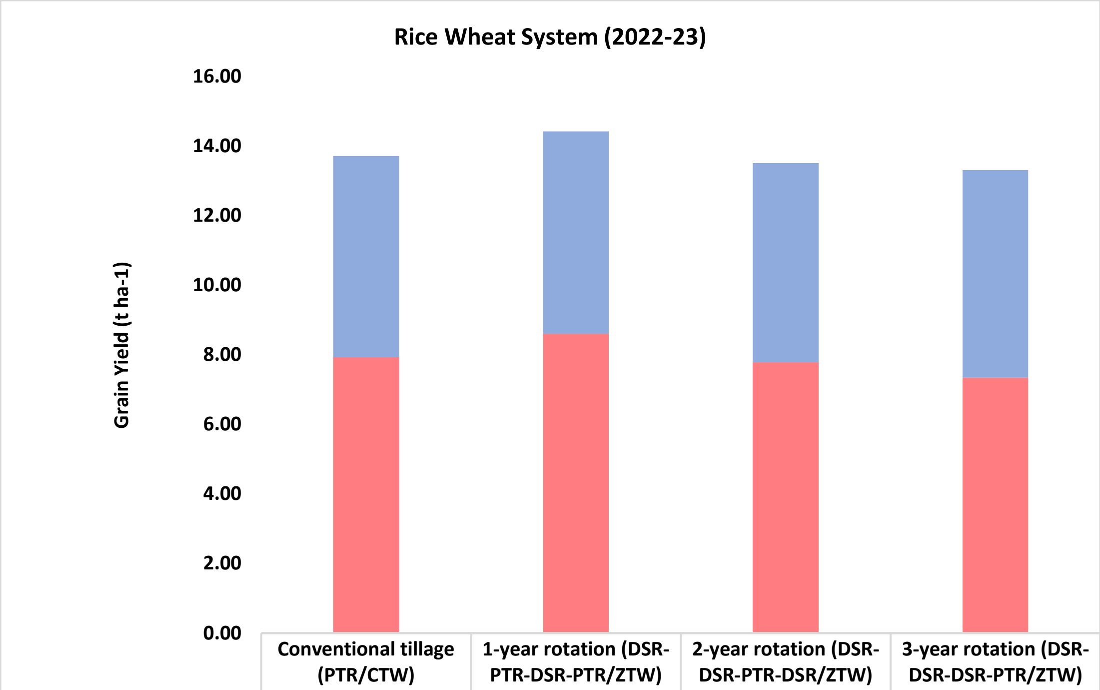
The one-year rotation i.e., DSR-PTR-DSR with zero tillage wheat (Sc 2) produced a yield of 14.42 t ha^{-1}, which was 5.13 % higher in comparison to the conventional tilled rice and wheat (Sc 1; 13.71 t ha^{-1}) (Fig 1.35).

b) Two-year rotation

Grain yield under two-year rotation i.e., DSR-DSR-PTR with zero tillage wheat (Sc 3) was 13.51 t ha^{-1} which was 1.48% lower than the conventional tilled rice and wheat (Sc 1; 13.71 t ha^{-1}) and 6.29% lower than one-year rotation i.e., DSR-PTR-DSR with zero tillage wheat (Sc 2; 14.42 t ha^{-1}) (Fig 1.35).

c) Three-year rotation

In three-year rotation i.e., DSR-DSR-DSR-PTR with zero tillage wheat (Sc 4) was 13.31 t ha^{-1}, which was lowest among rotational system (Fig 1.35). The three-year rotation system i.e., DSR-DSR-DSR-PTR (Sc 4) observed 2.96, 7.70 and 1.50% lower yield in comparison to conventional tilled rice and wheat (Sc 1), one-year rotation i.e., DSR-PTR-DSR (Sc 2) and two-year rotation i.e., DSR-DSR-PTR (Sc 3), respectively.



	Conventional tillage (PTR/CTW)	1-year rotation (DSR-PTR-DSR-PTR/ZTW)	2-year rotation (DSR-DSR-PTR-DSR/ZTW)	3-year rotation (DSR-DSR-DSR-PTR/ZTW)
Wheat Yield (2022-23)	5.78	5.82	5.73	5.97
Rice Yield (2023)	7.93	8.60	7.78	7.34

Fig 1.35: Effects of different rotation system on rice-wheat grain yield during 2022-23.
(Note: Sc 1- Conventional tilled rice; **Sc 2-** one-year rotation; **Sc 3-** two-year rotation; **Sc 4-** three-year rotation)

2. Output during period under report

(A) Special attainments/innovations

1. Efficient irrigation water management in rice–wheat cropping system.
2. Crop residue management and higher water productivity
3. Standardization of tillage management practices
4. Tangible and non-tangible benefits of resource conservation technologies (RCTs).
5. Soil properties changes under crop residue and conservation tillage under rice–wheat cropping system.
6. Popularization of CA technologies.

(B) Outputs (Achievements)

1. Zero tillage in wheat with and without rice residue crop is promising and sustainable.
2. Rice straw either incorporation or retention (stables/mulch) both practices are promising and economic for higher wheat productivity.
3. Reduced tilled DSR method with wheat residue incorporation (RTDSR+WRI) is a better option with higher water productivity.
4. Mini sprinkler irrigation in zero tillage wheat with rice residue mulch (MSIS-ZTW+RM) is economically feasible option for increasing irrigation water productivity and NUE. Mini sprinkler irrigation system in rice with DSR crop establishment technique is feasible option for increasing water productivity and NUE.
5. Drip irrigation method is feasible under zero tillage wheat sowing with 100% rice residue mulch, using Turbo seed drill machine for wheat seed sowing.
6. Drip irrigation method saved irrigation water and nitrogen in fertigation.
7. In rice crop drip irrigation method is feasible under reduced tillage with saving of irrigation water.
8. Crop residue management increased the carbon sequestration and carbon buildup rate and found helpful improving soil properties and crop yields.
9. Crop residue management avoid the burning and saved the environment from pollution.

10. Soil nutrient availability improved in the respective residue managed plots.

E. Effect of Machinery in Conservation Agriculture

CIAE
Promotion of Conservation Agriculture Machinery for Major Crops in Vertisols

To assess the performance of selected conservation agriculture machinery under maize-wheat-green gram cropping system, institute developed conservation agriculture machines like slit- till-drill (T1), mulcher -cum-seeder (T2), residue cleaner-cum-seeder/conservation seeder (T3) were assed in institute farm and compared with commercially available happy seeder as control (C) in full residue condition during 2023. The assessment is based on the crop yield, cost of operation and energy expenditure. The maize yield (Nath Samrat- 1144) was 4.13 (T1), 4.12 (T2), 4.10 (T3) and 3.70 (C), tone/ha. Wheat yield (HD CSW- 18) was 4.18 (T1), 3.85 (T2), 3.66 (3), 3.80 (C), tone/ha and green gram yield (PDM-139, Samrat) was 0.54 (T1), 0.56 (T2), 0.41 (3), 0.52.(C), tone/ha. The tractor-drawn CA machinery for slit-till drill, mulcher-cum seeder, residue cleaner-cum-seeder, and happy seeder required 45, 55, 45, and 60 hp, respectively. The field capacity was 0.62, 0.61, 0.65, and 0.76 ha/h for their respective treatments. The cost of operation was 717.16, 899.43, 690.50, and 988.00 Rs./h; and energy expenditure was 23438.84, 23475.06, 23415.07, and 23529.37 MJ/ha, for their respective treatments.

Plate 20: Conservation Agriculture Machinery for Maize crops

Plate 21: Conservation Agriculture Machinery for Wheat crop

Plate 22: Conservation Agriculture Machinery for Moong Crop

Rainfed Ecosystem / Dryland Ecosystem

A. Tillage and Residue management in Conservation Agriculture

IISS

Soybean-Wheat Cropping Systems

This field experiment was initiated during *kharif* 2015 in soybean-wheat cropping systems with five different tillage treatments, viz. T1: No Tillage (NT) with 30cm height of crop residue retention, T2: No Tillage (NT) with 60cm height of crop residue retention;, T3: Reduced Tillage with 30cm height of crop residue retention, T4: Reduced Tillage with 60cm height residue and T5: Conventional Tillage (CT)/Farmers practices with three nutrient doses namely N1:75% of the recommended dose of fertilizer (RDF), N2:100% RDF, N3: Soil test based recommendation. The experiment was taken in split plot design with three replications. Test crops (soybean and wheat) were sown using happy seeder during rainy and winter seasons by adopting standard package of practices (Plate 1.59). Biometric observations and yield parameters were recorded. Following cultivars were used - Soybean: cultivar- JS 2029; Wheat cultivar HI 154.

In the *kharif* season, soybean yield varied between 17.61-19.31 q/ha, (Table 1.19). Among the *rabi* season crops, wheat yield varied between 52.98 and 55.62 q/ha under different tillage treatments (Table 1.19). Barring soybean yield, tillage treatments did not show significant effect on yields of both the *kharif* and *rabi* seasons crops in 2021-22. Higher (balanced) nutrient application through 100%RDF and STCR dose recorded significantly higher grain yield under soybean-wheat cropping systems compared to N75% RDF.

Soybean yield was relatively higher under no tillage (T2) which was on par with reduced tillage +residue retention (T3, T4 and T5). However, nutrient doses showed significant effect of soybean yield. STCR based fertilizer application recorded significantly higher yield compared to N2 (100% RDF) and N1 (75% RDF) (Table 1.19).

Table 1.19: Effect of different tillage and nutrient doses on yield of different crops during 2021-22

Treatment	**Grain Yield**	
	Soybean*	**Wheat**
	(q/ha)	**(q/ha)**
Tillage		
T1 – NT with 30cm height residue	17.97	53.81
T2 – NT with 60cm height residue	19.12	53.69
T3 – RT with 30cm height residue	18.98	52.98
T4 – RT with 60cm height residue	17.61	55.62
T5 – CT (Conventional Tillage)	18.52	53.38
Mean	18.37	53.90
Nutrient levels		
N1- 75% RDF	16.32	48.11
N2-100% RDF	19.01	54.51
N3- STCR dose	19.96	59.07
Mean	18.37	53.90
C.D. (P< 0.05)		
Tillage System (TS)	0.806	NS
Nutrient Dose (ND)	0.839	0.647

Effect of conservation tillage practices on crop yield after 11 crop cycles

This long-term experiment is continuing at the experimental farm of the Institute for the last ten years with two tillage treatments namely conventional tillage (CT) with residue removed and no tillage (NT) with residue retained along with Soybean- Wheat cropping systems. After completion of 11 crop cycles, crop yields were recorded and converted into soybean grain equivalent yield (SGEY, q ha^{-1}). During *kharif* season, tillage system did not have significant effect on crop yield but cropping system had significant effect on crop yield. During Rabi season, tillage and cropping system had significant effect on gram yield after 11 crop cycles.

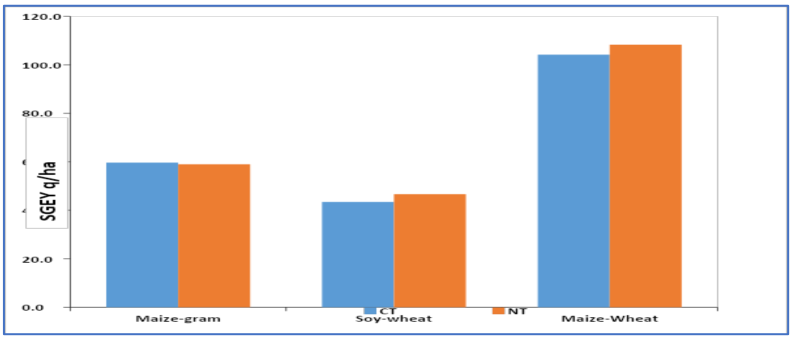


Fig 1.36: Effect of conservation agricultural practices on soybean grain equivalent yield (q ha^{-1}) after 11 crop cycles (2021-22) (MSP/Q; Soybean Rs 3950, Maize Rs 1870, WheatRs 1975; Gram Rs 5230)

Maize-Chickpea Cropping Systems

This field experiment was initiated during *kharif* 2015 in maize-chickpea cropping systems with five different tillage treatments, viz. T1: No Tillage (NT) with 30cm height of crop residue retention, T2: No Tillage (NT) with 60cm height of crop residue retention;, T3: Reduced Tillage with 30cm height of crop residue retention, T4: Reduced Tillage with 60cm height residue and T5: Conventional Tillage (CT)/Farmers practices with three nutrient doses namely N1:75% of the recommended dose of fertilizer (RDF), N2:100% RDF, N3: Soil test based recommendation. The experiment was taken in split plot design with three replications. Test crops (maize, chick pea) were sown using happy seeder during rainy and winter seasons by adopting standard package of practices (Plate 1.60). Biometric observations and yield parameters were recorded. Following cultivars were used - maize cultivar: Nath Samrat, Gram cultivar: JS 13.
In the *kharif* season, maize yield ranged between 48.57-49.83 q/ha (Table 1.20). Among the *rabi* season crops, chickpea yield varied between 16.76 and 17.53 q/ha (Table 1.20). Higher (balanced) nutrient application through 100%RDF and STCR dose recorded significantly higher grain yield under maize-gram cropping systems compared to N75% RDF.

Table 1.20 Effect of different tillage and nutrient doses on yield of different crops during 2021-22

Treatment	**Grain Yield**	
	Maize	**Gram**
	(q/ha)	**(q/ha)**
Tillage		
T1 – NT with 30cm height residue	49.83	17.43
T2 – NT with 60cm height residue	48.90	17.53
T3 – RT with 30cm height residue	48.77	17.01
T4 – RT with 60cm height residue	48.57	17.13
T5 – CT (Conventional Tillage)	48.84	16.76
Mean	48.98	17.17
Nutrient levels		
N1- 75% RDF	43.83	14.49
N2-100% RDF	50.24	17.57
N3- STCR dose	52.87	19.45
Mean	48.98	17.17
C.D. (P< 0.05)		
Tillage System (TS)	NS	NS
Nutrient Dose (ND)	0.856	1.357

Effect of conservation tillage practices on crop yield after 11 crop cycles

This long-term experiment is continuing at the experimental farm of the Institute for the last ten years with two tillage treatments namely conventional tillage (CT) with residue removed and no tillage (NT) with residue retained along with cropping systems namely Maize- Gram. During *kharif* season, tillage system did not have significant effect on crop yield but cropping system had significant effect on crop yield. During Rabi season, tillage and cropping system had significant effect on gram yield after 11 crop cycles (Fig 1.68).

Plate 23: Experimental plots under different tillage system

CRIDA

1. Pigeonpea + Setaria – Maize + cowpea system

The experiment was 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. In 2013 dhaincha a green manure crop was introduced between pigeonpea and castor crops as live mulch. In 2021 without changing the lay out the cropping system was changed to Pigeonpea+setaria – Maize+cowpea rotation. This year Maize +cowpea intercropping system was evaluated on different levels of pigeonpea and kora 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 pigeonpea crop and Foxtail millet at different heights (0 cm, 10 cm and 30 cm) to increase the residue contribution to the field. In the subplots the intercrop cowpea was introduced in 10 and 30 cm. The germination of both the crops maize and cowpea were good (Plate 1). The crop suffered from moisture stress during the initial stages. Zero tillage and reduced tillage recorded 19 and 4 % higher maize equivalent yields as compared to conventional respectively. The maize equivalent yields in 10 and 30 cm anchored residues recorded significantly higher yield as compared to no residues. 10 and 30 cm height crop residues recorded 23 and 20 % higher yield as compared to no residue. ((Fig. 1.37)

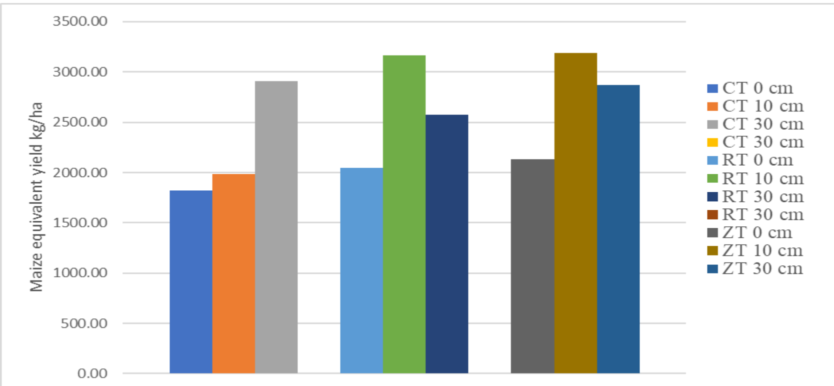


Fig 1.37: Influence of tillage and residue levels on maize equivalent yield

Weed growth **No weed growth with cowpea as Intercrop**

Plate 24: Strategies for enhancing residue retention in Rainfed region

CRIDA

2. Pigeonpea - Finger millet

The experiment was initiated in 2021 with in pigeonpea - finger millet sequence cropping in rainfed ecosystem at Bangalore (plate 3). Among different tillage practices, conventional tillage recorded significantly higher finger millet grain and straw yield (2486 & 3679 kg ha^{-1}) compared to zero tillage (2085 & 3086 kg ha^{-1}) but was on par with reduced tillage (2367 & 3503 kg ha^{-1}). Higher net returns (Rs.6021 ha^{-1}), and rain water use efficiency (2.98 kg ha-mm^{-1}) were recorded with conventional tillage as compared to reduced tillage (Rs.58141& 2.73 kg ha-mm^{-1}) and zero tillage (Rs.51802, & 2.73 kg ha-mm^{-1}).

Sunhemp

Horsegram

Finger millet under conventional tillage

Finger millet under reduced tillage

Plate 25: Performance of Finger millet in different treatments

Table 1.21: Biomass yield of cover crop under conservation agriculture

Treatment	Yield (t/ha)	
	C_2: Sun hemp	C_3: Horse gram
M_1: Conventional tillage	14.3	16.8
M_2: Reduced tillage	13.0	15.4
M_3: Zero tillage	11.5	12.0

Table 1.22: Yield, economics and water use efficiency influenced by conservation agriculture practices in finger millet under pigeonpea - finger millet sequence cropping system

Treatments	Finger millet Yield (kg ha^{-1})		CoC (Rs. ha^{1})	Net Returns (Rs. ha^{1})	B: C ratio	RWUE (kg hamm^{1})
	Grain	Straw				
Tillage practice						
M_1: Conventional tillage	2486	3679	23008	60212	3.62	2.98
M_2: Reduced tillage	2367	3503	21108	58141	3.75	2.92
M_3: Zero tillage	2085	3086	18008	51802	3.88	2.73
S. Em. ±	**17.60**	**26.06**				
CD (p=0.05)	**69.10**	**102.31**				
Cover crop						
C_1: Control	2192	3244	19458	53937	3.79	2.70
C_2: Sun hemp	2331	3450	20958	57095	3.74	2.89
C_3: Horse gram	2414	3573	21708	59122	3.73	3.04
S. Em. ±	**28.50**	**42.22**				
CD (p=0.05)	**87.90**	**130.10**				
Interaction						
M_1C_1	1586	3497	21758	57344	3.64	2.82
M_1C_2	2515	3722	23258	60934	3.62	2.97
M_1C_3	2580	3818	24008	62357	3.60	3.14
M_2C_1	2175	3219	19858	52959	3.67	2.68
$M2C_2$	2358	3489	21358	57580	3.70	2.95
M_2C_3	2568	3801	22108	63884	3.89	3.13
M_3C_1	2039	3018	16758	51510	4.07	2.60
M_3C_2	2122	3140	18258	52770	3.89	2.75
M_3C_3	2095	3100	19008	51126	3.69	2.86
S. Em. ±	**49.41**	**73.13**				
CD (p=0.05)	**NS**	**NS**				

M_1: Conventional tillage M_2: Reduced tillage M_3: Zero tillage
C_1: Control C_2: Sun hemp C_3: Horsegram

Growing horse gram as cover crop recorded significantly higher finger millet grain and straw yield, (2414 & 3573 kg ha-1) compared to control (2192 & 3244 kg ha-1) but was on par with sun hemp (2331, 2959, 168 & 3450 kg ha-1) (Table 1.22). Similar trend was observed with respect to net returns (Rs.59122 ha-1), benefit cost ratio (3.73) and rain water use efficiency (3.04 kg ha-mm-1). However, the interaction between tillage and cover crops was non-significant.

3. Maize –Pigeonpea System

CRIDA

An experiment was initiated with the integration of *in-situ* moisture conservation along with three principles of CA practices in maize-pigeonpea system in 2014. This year, the maize, test crop was laid out in RBD with different treatments (Conventional planting without residues, conventional tillage formation of raised bed every year, conventional planting with conservation furrow, CA flat sowing, permanent raised bed, CA+ permanent conservation furrows. The bed and furrows and conservation furrow were reshaped at the time of sowing in CA every year, whereas in conventional method, furrows and beds were prepared every year before sowing with the implements. Conventional tillage without residues recorded lowest yields.

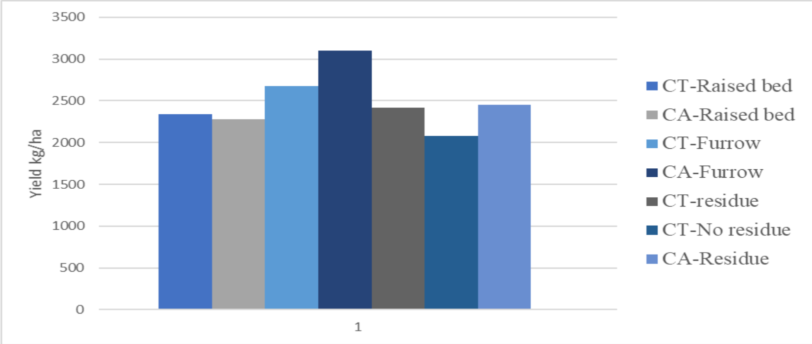


Fig 1.38: In-situ moisture conservation along with three principles of CA practices in maize-pigeonpea system

Integration of in-situ moisture conservation practices either through conservation furrow or bed and furrow method in both CA and Conventional tillage has recorded higher yield as compared to no moisture conservation treatments in both the crops. Among the conservation treatments permanent conservation furrow recorded higher yields (Fig 1.38). The higher yields in moisture conservation treatments were due to higher retention of soil moisture as compared to no moisture conservation.

Plate 26: Reshaping of a) Bed and furrow in Zero tillage b) Conservation furrow

4. Sorghum-Black gram system

CRIDA

A long-term experiment was initiated during 2013 with sorghum and black gram as test crops in yearly rotation at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad. The experiment was laid out in a split-plot design with two tillage systems: conventional (CT) and minimum (MT) in main plots and three residue retention treatments viz; no residue application (S0), retaining the residue by cutting the crop at 35 cm height (S1), retaining the residue by cutting the crop at 60 cm height (S2) in case of sorghum. For black gram crop, the residue retention treatments were no residue (S0), 50% residue retention (S1) (clearing of residue from alternate rows), 100% residue retention (S2).

Blackgram (variety PU 31) was grown in the year 2022 (plate 1.74). In the 10th year of the study, despite high yields, there were no significant differences in seed yield of blackgram with either tillage or residue retention (Table 1.23).

Plate 27: Blackgram (PU 31) crop with CT - conventional tillage (left) and MT - minimum tillage (right) under maximum residue retention (S2)

Table 1.23: Effect of tillage and residue management on grain yield of blackgram

Tillage	Residue	Seed yield (kg/ha)
Minimum tillage	S0: No residue application	1,407
	S1: Cutting at 35 cm height (1/3rd height)	1,424
	S2: Cutting at 60 cm height	1,338
Conventional tillage	S0: No residue application	1,082
	S1: Cutting at 35 cm height (1/3rd height)	1,085
	S2: Cutting at 60 cm height	1,126
CD (P=0.05)		
Tillage		NS
Residues		NS
T X R		NS

5. Soybean-Chickpea

CRIDA

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

The growth and yield attributes differed significantly among different crops (Table 1.24). Soybean yield, was significantly superior in T3 over other treatments however T1 and T3 were on par with each other. Whereas straw yield of soybean, were non-significant. The rainwater use efficiency was observed to be higher in the treatments T_3 and T_1 as compared to other treatments (Table 1.25).

Table 1.24: Growth, yield attributes and productivity of soybean as influenced by different treatment combinations during 2022

Treatments	Plant height (cm)	Number of pods / plant	Grain weight plant^{-1} (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	37.05	37.05	8.15	1728	2006
T_2	35.45	35.45	8.05	1582	1968
T_3	38.35	38.35	8.2	1863	2107
T_4	32.7	32.7	7.3	1369	1841
T_5	34.25	34.25	7.65	1453	1927
S. E. (m)	1.22	1.12	0.49	66.17	55.21
C.D. at 5%	3.81	3.48	N.A.	206.14	N.A.

Table 1.25: Productivity and Rain water use efficiency as influenced by different treatments in soybean crop during 2022

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Rain water use efficiency (kg ha^{-1}mm^{-1})
T_1	1728	2006	1.86
T_2	1582	1968	1.71
T_3	1863	2107	2.01
T_4	1369	1841	1.48

T_5	1453	1927	1.57

6. *Rabi* Chickpea

Chickpea grain and straw yield were significant among different treatments (Table 1.26). Chickpea yields were higher in T_3 and was significantly superior over T_4 and T_5 and were on par with T_1 and T_2. Whereas the straw yields were higher in T3 and were significantly superior over T_2, T_4, T_5 and was found at par with treatment T_1.

Table 1.26: Yield of chickpea as influenced by different treatment combinations 2022-23

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	1549	1738
T_2	1467	1625
T_3	1593	1828
T_4	1192	1374
T_5	1329	1505
S. E. (m)	71.35	57.57
C.D. at 5%	222.28	179.37

Plate 28: Sowing with BBF planter

Plate 29: Soybean crop in CT with crop residue mulch

Plate 30: Soybean crop in CT without crop residue mulch

Plate 31: Soybean in reduced tillage with crop residue mulch

	
Plate 32: Soybean in Zero tillage + crop residue mulch	*Plate 33: Permanent BBF, furrow after every 4 rows + crop residue mulch*

Plate 34: Performance of Soybean in different treatments

CRIDA

7. Foxtail millet- Greengram

A field experiment was started in Gunegal Research Farm of Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad during 2022. 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 ridge and furrow (soil and moisture conservation practice) and three residue retention treatments viz; Farmers' practice of harvesting close to the ground without any residue retention (S_1), Harvesting kharif and rabi crop at 20 cm height (S_2) and leaving the residues, harvesting only pods/panicles and retaining the entire residue (S_3). Setaria variety SiA 3222 was sown on 28thJune, 2022 and was harvested on 5thSeptember, 2022. WGG 42 Greengram crop was sown on 14thSeptember, 2022 and was harvested on 15thDecember, 2022. (plate 6). Zero tillage with ridge and furrow (T4) and Minimum tillage (T2) recorded 24 % and 19% higher yields respectively as compared to conventional tillage. Among different residue levels retention of entire residue (S3) has improved the system productivity by 27%.

 	
Conventional tillage with complete residue	Zero tillage with ridge and furrow with complete residue

Minimum tillage with complete residue

Zero tillage with ridge and furrow with complete residue

Plate 35: Crop growth in various treatments

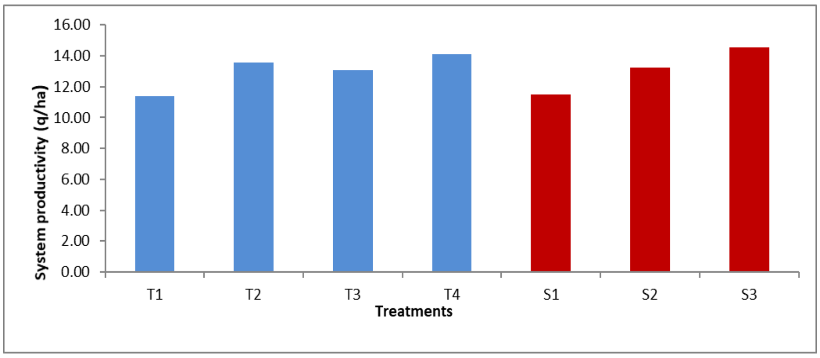


Fig 1.39: Effect of tillage practices and residue retention level on system productivity (q/ha)

C. Weed Management in Conservation Agriculture
Maize-Chickpea Cropping System

IISS

The experiment was conducted in a factorial randomized design to study the effect of different levels of crop residue retention and herbicide application in maize-chickpea cropping system. The treatments comprised of four levels of residue retention and four weed control treatments (table 1.27)

Table 1.27: Details of residue and nutrient level treatment

Factor. A↓/ Factor B→ Residue levels	**Herbicide treatment**	
	Chickpea	**Maize**
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%) without 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)

Response of different residue levels and herbicide treatments on chickpea crop

Weed species;

The dominant weed species present in the experimental field are presented in the table below

Table 1.28: Dominant weed species observed in the experimental field

Scientific name	Family	English name
Monocot weeds		
Dichanthiumannulatum	Poaceae	Santa Barbara grass
Asphodelustenuifolius	Asphodeloideae	Onion weed
Dicot weeds		
Anagallisarvensis	Primulaceae	Scarlet pimpernel
Cichoriumintybus	Asteraceae	Blue weed
Launaeaprocumbence	Asteraceae	Country dandelion
Medicagopolymorpha	Fabaceae	-
Viciahirsuta	Fabaceae	Hairy tare
Sonchusarvensis	Asteraceae	Sow thistle
Alternanthera sessile	Amaranthaceae	Sissoo spinach
Chenopodium album	Amaranthaceae	Lamb's quarters
Sedges		
Cyperusrotundus	Cyperaceae	Purple nut sedges

The data pertaining to weed density at 30 DAS presented in table 1.29 depicts significant effect on weed density as a result of different levels of crop residue retention. Maximum weed density (77.50 m^{-2}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (61.67 m^{-2}) ,60% crop residue retention (57.03 m^{-2}) and 90% crop residue retention treatment (52.69 m^{-2}). Different herbicidal weed control treatments showed significant influence on weed density. Under all residue levels, better weed control was observed in B1 (Imazethapyr) and B2 (Imazethapyr followed by hand weeding at 50 DAS) treatments. The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments varied but was not significant.

Table 1.29: 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	38.67	39.00	66.22	66.89	52.69
A2	44.44	42.33	71.44	69.89	57.03
A3	48.00	49.44	75.00	74.22	61.67
A4	64.22	63.11	91.56	91.11	77.50
MEAN OF B	48.83	48.47	76.06	75.53	
CD <0.05					
A	2.034	** 1%			
B	2.034	** 1%			
AB	4.067	NS			

Table 1.30: 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	67.00	27.22	45.67	29.33	42.31
A2	71.44	29.67	49.44	31.56	45.53
A3	74.67	33.11	53.33	36.56	49.42
A4	89.78	44.22	66.78	47.89	62.17
MEAN OF B	75.72	33.56	53.81	36.33	
CD 0.05					
A	2.246	** 1%			
B	2.246	** 1%			
AB	4.492	NS			

The data pertaining to weed density at harvest presented in table 1.30 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (62.17 m^{-2}) was recorded in no-residue treatment and significantly higher over 30% crop residue retention (49.42 m^{-2}), 60% crop residue retention (45.53 m^{-2}) and 90% crop residue retention treatments (42.31 m^{-2}). Among the weed control treatments, B_2 treatment (Imazethapyr followed by HW at 50 DAS) showed the best weed control efficacy. The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments varied but the interaction effect was not significant.

Table 1.31: Effect of different levels of crop residue retention and herbicidal weed control treatments on Weed biomass (kg ha^{-1}) in chickpea crop

	B1	B2	B3	B4	Mean of A
A1	1041.09	211.90	576.40	228.11	514.38
A2	1123.82	235.62	606.24	247.50	553.30
A3	1203.99	260.76	660.50	280.32	601.39
A4	1425.94	354.69	824.96	381.61	746.80
MEAN OF B	1198.71	265.74	667.03	284.39	
CD 0.05					
A	26.518	** 1%			
B	26.518	** 1%			
AB	53.037	** 1%			

The data pertaining to weed biomass presented in table 1.31 depicts significant effect on weed biomass as a result of different levels of crop residue retention. Maximum weed biomass (746.80 kgha^{-1}) was recorded in no-residue treatment and significant reduction in weed biomass was observed under 30% crop residue retention (601.39 kg ha^{-1}), 60% crop residue retention (553.30 kgha^{-1}) and 90% crop residue retention treatments (514.38 kgha^{-1}). At all residue levels, significantly lower weed biomass was observed under B2 treatment. The weed biomass as a result of interaction effect between residue levels and herbicidal weed control treatments varied significantly.

Table 1.32: 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	1263.83	1459.33	987.00	1093.83	1201.00
A2	1231.50	1431.50	971.00	1044.50	1169.63
A3	1209.00	1396.67	939.33	1026.00	1142.75
A4	943.33	1025.00	817.33	854.00	909.92
MEAN OF B	1161.92	1328.13	928.67	1004.58	
CD 0.05					
A	54.006	** 1%			
B	54.006	** 1%			
AB	108.012	* 5%			

The data pertaining to grain yield presented in table 1.32 depicts significant effect on grain yield as a result of different levels of crop residue retention. The maximum grain yield (1201.00 kgha^{-1}) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (1169.63 kgha^{-1}) and 30% crop residue retention (1142.75 kgha^{-1}) and significantly superior over without residue retention treatment (909.92 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 also varied significantly.

Plate 36: Effect of different levels of crop residue retention and herbicidal weed control treatments on Grain yield on chickpea crop

Response of different residue levels and herbicide treatments on maize crop

Weed species

The dominant weed species present in the experimental field are presented in the table below

Table 1.33: Dominant weed species present in the experimental field

Scientific name	Family	English name
Monocot weeds		
Commelinabenghalensis	Commelinaceae	Wandering jew
Commelinacommunis	Commelinaceae	Asiatic dayflower
Echinocloacolonum	Poaceae	Barnyard grass
Sorghum helepense	Poaceae	Johnson grass, Aleppo grass
Dicot weeds		
Digeraarvensis	Amaranthaceae	Pig weed
Acalyphaindica	Euphorbiaceae	Indian mercury
Euphorbia hypericifolia	Euphorbiaceae	Golden spurge
Euphorbia geniculate Ortega	Euphorbiaceae	Mexican fire plant
*Phyllanthusmaderaspatensis*L.	Euphorbiaceae	Madras leaf-flower
Sedges weed		
*Cyperusiria*L.	Cyperaceae	Rice sedge

Table 1.34: 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	27.56	53.33	54.67	55.00	47.64
A2	32.22	57.11	58.00	58.11	51.36
A3	37.78	61.78	62.78	62.44	56.19
A4	50.89	76.33	76.89	79.78	70.97
MEAN OF B	37.11	62.14	63.08	63.83	

CD 0.05					
A	2.406	** 1%			
B	2.406	** 1%			
AB	4.812	NS			

The data pertaining to weed density at 30 DAS presented in table 1.34 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (70.97 m^{-2}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (56.19 m^{-2}), 60% crop residue retention (51.36 m^{-2}) and 90% crop residue retention treatment (47.64 m^{-2}). Different herbicidal weed control treatments showed significant influence on weed density. Lowest weed density was observed under B1 treatment across residue treatment levels.

Table 1.35: Effect of different levels of crop residue retention and herbicidal weed control treatments on weed density at harvest in maize (number m^{-2}) in maize crop.

	B1	B2	B3	B4	Mean of A
A1	49.89	27.00	23.11	4.89	26.22
A2	56.44	30.11	26.66	8.00	30.30
A3	62.00	33.00	30.00	11.11	34.03
A4	74.78	43.44	40.89	16.89	44.00
MEAN OF B	60.78	33.39	30.16	10.22	
CD 0.05					
A	1.354	** 1%			
B	1.354	** 1%			
AB	2.707	** 1%			

The data pertaining to weed density at harvest presented in table 1.35 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (44.00 m^{-2}) was recorded in without residue retention level and which was at par with 30% crop residue retention (34.03 m^{-2}) and significantly higher over 60% crop residue retention (30.30 m^{-2}) and 90% crop residue retention treatment (26.22 m^{-2}). Maximum weed control was observed under B4 treatment (Tembotrione@120g a.i. ha^{1}+Atrazin @ 625g a.i. ha^{-1} (30 DAS) fb HW at 50 DAS) across all residue retention levels. The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments also varied significantly.

Table 1.36: 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	822.00	392.93	343.17	96.26	413.59
A2	896.10	418.03	372.82	119.29	451.56
A3	974.67	449.09	408.08	141.27	493.28
A4	1110.73	554.24	506.54	185.61	589.28
MEAN OF B	950.88	453.58	407.65	135.61	
CD 0.05					
A	14.227	** 1%			
B	14.227	** 1%			
AB	28.454	** 1%			

The data pertaining to weed biomass presented in table 1.36 depicts significant effect on weed biomass as a result of different levels of crop residue retention. The maximum weed biomass (589.28 kg ha^{-1}) was recorded in no-residue treatment, which was significantly higher as compared to 30% crop residue retention (493.28 kg ha^{-1}), 60% crop residue retention (451.56 kg ha^{-1}) and 90% crop residue retention treatment (413.59 kg ha^{-1}). Lowest weed biomass was observed under B4 treatment. The weed biomass as a result of interaction effect between residue levels and herbicidal weed control treatments also varied significantly.

Table 1.37: 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	4456.00	5315.67	5389.33	6021.00	5295.50
A2	4358.67	5203.00	5266.33	5436.33	5066.08
A3	4139.50	4837.00	4964.67	5364.00	4826.29
A4	3915.00	4071.83	4179.83	4530.33	4174.25
MEAN OF B	4217.29	4856.88	4950.04	5337.92	
CD 0.05					
A	252.440	** 1%			
B	252.440	** 1%			
AB	504.881	NS			

The data pertaining to grain yield presented in table 1.37 depicts significant effect on grain yield as a result of different levels of crop residue retention. The maximum grain yield (5295.50 kg ha^{-1}) was recorded in 90% crop residue retention level, which was significantly superior over 60% crop residue retention (5066.08 kg ha^{-1}), 30% crop residue retention (4826.29 kg ha^{-1}) and no-residue treatment (4174.25 kg ha^{-1}). Among herbicidal treatments, highest grain yield was observed under B4 treatment. The grain yield as a result of interaction effect between residue levels and herbicidal weed control treatments varied and was not significant.

Table 1.38: 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	7107.32	8252.48	8288.95	8899.82	8137.14
A2	7021.02	8249.06	8219.48	8249.17	7934.68
A3	6792.43	7634.37	7788.15	8361.04	7644.00
A4	6700.57	6667.84	6852.26	7317.04	6884.43
MEAN OF B	6905.33	7700.94	7787.21	8206.77	
CD 0.05					
A	402.550	** 1%			
B	402.550	** 1%			
AB	805.099	NS			

The data pertaining to stover yield presented in table 1.38 depicts significant effect on stover yield as a result of different levels of crop residue retention. The maximum stover yield (8137.14 kg ha^{-1}) was recorded in 90% crop residue retention level and significantly superior over 60% crop residue retention (7934.68 kg ha^{-1}), 30% crop residue retention (7644.00 kg ha^{-1}) and without residue retention treatment (6884.43 kg ha^{-1}). Stover yield was highest under B4 treatment across all residue retention levels.The interaction effect of residue level and herbicidal weed control was not significant.

Plate 37: Effect of different levels of crop residue retention and herbicidal weed control treatments on maize crop

C. Water Management in Conservation Agriculture

Soybean-Wheat Cropping Systems

IISS

Wheat crop 2021-2022

During the winter season, wheat (cv. HI 1544) was grown with three methods of irrigation (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. Flood irrigated plots in wheat received 5 post sowing irrigations and a seasonal total of 416 mm water was applied. In sprinkler irrigation plots a measured total amount of 355 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 290 mm of irrigation water (about 60% of the flood irrigation water) was applied through drip system at alternate day interval throughout the season. Better temporal distribution of irrigation water and consequently better profile moisture distribution could be attained in sprinkler and drip systems with less but more frequent irrigation water application to wheat. Data showed that grain and straw yield of wheat did not vary significantly among the irrigation method, tillage system and different nutrient doses.

Table 1.39: Effect of tillage systems and different nutrients doses under different irrigation systems on wheat 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 (%)**
Irrigation methods			
Flood	5256	5179	0.50
Sprinkler	5155	5230	0.50
Drip	4745	4923	0.49
LSD (0.05)	NS	NS	NS
Tillage systems			
CT	4933	5059	0.49
RT	5058	5085	0.50
NT	5156	5188	0.50
LSD (0.05)	NS	NS	NS
Nutrients Doses			
100% RDF	5092	5106	0.50
75% RDF	4747	4902	0.49
STCR dose	5307	5358	0.50
LCC dose	5063	5076	0.50
LSD (0.05)	279.8	337.98	NS

Plate 38: Field experiment view of development of Water and Nutrient Management Practices in rabi season 2021-2022

Soybean Crop 2022

The field experiment conducted on soybean crop in kharif season in year 2022. There were three levels of fertilizer treatments (F_1=100 % RDF, F_2=75% DRF, F_3=STCR and three levels of tillage treatment (CT-Conventional tillage, RT-Reduced tillage and NT- No tillage) were tested. The soybean variety of RVS 2001-4 was sown on22 June, 2022 and harvested in the month of October, 2022. The grain and straw yield of soybean (1098 and 3350 kg ha^{-1}) was slightly higher under reduced tillage system as compared conventional tillage. The lowest grain and straw yield were recorded under no tillage (1036 and 3060 kg ha^{-1}) but all the tillage systems were significantly at par. Similarly, in case of fertilizer treatments, the STCR dose recorder slightly higher grain yield of soybean (1080 and 3260 kg ha^{-1}) followed by 100% RDF and less yield was in 75% RDF (1039 and 3020 kg ha^{-1}). However, all the fertilizer treatments were also significantly at par. The interaction effect of tillage systems and different nutrient doses was found non-significant (Table 1.40). Conservation agriculture system-maintained yield level on par with the conventional agricultural practices with concomitant savings of time, labour and input cost and improvement in soil health parameters and sustainability of yield. (Plate 1.81)

Table 1.40: 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})**			
	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	1085	1013	1056	1051	3130	3010	3160	3100
RT	1103	1055	1136	1098	3540	3030	3490	3350
NT	1011	1049	1048	1036	3030	3030	3130	3060
Mean	1067	1039	1080		3230	3020	3260	
	Tillage: NS, Nutrient Dose: NS, Tillage x Fertilizer dose: NS				Tillage: NS, Nutrient Dose: NS, Tillage x Fertilizer dose: NS			

Plate 39: View of soybean sowing and crop performance in 2022

4. Nutrient Management in Conservation Agriculture
Soybean–Wheat Cropping System

The experiment was conducted in a factorial randomized design to study the effect of different levels of crop residue retention and optimum doses of nutrient application in soybean-wheat cropping system. The treatments comprised of four levels of residue retention and optimized doses of nitrogen, phosphorus and potassium application as compared to 100% nutrient application (table 1.41)

Table 1.41: Details of residue and nutrient level treatment

Factor. A↓/ Factor B→ Residue levels	Nutrient level treatment	
	Soybean	Wheat
A_1(90%) Crop residue	B_1. 25:60:40 kg ha^{-1} N, P_2O_5, K_2O	B_1. 120:60:40 kg ha^{-1} N, P_2O_5, K_2O
A_2(60%) Crop residue	B_2. 15:60:40 kg ha^{-1} N, P_2O_5, K_2O	B_2. 90:60:40 kg ha^{-1} N, P_2O_5, K_2O
A_3(30%) Crop residue	B_3. 25:45:40 kg ha^{-1} N, P_2O_5, K_2O	B_3. 120:45:40 kg ha^{-1} N, P_2O_5, K_2O
A_4(0%) without Crop residue	B_4. 25:60:30 kg ha^{-1} N, P_2O_5, K_2O	B_4. 120:60:30 kg ha^{-1} N, P_2O_5, K_2O

Grain yield of Wheat crop

The data pertaining to grain yield of wheat crop (table 1.42) shows significant differences in grain yield as a result of different levels of crop residue retention. The maximum yield (6215.67kg ha^{-1}) was recorded in 90% residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 5772.22, 5368.92, 5158.19 kg ha^{-1}, respectively and the lowest grain yield (5158.19 kg ha^{-1}) was observed in without residue treatment. In case of various levels of nutrient applications there was nonsignificant effect of nutrient doses on grain yield and the grain yield varied between (5554.44 to 5766.53 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant effect on grain yield (Table 1.42). The highest grain yield (6600 kg ha^{-1}) in 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (5077.78 kg ha^{-1}) 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 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	6600.00	5989.22	6029.00	6244.44	6215.67
60% R	5733.33	5911.11	5777.78	5666.67	5772.22
30% R	5500.01	5275.78	5277.67	5422.22	5368.92
WR	5232.78	5077.78	5133.33	5188.89	5158.19

Mean	5766.53	5563.47	5554.44	5630.56	
CD 0.05					
Residue	363.004	** 1%			
Nutrient	363.004	NS			
Residue x Nutrient	726.008	NS			

Straw yield

The data pertaining to straw yield of wheat crop (table 1.43) shows significant differences in straw yield as a result of different levels of crop residue retention. The maximum straw yield (9738.94 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 9356.75, 8801.75, 8265.75kg ha^{-1} respectively and the lowest straw yield (8265.75 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 straw yield and the straw yield varied between (8872.05 to 9293.69 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on straw yield as a result of different residue levels and nutrient doses (Table 1.43). The highest straw yield (10025kg ha^{-1}) recorded from 90% crop residue with 100%RDF treatment, was statistically at par with other residue levels. The lowest straw yield (8872 kg ha^{-1}) was observed in no-residue treatment with 75% N, 100% P, K doses.

Table 1.43: Effect of different levels of crop residue and nutrient doses on straw 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	10024.61	9565.67	9676.42	9689.07	9738.94
60% R	9390.80	9405.21	9328.00	9303.00	9356.75
30% R	9087.33	8599.00	8728.00	8792.67	8801.75
WR	8672.00	7918.33	8021.00	8451.67	8265.75
Mean	9293.69	8872.05	8938.35	9059.10	
CD 0.05					
Residue	159.250	** 1%			
Nutrient	159.250	** 1%			
Residue x Nutrient	318.501	NS			

Plate 40: Effect of different levels of crop residue and nutrient doses on wheat crop

Soybean crop

Seed yield

The data on grain yield of soybean crop (table 1.44) shows significant differences in grain yield as a result of different levels of crop residue retention. The maximum yield (1276 kg ha^{-1}) was recorded in 90% residue retention treatment which was significantly superior to 60%, 30% and no-residue treatment with the mean value of 1197.38, 1128.83, 1054.50 kg ha^{-1}, respectively and the lowest grain yield (1054.50 kg ha^{-1}) was observed in no-residue treatment. 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 (1132.08 to1195.58 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 (1332.67 kg ha^{-1}) was obtained from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (1017 kg ha^{-1}) was observed in no-residue treatment 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 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	1332.67	1234.33	1258.33	1280.00	1276.33
60% R	1227.33	1164.67	1190.83	1206.67	1197.38
30% R	1140.67	1112.33	1125.00	1137.33	1128.83
WR	1081.67	1017.00	1055.33	1064.00	1054.50
Mean	1195.58	1132.08	1157.38	1172.00	
CD 0.05					
Residue	19.626	** 1%			
Nutrient	19.626	** 1%			
Residue x Nutrient	39.251	NS			

Straw yield

The data pertaining from straw yield of soybean crop (table 1.45) shows no significant differences in straw yield as a result of different levels of crop residue retention. The maximum straw yield (2493.21 kg ha^{-1}) was recorded in 90 % residue retention treatment which was at par with rest of the residue levels and he lowest straw yield (1991.21 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 straw yield and the straw yield varied between (2195.21 to 2286.71 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on straw yield as a result of different residue levels and nutrient doses (Table 1.45). The highest straw yield (2608.50 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 (1950.00 kg ha^{-1}) was observed in without crop residue with 75% N, 100% P, K doses.

Table 1.45: Effect of different levels of crop residue retention and nutrient doses on straw 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	2608.50	2430.17	2466.67	2467.50	2493.21
60% R	2315.00	2300.67	2394.17	2250.83	2315.17
30% R	2144.17	2100.00	2093.17	2104.33	2110.42
WR	2079.17	1950.00	1964.00	1971.67	1991.21
Mean	2286.71	2195.21	2229.50	2198.58	
CD 0.05					
Residue	45.063	** 1%			
Nutrient	45.063	** 1%			
Residue x Nutrient	90.125	* 5%			

Plate 41: Effect of different levels of crop residue retention and nutrient doses on Soybean crop

CRIDA

Maize –Pigeonpea system

To optimize the tillage practices and nitrogen levels for improving the soil health in dryland farming system (maize-pigeonpea crop rotation) and farm productivity and profitability, an experiment was initiated in 2012. Maize was sown during *kharif* 2022. Experiment was laid out in split plot with three tillage practices, as main plots *viz.* 1. Conventional Tillage- Summer ploughing + Cultivator +Disc harrow before sowing and no residue retention of previous pigeopea crop. 2. Reduced Tillage- One-time cultivator+ Disc harrow before sowing+ Residue retention up to 30 cm plant height of previous pigeopea crop and 3. No Tillage- Direct sowing + Residue retention up to 30 cm stem height of previous pigeonpea crop. Four nitrogen levels, viz. 1. No Nitrogen (N-0). 2. 75% of the recommended dose of nitrogen (N-75). 3. 100% of the recommended dose of nitrogen (N-100) and 4. 125% of the recommended dose of nitrogen (N-125) as sub plots.

This year maize crop was sown (plate 42). Results revealed that both tillage practices and nitrogen management did not influence the seed germination of maize. NT and RT recorded 20.7 and 10.5% higher mean maize grain yield respectively as compared to CT. NT recorded 9.2 % higher seed yield over RT. The increase in the nitrogen levels enhanced the seed yield significantly. Due to continuous omission of the nitrogen in control plot (N-0) since last 10 years the yield very low as compared to the other nitrogen levels. The maize grain yield in N-0, N-75, N-100 and N-125 were 231.2, 2668.1, 3326.3 and 3639.9 kg ha^{-1}, respectively. The interactive effect of tillage practices and nitrogen levels found to be non-significant (Fig. 1.40).

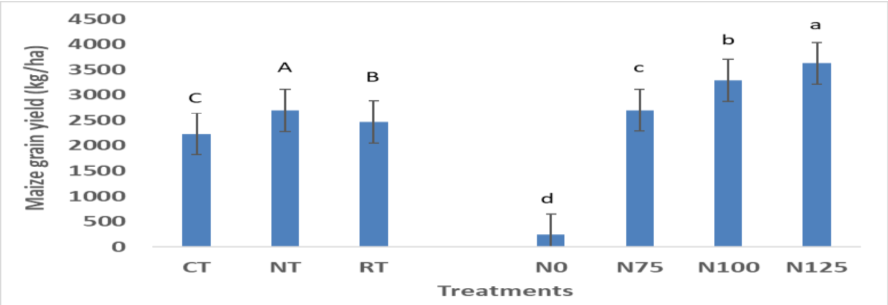


Fig 1.40: Mean effect of tillage practices and nitrogen levels on maize grain yield (kg/ha).

Plate 42: Maize crop growth in the no-tillage plot along with N125% RDN.

2. Pearlmillet – Horsegram/ Pigeonpea

A field experiment was conducted since 2016 in sandy loam soil of Gunegal Research Farm at ICAR-Central Research Institute for Dryland Agriculture (ICAR-CRIDA), Hyderabad with different treatments: zero tillage (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}), Horsegram on residual fertility, Pigeon pea: 20-50-0 kg N, P_2O_5, K_2O 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) (plate 8). Short duration (75-80 days) pearlmillet (MP MH21) was selected to take the advantage of early sowing of horsegram and increase cropping intensity. In pearlmillet (PM)-horsegram (HG) sequence-pigeonpea (PP) rotation: Significantly higher yield was obtained in ZT (1100 kg/ha) as compared to CT (831 kg/ha) in 2022 (Fig 1.41).

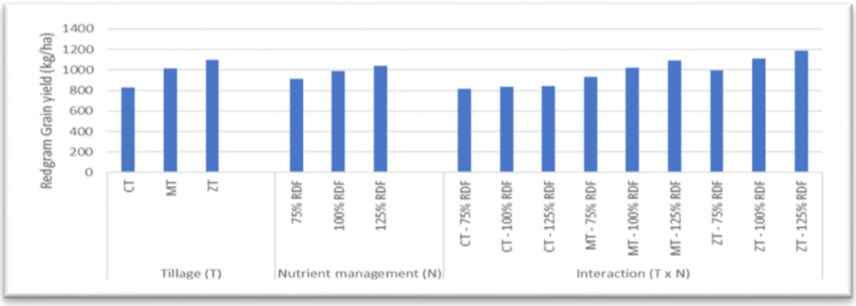


Fig. 1.41: Effect of tillage and different fertilizer doses on pigeon pea yield

Plate 43: Effect of tillage and nutrient management in pigeon pea

3. Cotton – Pigeonpea system

In cotton- pigeonpea system, the RDF of 120-60-60 kg N, P_2O_5, K_2O ha^{-1} was applied. (plate 9). Significantly higher seed cotton yield was observed in ZT (2686 kg/ha) followed by MT (2420 kg/ha) and CT (2339 kg/ha), Where as in nutrient management 125% RDF reported significantly higher seed cotton yield (2571 kg/ha) which was on par with 100% RDF (2523 kg/ha) followed by 75% RDF (2352 kg/ha) (Fig. 1.42).

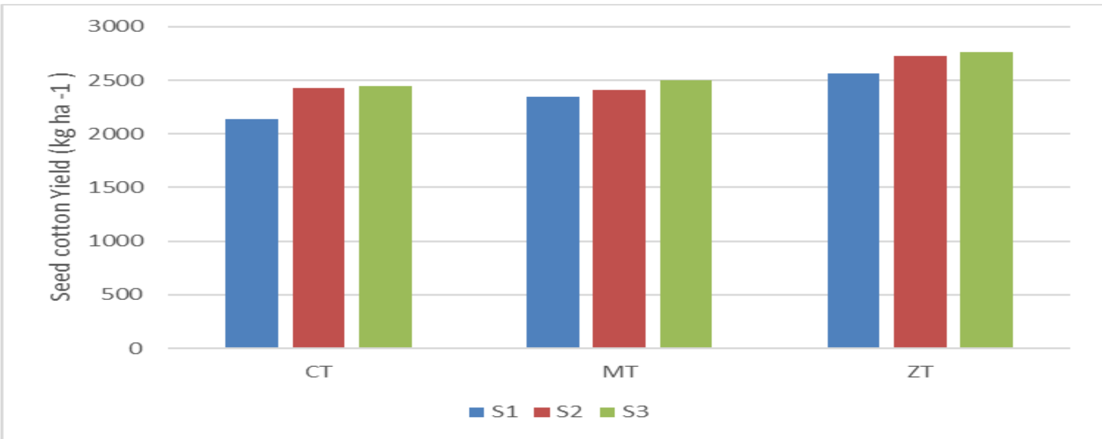


Fig 1.42: Effect of tillage and different fertilizer doses on seed cotton yield

Plate 44: Effect of tillage and nutrient management in cotton

CRIDA

Pigeonpea Crop

An experiment was initiated at CRIDA with integration of in situ moisture conservation and weed control along with CA practices as complimentary practices. Pigeonpea was the test crop. This year integration of in situ moisture conservation practices through permanent bed and furrow, permanent conservation furrow recorded 15 and 40 % higher pigeonpea yields as compared to conventional tillage without moisture conservation. Among the weed control treatments pre-emergence + post emergence herbicide application recorded higher yields as compared to other weed management practices. Reduction in crop yield in un weeded treatment in ZT normal sowing was higher than in conventional tillage and Zero tillage with in situ moisture conservation. It was observed that ZTF recorded higher yield in control since dhaincha is grown as intercrop. (Fig. 1.43)

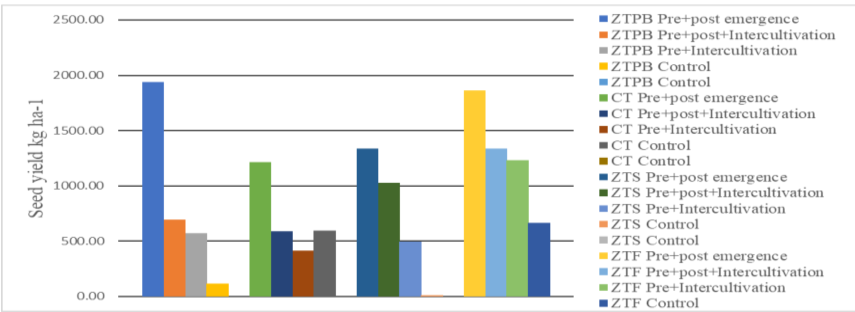


Fig 1.43: Influence of different treatments on pigeonpea seed yield

NIASM

Sugarcane responses to plant growth regulators and deficit irrigation under conservation agricultural practices

A new experiment to study the interaction effects plant growth regulators (PGRs) and deficit irrigation (DI) was established in sugarcane (Variety: Co–86032) cropping system during year 2022. The CA practices of crop residue management and tillage were imposed in recently harvest crop. The main treatments included three DIlevels i.e. 50% ETc; 75% ETc and 100% ETc (full irrigation) were applied using subsurface drip irrigation system. Two soil surface cover (mulching) practices *viz.*, S1: crop residue covering and S2: no residue was accommodated in subplots. Four PGRs namely thio-urea (TU, 1800 ppm), irradiated chitosan (IC, 5 ml/L), nano-urea (NU, 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) for alleviating water stress as sub-sub plot treatments. The real time crop-soil-water parameters were measured with interval of 30-45 days interval. The preliminary results of IC and NU at 75% ETc seems to promising for enhancing the growth attributes and cane yields of plant sugarcane.

Optimizing planting geometry, intercropping and crop residue management in sub-surface drip irrigation

In year 2022, field experiment was repeated to optimize the effect of zigzag paired row planting, subsurface drip irrigation and intercropping (groundnut-fenugreek) with aim of enhancing productivity of ratoon sugarcane (Co-86032) cropping system. The main plot treatments included, M1: Zigzag Paired Row (ZPR) with (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,180 cm) + 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 first-year results showed 39.5, 51.3 and 28% improvement in yields of groundnut, fenugreek and sugarcane in M5S1 treatments in comparison to M3S2, respectively indicating possibility of improving productivity sugarcane cropping system.

Objective 2: Quantification of tangible and non-tangible effects

1. Physical Property

A. Mean Weight Diameter (MWD)

IARI

Cotton-wheat system: After tenth year of cropping system, it was observed that under CA practices cotton-wheat cropping system at ICAR-Indian Agricultural Research Institute (IARI), there was improvement in the mean weight diameter (MWD) of soil at 0-5 and 5-15 cm soil depth by 13.9, 58%, respectively and water stable aggregate percentage (WSA) by 0.43 and 1.4%, respectively compared to the conventional tillage system in cotton-wheat system (Table 2.1). Among the CA systems retention of crop residues could improve the MWD at 0-5 and 5-15 cm soil depth by 16.7 and 2.6%, respectively. Among the landform treatments, broad bed system registered higher MWD and WSA than Narrow-bed system at 0-5 cm soil depth. Among the CA practices i.e. zero tilled flatbed with residue retention registered highest MWD at 0-5 and 5-15 cm soil depth.

Table 2.1: Mean weight diameter (mm) of water stable aggregates under conservation and conventional agriculture practices.

Treatment	Mean weight diameter (mm)			Water stable aggregates (%)		
	0-5 cm	5-15 cm	15-30 cm	0-5 cm	5-15 cm	15-30 cm
Zero tillage (ZT)	0.98[b]	0.77[a]	0.78[ab]	67.30[b]	69.0	62.80[b]
ZT + Residue	1.19[a]	0.81[a]	0.71[bc]	68.30[b]	66.9	63.00[b]
PBB + Residue	0.97[b]	0.78[a]	0.62[c]	65.30[bc]	63.3	74.20[a]
Broad bed (BB)	0.76[d]	0.76[a]	0.65[c]	80.70[a]	66.5	62.50[b]
PNB + Residue	0.78[d]	0.77[a]	0.62[c]	63.30[bc]	65.1	57.50[b]
Narrow bed (NB)	0.77[d]	0.79[a]	0.73[bc]	57.90[c]	71.7	74.10[a]
Flatbed (FB)	0.86[c]	0.50[b]	0.88[a]	65.20[bc]	63.7	81.10[a]
Mean	0.90	0.74	0.71	66.86	66.60	67.89
P Value	<.0001	<.0001	<.0001	<.0001	0.0738	<.0001
CA vs CT						
CA	0.98	0.79	0.65	65.63	65.10	64.90
CT	0.86	0.50	0.88	65.20	63.70	81.10
P Value	<.0001	<.0001	<.0001	0.8414	0.5235	<.0001

Residue vs no-residue						
R+	0.98	0.79	0.65	65.63	65.1	64.90
R0	0.84	0.77	0.72	68.63	69.07	66.47
P Value	<.0001	0.4980	0.0029	0.0684	0.0219	0.3305
PBB vs PNB						
PBB	0.87	0.77	0.64	73.00	64.90	65.80
PNB	0.78	0.78	0.68	60.60	68.40	68.35
P Value	<.0001	0.2761	0.1084	<.0001	0.0822	0.2026

B. Aggregate Size distribution

RCER

Soil aggregation got affected significantly due to the adoption of different CERM practices at RCER, Patna. However, effect was limited to 0–15 cm soil layers (Table 2.2). Among the tillage treatments, ZTDSR resulted in 74 and 77% higher (p<0.05) MWD of aggregate compared to CTDSR & PTR, respectively. Similarly, macroaggregate content in ZTDSR was higher by 14-16% than others but was statistically at par. In contrast, a reduction (31-32%) in microaggregate content was noted in ZT-DSR. Water stable aggregate contents were comparable among treatments and varied between 86-87%. Among different cropping systems, rice-mustard system registered the highest MWD of aggregates (0.77 mm), while the lowest (0.59) with rice-safflower system. Crop residue had favourable changed soil aggregation & increased MWD of aggregates & macroaggregate content by 17 and 8%, respectively to non-residue retained treatments. Similar trends were noted for diverse tillage practice in 15-30 cm soil layer. However, better aggregation characteristics were noted for rice-linseed & rice-safflower system in lower soil layer but statistically at par.

Table 2.2: Aggregation characteristics as affected by diverse crop-establishment-cum-residues management (CERM) under rice fallows of eastern India

Treatments	MWD	MacA	MicA	WSA	MWD	MacA	MicA	WSA
	0-15 cm				15-30 cm			
[ZTDSR-ZT] R-	0.832^{AB}	62.3ns	21.2ns	83.5ns	0.909ns	74.3ns	17.3ns	91.6ns
[ZTDSR-ZT] R+	1.099^{AB}	69.5	18.7	88.3	0.663	57.3	30.8	88.1
[CTDSR-ZT] R-	0.544^{B}	54.8	31.9	86.7	0.678	62.6	23.8	86.5
[CTDSR-ZT] R+	0.567^{B}	61.2	27.0	88.2	0.561	60.3	29.7	90.0
[TPR-ZT] R-	0.530^{B}	57.0	28.7	85.8	0.617	71.9	15.1	87.0
[TPR-ZT] R+	0.563^{B}	57.0	28.7	85.7	0.677	65.6	22.9	88.5
ZTDSR	0.965^{A}	65.9ns	19.9ns	85.9ns	0.786ns	65.8ns	24.1ns	89.9ns
CTDSR	0.556^{B}	58.0	29.4	87.4	0.619	61.4	26.8	88.2
TPR	0.546^{B}	57.0	28.7	85.7	0.647	68.7	19.0	87.8
Residue	0.743ns	62.6ns	24.8ns	87.4ns	0.634ns	61.1ns	27.8ns	88.9ns
No residue	0.635	58.0	27.3	85.3	0.734	69.6	18.8	88.4
Chickpea	0.732ns	63.8ns	20.8ns	84.6ns	0.644ns	69.3ns	17.8ns	87.1ns
Lentil	0.632	52.0	32.4	84.4	0.533	64.4	25.2	89.6
Safflower	0.592	58.8	28.5	87.3	0.815	69.3	20.3	89.6
Linseed	0.720	70.3	19.8	90.1	0.808	68.4	21.1	89.5
Mustard	0.769	56.7	28.7	85.4	0.621	55.3	32.0	87.3

MWD: mean weight diameter of aggregates; MacA: macro-aggregate; MicA: micro-aggregate; WSA: water stable aggregate; ZT: zero-till; ZTDSR: zero-till-direct seeded rice; CTDSR: conventional-till-direct seeded rice; TPR: transplanted puddle rice; R+: crop residue (30%RT); R-: without residue/control; R-S: rice-safflower; R-M: rice-mustard; Mean values followed by different capital letters within a column are significantly different at p<0.05 by Tukey's HSD test.

IARI

The conservation agriculture (CA) plots had higher cumulative carbon mineralization rate over conventionally tilled (CT) plots in bulk soils, macroaggregates and microaggregates. After ten years, at ICAR-Indian Agricultural Research Institute (IARI), the plots under PBB+R had ~39% higher macroaggregate-associated total SOC and ~52% more labile C within macroaggregates than CT plots in the topsoil indicating the capacity of better occlusion of C in macroaggregates (Table 2.3). The residue retained plots had ~17, 17 and 7% more SOC concentrations within the macroaggregates than their respective residue removal plots showing that residue retention had positively influenced the SOC pool in soil. The plots under PBB+R, PNB+R and ZT+R had ~28, 25 and 25% higher C concentration within cPOM_M fraction than the PBB, PNB and ZT plots, respectively. Long-term adoption of PBB+R treatment increased the iPOM_mM associated C by ~39 and 48% more than the CT treatment in the 0-5 and 5-15 cm soil depths, respectively which could provide more physical stabilization to the C in soil. Retention of residue enhanced the percentage of macroaggregates in the PBB+R, PNB+R, and ZT+R plots over the CT plot by ~35, 32 and 26%, respectively in the topsoil. Also due to residue retention, the proportion of macroaggregates increased by 18, 21, and 15% over the PBB, PNB, and ZT plots, respectively, in the 0-5 cm soil depth. Also the plots under PBB+R had ~31% higher microaggregates within macroaggregates in the 0-15 cm depth than the conventionally tilled (CT) plots (24.4 g 100 g^{-1} soil).

Table 2.3. Effect of long-term conservation agriculture on aggregate-associated C (g kg^{-1}) in 0-5 cm soil depth under a cotton-wheat cropping system in an Inceptisol

Treatments	Macroaggregates	Microaggregates	Silt+clay
CT	6.60	5.98	4.78
PNB	7.10	6.33	4.89
PNB+R	8.66	8.04	6.89
PBB	7.37	6.61	5.94
PBB +R	9.16	8.55	7.32
ZT +R	8.42	7.87	6.63
ZT	7.52	6.46	5.31
LSD (P=0.05)	1.04	1.03	0.50

C. Bulk density (BD)

CSSRI

The 17-year (2006-2023) long-term tillage and residue management experiment (LT&RE) at CSSRI, Karnal resulted the ZT+R (zero tillage with residue retention) treatment exhibited the lowest bulk density (1.45 Mg m^{-3}). Tillage and residue management (TRM) practices had a significant effect on soil bulk density (BD) in the 0-15 cm soil layer (surface soil). In surface soil, BD was statistically at par between CT and RT, whereas in ZT significant reduction in BD was recorded. The lowest BD was reported in the treatment combining ZT with residue retention which was 5% lower than the CT treatment having highest BD (1.53 Mg m^{-3}).

IISS

At ICAR-IISS, Bhopal, data pertaining to soil BD of soil are given in Table 2.4. The bulk density of soil was significantly influenced by various tillage and nutrient management practices under maize and soybean crops at various depths of the soil. Under maize crop, soil bulk density at upper most layer (0-

5cm) was significantly low in T1 (No tillage + 30cm CR) followed by T4. The Nutrient management with STCR and 100% RDF had similar and lowest soil bulk density. At 5-10 cm soil depth in maize crop, soil bulk density was influenced by tillage as well as nutrient management treatments. The lowest value of bulk density was associated with T1 followed by T2 (No tillage +60 cm CR), T3, T4 (RT with 60% CR) and T5 (conventional tillage) with significant difference with each other. Among nutrient management practices, STCR was recorded with lowest value of bulk density of soil.

Under soybean crop at 0-5 cm soil depth among tillage practices, T4 was recorded with lowest soil BD value followed by T1 and T5. However, among nutrient management treatments, 100%RDF was observed with lowest BD value. At 5-10 cm soil depth, T2, T4 and T5 had similar values of soil bulk density which was also lowest. In case of nutrient management practices, STCR was recorded with lowest BD value

Table 2.4: Effect of various tillage and nutrient doses on bulk density of soil under maize-chickpea and soybean-wheat system.

Bulk Density				
Treatments	**Maize**		**Soybean**	
	0-5 cm	**5-10 cm**	**0-5 cm**	**5-10 cm**
T1	1.18	1.29	1.13	1.24
T2	1.21	1.36	1.14	1.22
T3	1.21	1.37	1.16	1.23
T4	1.19	1.38	1.10	1.22
T5	1.22	1.42	1.14	1.22
CD	**0.003**	**0.002**	**0.002**	**0.002**
N100	1.20	1.43	1.10	1.26
N75	1.21	1.37	1.18	1.23
STCR 150	1.20	1.30	1.12	1.19
CD	**0.002**	**0.000**	**0.000**	**0.000**

IARI

The bulk density (BD) of soil increased with soil depth under Rice-wheat cropping system at ICAR-IARI, New Delhi. The 7-year continuous field experimentation under CA in rice-wheat rotation revealed reduction in the sub-surface soil strength due to lowering in bulk density (Fig.2.1). Global data synthesis (meta-analysis) revealed an overall improvement in soil physical condition though conservation tillage practice. Change in soil bulk density due to conversion to CA system was not significant in shorter time period (Fig. 2.2).

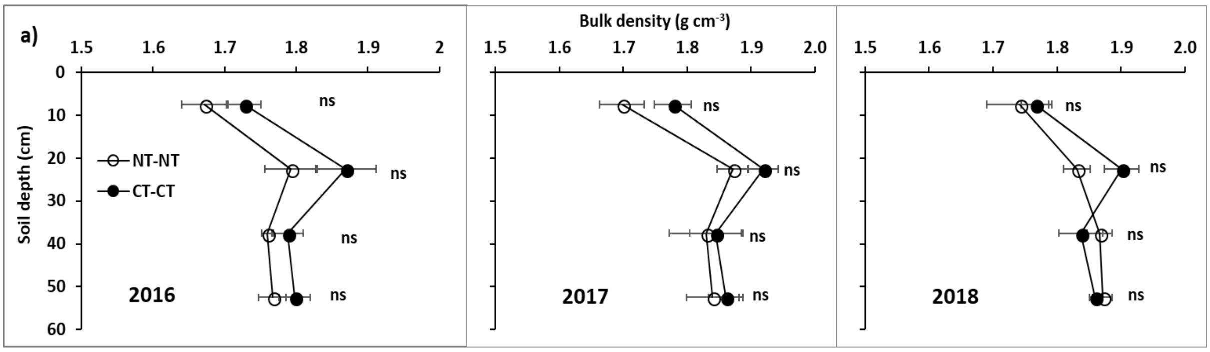


Fig. 2.1. Bulk density of soil under conventional vis-à-vis conservation agriculture practice in rice-wheat system

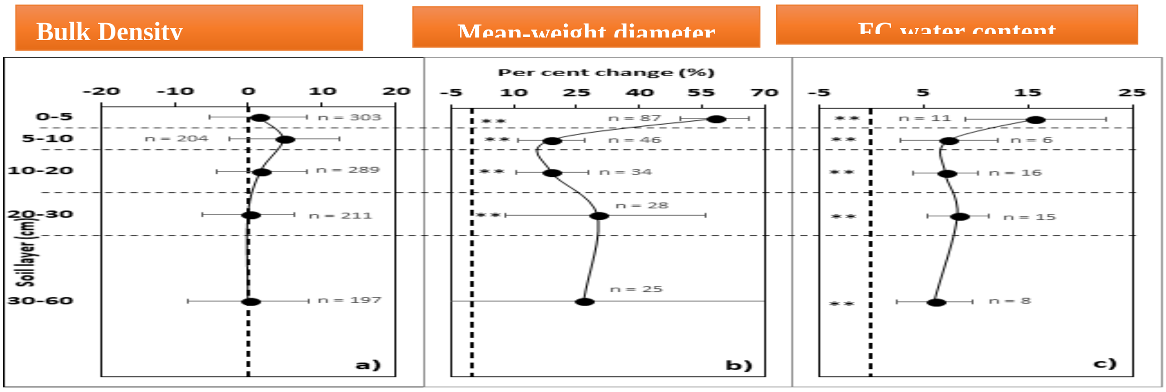


Fig 2.2: Meta-analysis of soil physical properties under conventional vis-à-vis conservation agriculture practices

The bulk density (BD) of soil increased with soil depth under Cotton-wheat system cropping system at ICAR-IARI, New Delhi. In the CA system retention of residue further reduced the BD compared to residue removal. Among the CA practices minimum BD at 0-5 cm soil depth was recorded under permanent broad bed with residue retention. (Fig. 2.3)

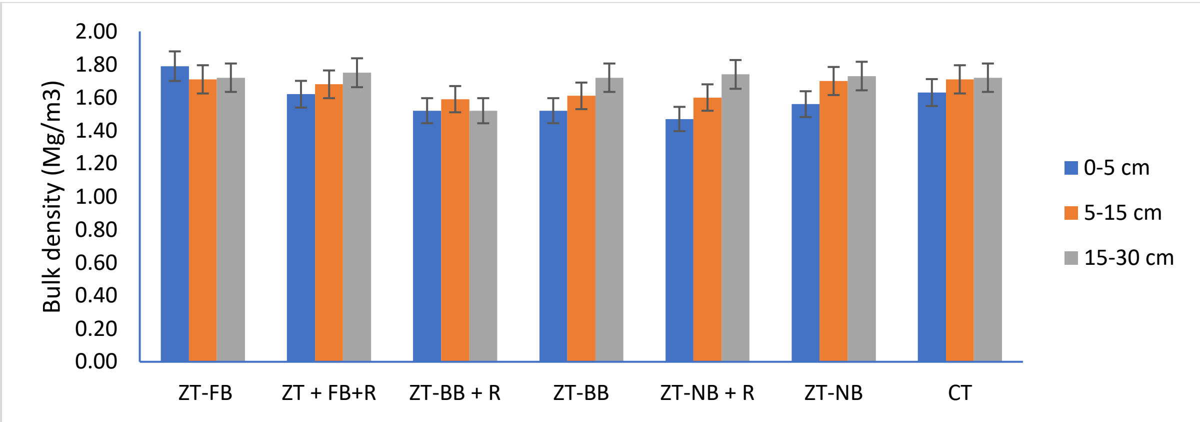


Fig 2.3: Bulk density at 0-5, 5-15 and 15-30 cm soil depth in cotton-wheat system as influenced by tillage practices

CRIDA

At ICAR-CRIDA, Hyderabad In general, all the cropping systems, ZT recorded slightly lower BD as compared to CT. This decrease in BD was higher in ZT with residues (CA) than ZT without residues. The lower BD is generally due to less soil disturbance and subsequent retention of crop residues in ZT, and lack of repeated trafficking of the soil by agricultural machinery. Slight increase in bulk density was observed in zero tillage (6%) as compared to conventional tillage. There was a slight decrease in bulk density (1.55 g cm^{-3}) in ZT compared to CT (1.64 g cm^{-3}**).**

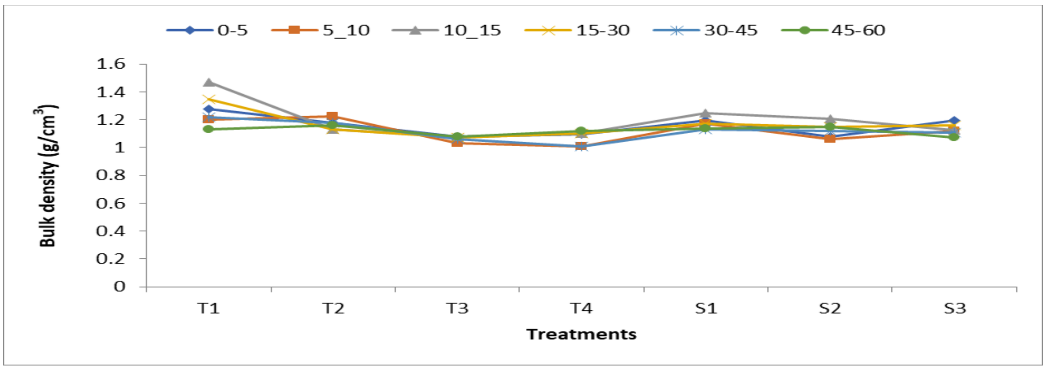


Fig 2.4: Effect of tillage practices and residue retention levels on bulk density (g/cm^3)

Crop residue mulch (T_1), without crop residue mulch (T_2), Broad bed and furrow every year + Pre and post emergence herbicide application + crop residue (T_3), Zero tillage + crop residue (T_4), Permanent BBF furrow after every 4 rows + crop residue mulch (T_5).

In Foxtail millet- Greengram System, zero tillage with soil and moisture conservation practices (T4) recorded slightly lower Bulk density (g/cm^3) was found to be lower in Zero tillage (T3) as compared to other treatments (Fig. 2.4).

In Maize-pigeonpea cropping system with different tillage and nitrogen levels 16.1% lower soil bulk density was observed in NT where as 8.7% lower soil bulk density observed in RT over CT. 125 %RDN recorded 9.7% lower soil bulk density as compared to the N-0. (Fig. 2.5)

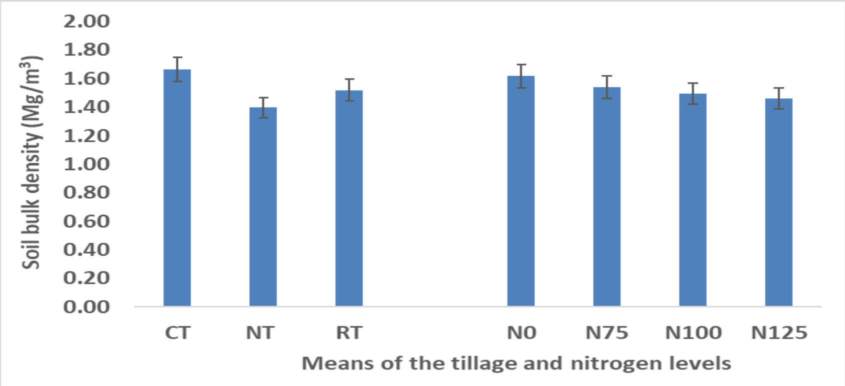


Fig 2.5: Effect of tillage practices and nitrogen levels on bulk density (g/cm^3)

IIFSR

At ICAR-IIFSR, Modipuram, adoption of conservation agriculture among different cropping systems recorded lower bulk density as compared to conventional tillage practices. Among All the CA based treatments recorded significantly lower BD over the R-W CT treatment. Among the different treatments ZT maize-ZT mustard-greengram and ZTDSR-ZTW-greengram treatments recorded 9.13% and 7.65% lower BD over CT R-W.

D. Soil Penetration Resistance

CSSRI

Soil penetration resistance under rice -wheat cropping system was measured at CSSRI, Karnal. The average Soil Penetration Resistance (SPR) within 0 to 45 cm soil profile exhibited distinct patterns across different tillage treatments (Fig. 2.6). Specifically, the lowest SPR was observed in the ZT+R treatment, while the highest was recorded in the CT-R treatment. However, this trend varied significantly across various soil depths, particularly concerning the maximum SPR values. Between 10 and 12.5 centimeters deep, the SPR value was higher in CT+R treatment compared to CT-R. At the 0-15 cm depth, there was a moderate rise in SPR values with conventional tillage compared to zero tillage. However, a sharp increase in SPR values emerged below the depth of 15 cm, reaching its peak at 22.5 cm under conventional tillage, followed by a gradual decline with increasing soil depth. These findings underscore the differential impact of tillage practices, displaying a more pronounced effect at lower soil depths compared to the surface layers. Unlike bulk density, non-significant effect of TRM treatments on SPR was recorded (Table 2.5).

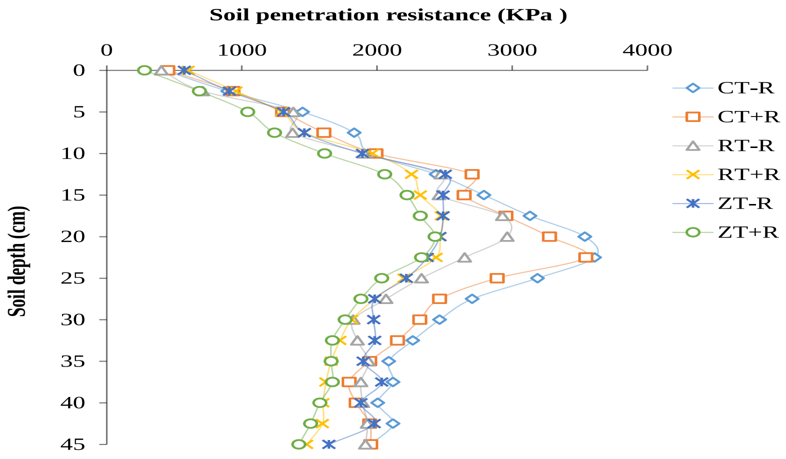


Fig 2.6: Soil penetration resistance after 15-years of the tillage and residue management in rice-wheat system.

CT, RT and ZT represent conventional, reduced and zero tillage, respectively. -R and +R represent no crop residues and 1/3rd crop residue addition, respectively.

The lowest SPR was observed in ZT with residue retention treatment (ZT+R), registering a 22% decline compared to CT. The SPR remained unaffected in the surface soil (0-15 cm), and significant variations were reported at the deeper depth, with the minimum SPR recorded in the ZT+R, recording a 30.9% decrease compared to CT-R.

IARI

Soil penetration resistance under rice -wheat cropping System was measured at ICAR-IARI, New Delhi. The 7-year continuous field experimentation under CA in rice-wheat rotation revealed reduction in the sub-surface soil strength and higher water content at this layer as evidenced by decrease in cone penetration resistance (Fig. 2.7)

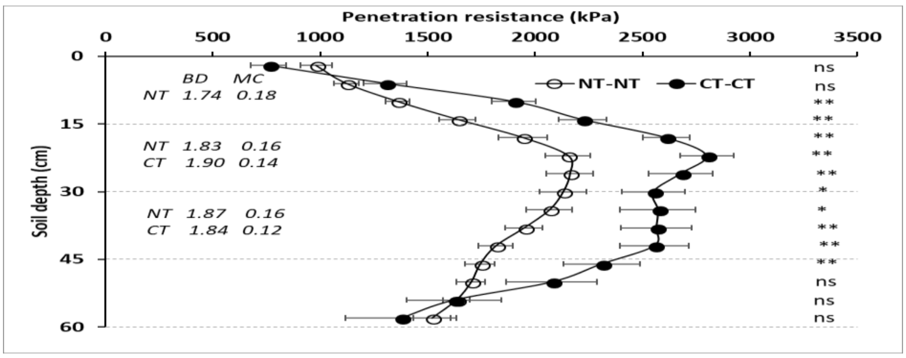


Fig 2.7: Cone penetration resistance under conventional vis-à-vis conservation agriculture practice in rice-wheat system

E. Infiltration Rate and Cumulative Infiltration

CSSRI

Infiltration rate as influenced by different tillage and residue management practices was measured after harvesting of wheat crop at ICAR-CSSRI, Karnal under rice-wheat cropping system (table 2.5). The times trend of the infiltration rate after harvest of wheat crop presented in Fig. 2.8(a) illustrates the changes in infiltration rate over a period of observation across different TRM treatments. The initial values of infiltration varied from 55.3 mm hr^{-1} in CT-R to 75.0 mm hr^{-1} in ZT+R treatment. During initial 5 minutes, the infiltration was highest in all the treatments, might be due to the presence of soil macropores and rapid release of trapped air and then decline sharply till 90 minutes. Between 180 to 330 minutes, the infiltration rate remained relatively constant, indicating a period of stable infiltration capacity.

The cumulative infiltration rate (CIR) depicted in Fig. 2.8(b) exhibits an initial steep rise during the early one and a half hour indicating rapid water absorption by the soil, followed by a gradual increase that continues till next two hours. Beyond this point, the rate of increase slows down, indicating a stabilization phase. This trend was consistent under all the treatments with the higher CIR under zero tillage and the minimum values were recorded under conventional tillage. The subsequent stabilization phase might be attributed to soil saturation influencing soil permeability over time. Data pertaining to the effect of TRM exhibited significantly higher values (7.8 mm hr^{-1}) in ZT+R whereas the lowest was recorded in CT-R (3.0 mm hr^{-1}).

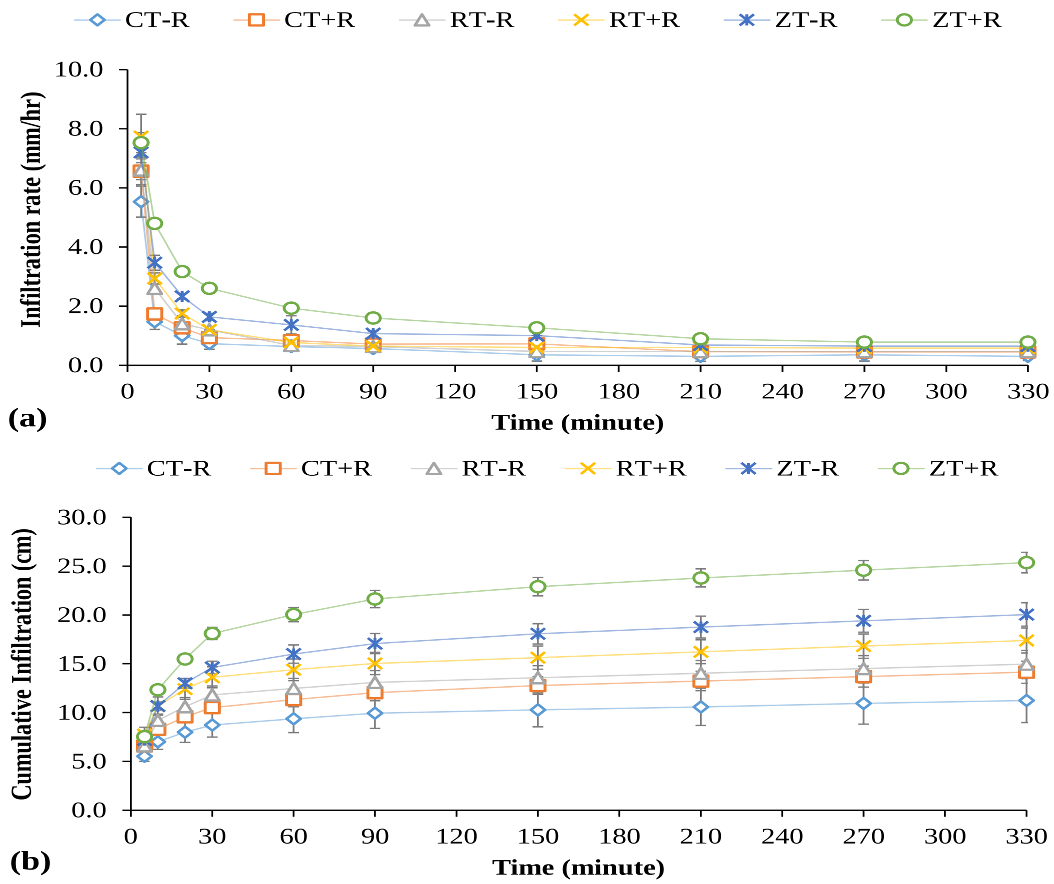


Fig 2.8: Soil infiltration (a) infiltration rate, and (b) cumulative infiltration as influenced by the 15-years of tillage and residue management in rice-wheat system.

CT, RT and ZT represent conventional, reduced and zero tillage, respectively. -R and +R represent no crop residues and 1/3rd crop residue addition, respectively.

Table 2.5. Soil physical properties after 15-years of tillage and residue management in rice-wheat system (2-years pooled average data)

Treatments/ scenarios	Soil physical Properties (CSSRI)		
	Bulk density (Mg m^{-3})	Soil penetration resistance (KPa)	Infiltration rate (mm hr^{-1})
0-15 cm soil layer			
CT-R	1.53^{a}	1681.91	3.0^{e}
CT+R	1.52^{a}	1662.00	4.4^{d}
RT-R	1.52^{a}	1529.45	4.7^{d}
RT+R	1.50^{ab}	1550.82	5.8^{c}
ZT-R	1.47^{bc}	1591.23	6.5^{b}
ZT+R	1.45^{c}	1306.02	7.8^{a}
Treatment	**	NS	***
Year	NS	NS	NS
Treatment × Year	NS	NS	NS

Contrast			
-R *vs* +R	NS	NS	***
CT *vs* RT	NS	NS	***
CT *vs* ZT	***	*	***
RT *vs* ZT	**	NS	***
15-30 cm soil layer			
CT-R	1.67	2985.11[a]	
CT+R	1.66	2798.95[ab]	
RT-R	1.65	2373.09[abc]	
RT+R	1.64	2156.91[bc]	
ZT-R	1.65	2211.86[bc]	
ZT+R	1.66	2060.86[c]	
Treatment	NS	*	
Year	NS	NS	
Treatment × Year	NS	NS	
Contrast			
-R *vs* +R	NS	NS	
CT *vs* RT	NS	**	
CT *vs* ZT	NS	***	
RT *vs* ZT	NS	NS	

Treatment means within a column with dissimilar letters (lowercase) varied significantly (P < 0.05, Tukey's test)

***, **, * represent 0.1% (0.001), 1% (0.01), and 5% (0.05) level of significance, and NS represent non-significant.

CT, RT and ZT represent conventional, reduced and zero tillage, respectively. -R and +R represent no crop residues and 1/3rd crop residue addition, respectively.

IARI

The 7-year continuous field experimentation under CA in rice-wheat rotation at ICAR-IARI, revealed reduction in the sub-surface soil strength. Greater total porosity and relatively greater relative proportion of micro-pores ensured higher soil water retention in CA in the subsurface layer. The infiltration rate was higher and sorptivity was lower under CA than conventional tillage system (Fig. 2.9).

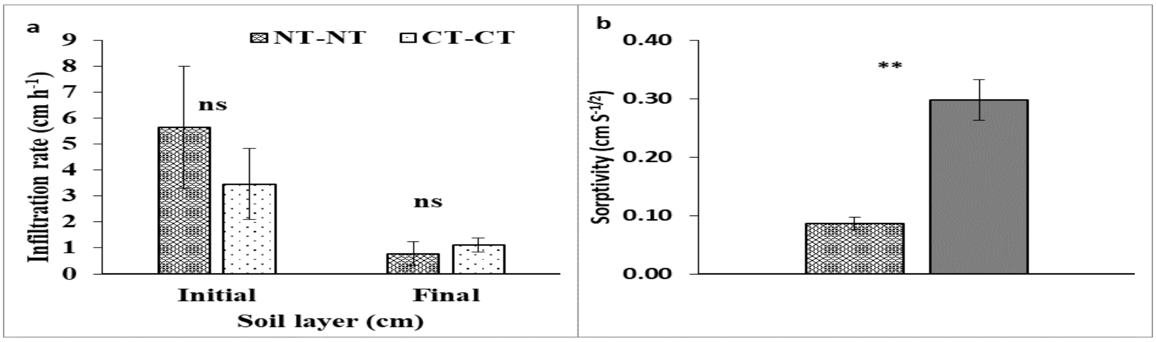


Fig 2.9: Infiltration rate and sorptivity under conventional vis-à-vis conservation agriculture practices

It can be inferred from the meta-analysis that root length density of crops was significantly higher in the top 0-5 cm soil layer due to improved soil physical environment (Fig. 2.10). Root water uptake was 14-17% higher in CA than CT practice (Fig. 2.11).

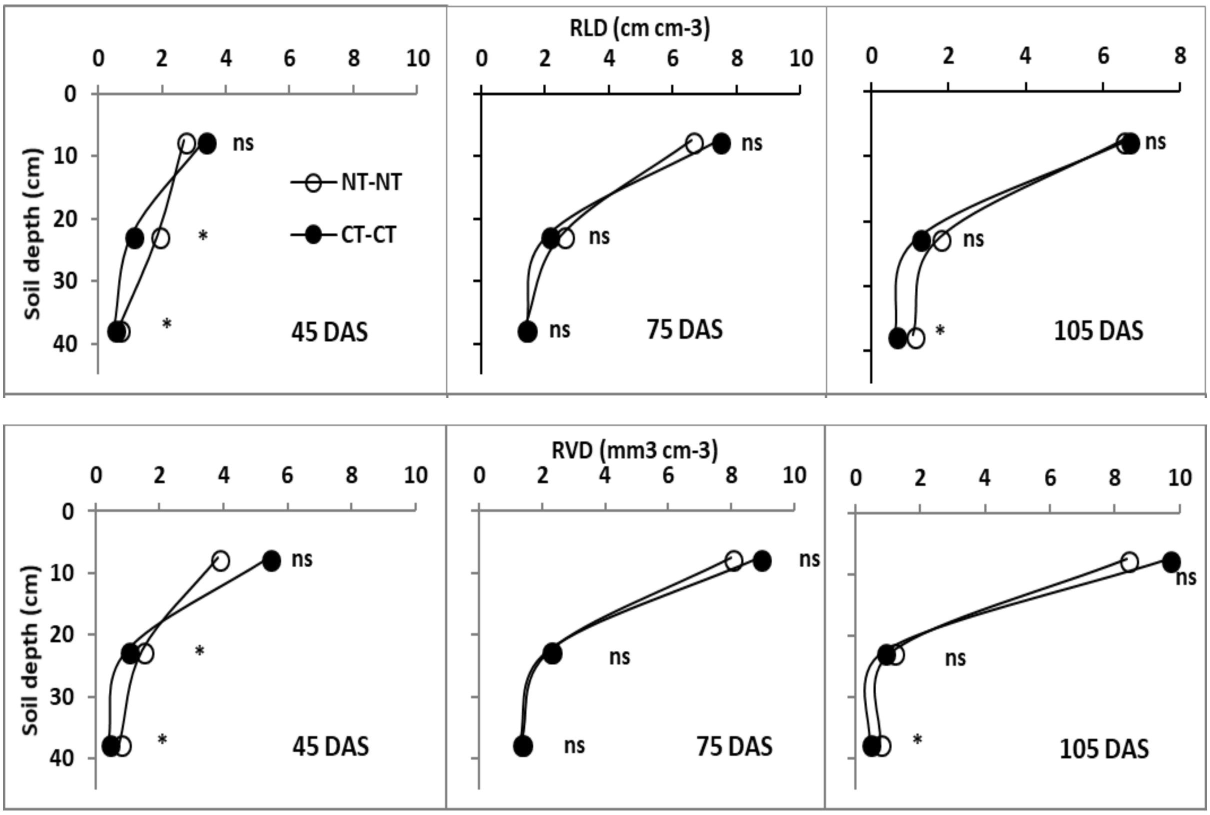


Fig 2.10: Root length density and root volume density of wheat under conventional vis-à-vis conservation agriculture practices in rice-wheat system

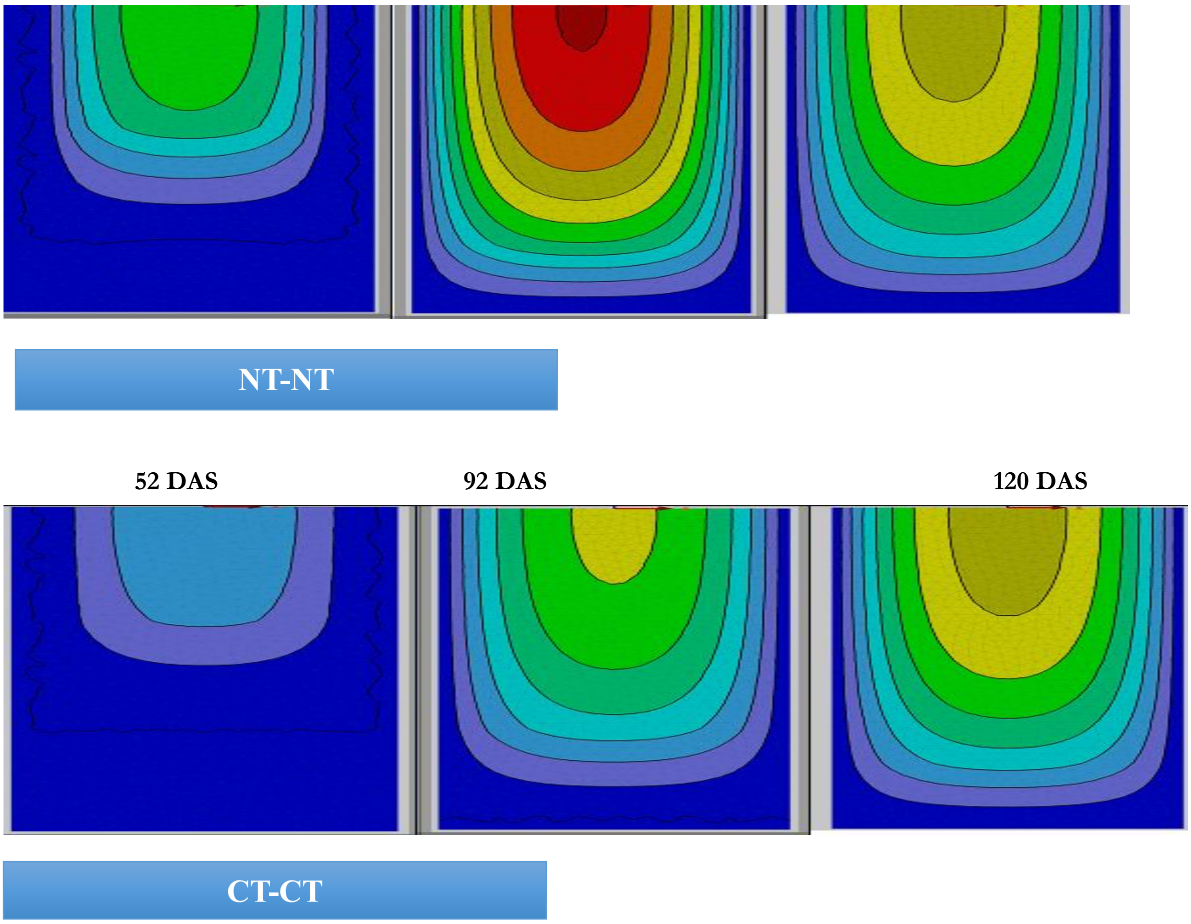


Fig 2.11: Simulation of root water uptake by wheat under conventional vis-à-vis conservation agriculture practices in rice-wheat system using HYDRUS-2D model

Maize-wheat system

Initial infiltration rate was highest (25.92 cm/hr) in PBB+R and was lowest (9.68 cm/hr) in CT. Initial infiltration rate and steady state infiltration rate of broad bed with residue was almost three times higher than the CT. Steady state infiltration in PBB+R was higher and the time taken to reach was 2.2 hrs. The lowest steady state infiltration of 1.52cm/hr observed in CT and time taken to reach was 1.52 hrs. From the results it can be attributed that all the residue applied plots (PBB+R> PNB+R>ZT+R) had significantly high($p<0.01$) steady state infiltration rate than CT. Bed cultivation (PBB or PNB) also reported significantly high infiltration rate than CT (Table 2.6).

Table 2.6: Initial infiltration rate, steady state infiltration rate and cumulative infiltration rate under CT and CA treatments

Treatment	Infiltration		
	Initial infiltration rate (cm hr^{-1})	Steady state infiltration rate (cm hr^{-1})	Cumulative infiltration(cm)
ZT+R	21.80[c]	5.57[b]	21.03[c]
ZT	12.47[e]	2.81[d]	12.13[e]
PBB+R	25.92[a]	7.31[a]	29.40[a]
PBB	18.40[d]	6.10[b]	17.77[d]
PNB+R	23.43[b]	5.79[b]	26.03[b]
PNB	17.67[d]	4.36[c]	21.27[c]
CT	9.68[f]	2.13[d]	6.90[f]

F. Soil Moisture Content

IISS

Soil moisture data recorded at different time interval and their statistical significance with respect to tillage system, nutrient level and soil depths under in maize and soybean crops at ICAR-IISS, Bhopal are given in Table 2.7. Under both the crops at the harvest stage, there was no significant effect of conservation tillage and nutrient management practices on soil moisture content at 0-15 and15-30 cm soil depths, however, significant effect was observed at 60 DAS at both the depths in maize and soybean crop. In maize crop at 0-15cm soil depth among tillage practices, T2 (NT with 60 cm height residue) followed by T1 (NT with 30cm height residue), T5 (CT) and T4 (RT with 60 cm residue height) were recorded with higher soil moisture content, and their difference was significant. However, at 15-30cm soil depth, T2 and T1 were observed with higher soil moisture content, but the difference was non-significant. With nutrient management treatments at 0-15 cm soil depth in maize crop, maximum soil moisture was associated with 75% RDF followed by STCR, which was significantly lower than 75% RDF practice. However, maximum soil moisture at 15-30 cm soil depth was found in 100% RDF followed by 75% RDF.

In Soybean crop at 0-15 cm & 15-30 cm soil depths, T1 was associated with maximum soil moisture followed by T4, and their difference was statistically significant. Among nutrient management treatments, 75% RDF was observed with maximum soil moisture at both the soil depths followed by STCR dose.

Table 2.7: Effect of various tillage and nutrient doses on soil moisture (%) under maize-chickpea and soybean-wheat system

	Soil Moisture %							
	Maize				Soybean			
Treatments	60 DAS		At Harvest		60 DAS		At Harvest	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T1	9.84	10.75	10.79	14.90	10.63	11.11	11.01	15.83
T2	9.95	10.77	11.55	14.56	9.66	10.05	12.35	17.08
T3	9.16	10.26	11.17	15.44	9.92	10.29	11.32	16.37
T4	9.40	9.76	11.68	15.89	10.56	10.86	9.73	14.62
T5	9.45	10.50	10.60	14.53	10.19	10.56	11.59	15.60

CD	**0.013**	**0.030**	**N/A**	**N/A**	**0.016**	**0.012**	**N/A**	**N/A**
N100	9.32	11.01	11.30	15.11	9.99	10.39	11.42	16.38
N75	9.94	10.36	11.48	15.00	10.36	10.80	11.23	15.65
STCR 150	9.42	9.86	10.69	15.08	10.23	10.53	10.94	15.65
CD	**0.006**	**0.004**	**N/A**	**N/A**	**0.002**	**0.004**	**N/A**	**N/A**

G. Water holding capacity (WHC) and Water productivity

IIFSR

Soil samples collected at 0-15 and 15-30 cm soil depth at the harvest of rabi season crops in 2023 at IIFSR, Modipuram. Among the different treatments ZT maize-ZT mustard-greengram and ZTDSR (zero tilled direct seeded rice)-ZTW-greengram treatments recorded 10.75% and 6.45% higher WHC over the business as usual (R-W CT).

NIASM

A long term (six-year) impact of tillage, surface trash retention and fertigation strategies on productivity and water-energy-carbon nexus in drip irrigated sugarcane was assessed at NIASM, Baramati. The plant crop included three treatments of tillage (CT: Conventional tillage + 10% RDF basal and 90% fertigation; RT_1: Reduced tillage (RT) + 10% RDF basal and 90% fertigation, and RT_2: RT+10% RDF basal, 40% band placement and 50% fertigation) in main plots and (ii) soil surface trash retention practices, namely mulching (M) and non-mulching (NM), in subplots. The sub-plots were further divided to sub-sub plots to adjust three nutrient levels (N_1: 25% RDF as basal and rest through fertigation, N_2: 50% RDF as basal using multifunctional SORF (stubble shaving, off-barring, root pruning and band placement of fertilisers) drill and rest 50% through fertigation, and N_3: SORF with 75% RDF as basal using SORF drill and rest 25% through fertigation). RT_2+M+N_2 also showed superior water productivity (16.4 kg m^{-3}), partial factor productivity (518.1 kg N kg^{-1}), and reduced water footprint (54.0 kg^{-1}), with favourable soil properties. Notably, the plant crop exhibited higher GHG loss (9.0–10.4 Mg CO_2-eq ha^{-1}) and lower energy use efficiency (EUE, 22.8–33.5) than the ratoon crop (6.5–7.7 Mg CO_2-eq ha^{-1} and 24.7–56.5). Over six years, these practices enhanced carbon sequestration (65.5–73.1%), consequently reducing the carbon footprint (72–88%). Overall, integrated CA practices hold promise in minimizing yield gaps, maximizing productivity, ensuring profitability, and sustaining environmental quality in sugarcane production, particularly in semi-arid regions.

Water saving

In 2023–24, after the harvest of the plant crop, a field trial was established to evaluate the effects of deficit irrigation (DI), foliar application of PGRs and surface trash retention on the ratoon crop (Co–86032) with existing tillage practices. The experiment was replicated thrice with three levels of deficit irrigation *viz.*, DI_1: 50% ETc; DI_2: 75% ETc and DI_3: 100% ETc (full irrigation) were applied using a drip system in main plots and four plant growth regulators (PGRs) namely thio-urea (TU, 1800 ppm), irradiated chitosan (IC, 5 ml/L), nano-urea (NU, 4 ml/L), salicylic acid (SA, 25 µM) and no PGRs (control) were applied exogenously with interval of two months after ratoon crop establishment (60 days) as subplot treatments. Further, two soil surface trash retention practices (S1: trash mulch and S2: without trash mulch) were maintained as sub-subplots treatments. The highest ratoon cane yields of 140 t ha^{-1} was obtained in DI_2+ IC +S_1 i.e. when irrigated at 75% ETc with irradiated chitosan (5 ml/ litre) in trash retained (S_1) plots under reduced tillage practices. Surface trash retention (S_1) improved ratoon cane yields by 9.4, 21.0, and 36.4% in full (100% ETc), 75% ETc and 50% ETc when compared control (S_2). PGRs improved ratoon cane yields by 5.0–12.0%, 9.9–25.4% and 15.9–35.4% under full (100% ETc), 75%ETc and 50% ETc, water deficit levels, respectively. When compared with previous results of plant crop (2022–23), combined practice of 75%ETc, IC (5ml/L), and surface trash retention reduced the yield gaps between plant and ratoon crops up to 7.6% along with 25% water saving over farmers' practice.

H. Temperature

IIWBR

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 system 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). Observations were taken on soil temperature in the morning and noon on different dates (Fig 2.12 and 2.13). The morning temperatures were on slightly higher in CA system where as reverse in the noon, where the temperatures were on lower side. The noon temperatures in the control plots were higher than different nutrient management treatments.

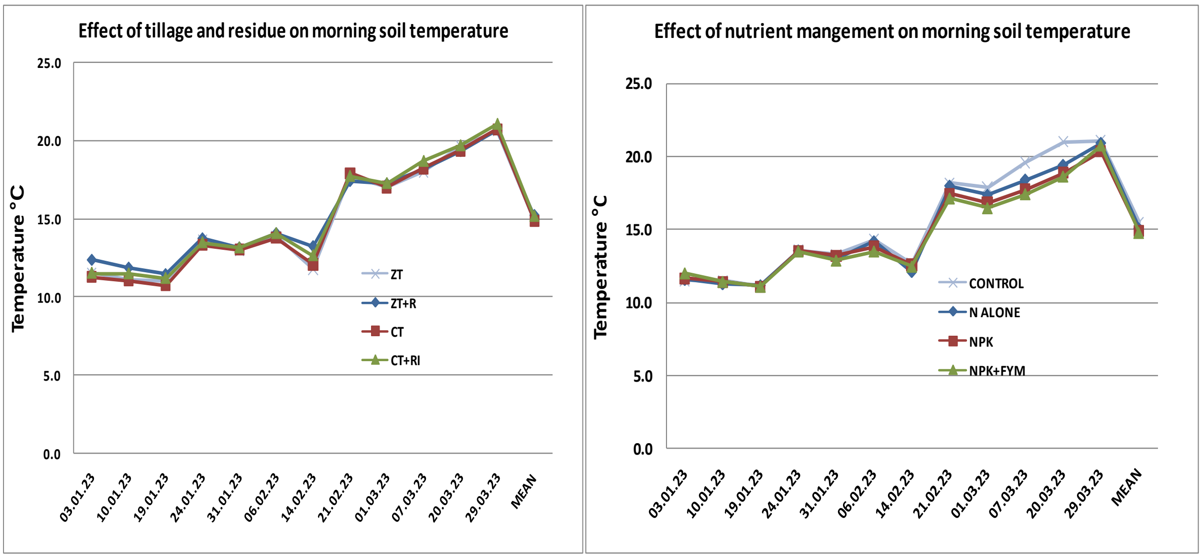


Fig 2.12: Effect of tillage, residue and nutrient management on morning soil temperature in long term maize-wheat-greengram experiment

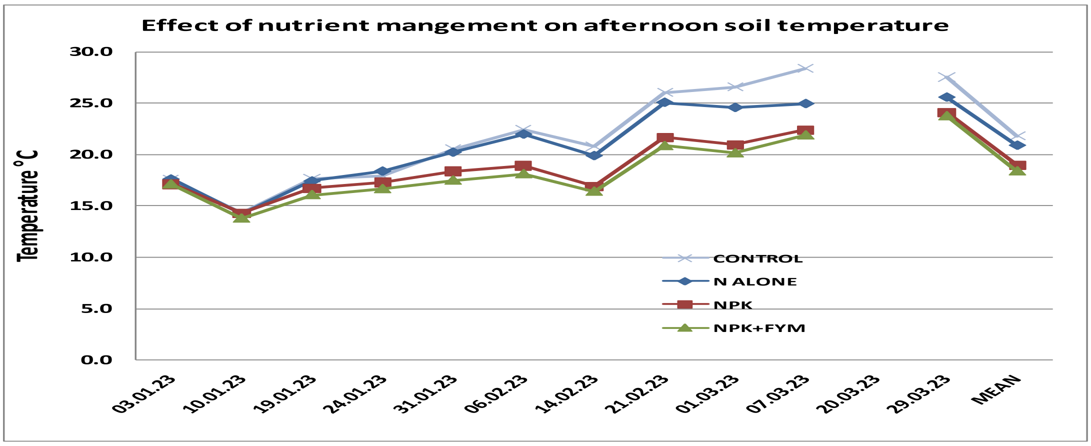


Fig 2.13: Effect of tillage, residue management and nutrient management on afternoon soil temperature during different crop seasons in long term maize-wheat-greengram experiment

I. Hydraulic conductivity

IARI

Effect of long-term conservation agricultural practices on soil hydraulic properties under Maize-wheat system In 0-15 cm soil depth highest saturated hydraulic conductivity (HC) of 44.22 cm/day was obtained in PBB+R and lowest value 32.22 cm/day was observed in CT (Fig 2.14). In 0-15 cm the trend was as follows: - PBB+R>PNB+R>ZT+R>PBB>PNB>ZT>CT. The hydraulic conductivity was 37.22, 34.91 and 29.11% higher in PBB+R, PNB+R and ZT+R respectively than in CT.

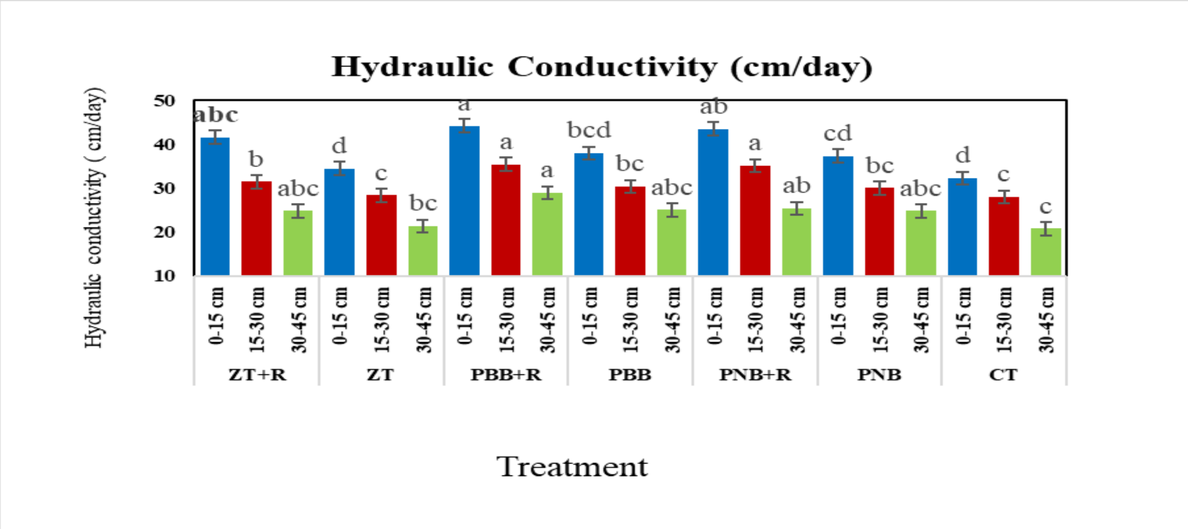


Fig 2.14: Variation of soil hydraulic conductivities under CT and different CA treatments

2. Soil Chemical Properties

A. SOC, Carbon Stock and Carbon Sequestration

NIASM

Sequestration of carbon in arable cropping systems is considered one of the potential climate change mitigation strategies. In 2023, we evaluated the impacts of minimum soil disturbance, residue retention, and nutrient management practices on changes in total soil organic carbon (SOC), its pools, in four-year-old multi-ratooning sugarcane systems in the black soils of semi-arid tropics at NIASAM, Baramati. Results indicated that plots with residue retention (RR) had 17% higher total SOC with 63%, 34%, and 15% higher labile, less labile, and non-labile C pools, respectively, than residue burning (RB) plots. Of the total SOC stock, the contribution of passive pools was higher at 72–78% than active pools. Reduced tillage (RT), residue burning (RB), and 50% of RDF as basal and 50% through fertigation plots showed higher microbial and enzymatic activities at topsoil layers (0–30 cm). RT coupled with RR reported the highest net SOC enrichment of 5.23 Mg C ha^{-1}. Over four seasons, the maximum average ratoon cane yields of 153 t ha^{-1} and 137 t ha^{-1}were obtained in RT with RR and RB, respectively, while their corresponding values in CT were 113 and 95 t ha^{-1}, respectively. The highest improvement in cane yield by 30.7% and 37.1% was observed in RT with 50% application RDF as basal in band placement and remaining through fertigation with RR and RB, respectively, over farmer's practice. Overall, RT with RR and 50–75% RDF as basal are recommended for higher cane yield, soil C retention, and soil microbial activity for sustained sugarcane productivity. Over six years, these practices enhanced carbon sequestration (65.5–73.1%), consequently reducing the carbon footprint (72–88%).

IIFSR

Different soil physical properties were analyzed in the soil samples collected at 0-15 and 15-30 cm soil depth at the harvest of rabi season crops in 2023 at IIFSR, Modipuram. All the CA based treatments recorded significantly improvement in soil organic carbon is an important aspect of CA based management practices. Significantly 43.59%, 41.45%, 18.59% and 17.52% higher Walkley-Black carbon was recorded in CA based M-M-GG (CT), R-W-GG (CA), R-W (CT) and S-R-W (CT) cropping systems over the R-W cropping system.

CSSRI

Data pertaining to the effect of long-term TRM practices on soil chemical properties is presented in Table 2.8. No significant differences were observed in soil among various treatment combinations across both soil surfaces (0-15 and 15-30 cm) at CSSRI, Karnal. In surface soil (0-15 cm), RT treatment with residue incorporation (RT+R) exhibited significantly higher SOC content and minimum was recorded under CT without residue (CT-R). On average, SOC content and stock were 15.8-31.6% and 15.8-26.8% higher in different conservational tillage treatments over CT-R at 0–15 cm soil depth, respectively. At subsurface soil (15-30 cm), a significant effect on SOC content was observed, while statistically at par values were recorded in case of SOC stock. There was a gradual decline in SOC content and an increase in SOC stock with increasing soil depth. Residue addition typically raised SOC and SOC stock in the surface layer by 9.40% and 8.19%, respectively in the surface layer. Significant increases in SOC (15.42% and 19.59%) and SOC stock (13.93% and 14.47%) were observed with both RT and ZT treatments compared to CT. The higher SOC and SOC stock in various RCT treatments over CT-R may be attributed to higher carbon input through residue retention.

Table 2.8: Soil chemical properties after 15-years of tillage and residue management in rice-wheat system (2-years pooled average data)

Treatments/ scenarios	Soil chemical Properties			
	$pH_{1:2}$	$EC_{1:2}$ (dS m^{-1})	Soil organic carbon (%)	Soil organic carbon stock (Mg ha^{-1})
0-15 cm soil layer				
CT-R	7.53	0.27	0.57^{d}	17.33^{d}
CT+R	7.50	0.29	0.66^{c}	20.07^{c}
RT-R	7.50	0.25	0.68^{bc}	20.63^{bc}
RT+R	7.52	0.28	0.74^{a}	21.98^{a}
ZT-R	7.52	0.24	0.72^{ab}	21.03^{abc}
ZT+R	7.52	0.23	0.75^{a}	21.78^{ab}
Treatment	NS	NS	***	***
Year	NS	NS	***	***
Treatment × Year	*	***	NS	NS
Contrast				
-R *vs* +R	NS	**	***	***
CT *vs* RT	NS	**	***	***
CT *vs* ZT	NS	***	***	***
RT *vs* ZT	NS	***		NS
15-30 cm soil layer				
CT-R	7.96	0.21	0.45^{c}	29.65
CT+R	7.89	0.24	0.47^{b}	30.97
RT-R	7.84	0.20	0.47^{b}	31.04
RT+R	7.81	0.24	0.47^{b}	30.90
ZT-R	7.98	0.20	0.46^{b}	30.13
ZT+R	7.88	0.19	0.49^{a}	32.33
Treatment	NS	NS	*	NS
Year	***	***	***	***
Treatment × Year	***	**	***	***
Contrast				
-R *vs* +R	NS	**	NS	NS
CT *vs* RT	***	NS	NS	NS
CT *vs* ZT	NS	**	NS	NS
RT *vs* ZT	NS	**	NS	NS

IISS

A study was conducted to assess the dynamics of soil organic carbon (SOC) under no-tillage (NT) and residue retention (RR) in the Vertisols of central India. The experiment was initiated in the year 2015 with four different levels of residues (0, 30, 60, and 90%) under no till system ICAR-IISS, Bhopal. The site was established on a Vertisol under sub-humid, dryland conditions to examine the impact of NT along with residue retention on soybean (*Glycine max* L.), wheat (*Triticum aestivum* L), maize (*Zea mays*) and chickpea (*Cicer aerietinum* L) production. Retention of residues of previous crop significantly affected soil total carbon under both the cropping systems. As the levels of residue increased, soil total carbon also increased under the no-till system. However, the effect was only confined to 0 to 10 cm of soil depth. No significant impact of residue retention was recorded in 10-20 cm of soil depth. Moreover, no till system without residue retention could not make any significant change in the soil total carbon content. Retention of 30, 60, and 90% of residues of previous crops resulted in 28.9, 32.7, and 41.1%, respective increase in soil carbon concentration in the maize-chickpea cropping system. However, this increase in soil total carbon could not make any significant change in the soil carbon content of recalcitrant pool. The trend was similar for oxidizable carbon (WBC) also. The increase in carbon mainly contributed to the mineralizable pool (active+slow) of soil carbon. Here, retention of 60 and 90% of residue resulted in enhancement of mineralizable pool of soil carbon by 48.5 and 78.8%, respectively under maize-chickpea rotation (Table 2.9). In case of soybean-wheat rotation, retention of 90% of residue resulted in a 19% improvement in soil total carbon at 0-10 cm of soil depth. A 17% and 22% increase in recalcitrant and oxidizable carbon content was recorded in 90% residue retained treatment in 0-10 cm of soil depth**.**

Table 2.9: Effect of different levels of residue retention on soil carbon concentration

IISS

Maize-Chickpea	**Total carbon (%)**		**Recalcitrant carbon (%)**		**WBC (%)**		**Active + Slow (%)**	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 Cm	0-10 cm	10-20 cm
NT-0% Residue retention	1.28ab	0.84a	0.86a	0.62c	0.97a	0.54b	0.42ab	0.22a
NT-30% Residue retention	1.38b	0.77a	0.94a	0.56a	1.10a	0.50ab	0.44ab	0.21a
NT-60% Residue retention	1.42b	0.73a	0.92a	0.53a	1.14a	0.43a	0.49bc	0.19a
NT-90% Residue retention	1.51b	0.77a	0.91a	0.56a	1.15a	0.48ab	0.59c	0.21a
CT-0% Residue retention	1.07a	0.80a	0.75a	0.59b	0.88a	0.47ab	0.33a	0.21a
Soybean-wheat								
NT-0% Residue retention	1.12a	0.73a	0.76a	0.56a	0.88a	0.73b	0.36a	0.18a
NT-30% Residue retention	1.14a	0.75a	0.76a	0.57a	0.88a	0.75b	0.38a	0.19a
NT-60% Residue retention	1.23ab	0.72a	0.81ab	0.56a	0.92a	0.72b	0.42a	0.16a
NT-90% Residue retention	1.33b	0.75a	0.89b	0.57a	1.08b	0.75b	0.45a	0.17a
CT-0% Residue retention	1.13a	0.77a	0.75a	0.59a	0.86a	0.52a	0.38a	0.18a

In order to determine active and slow pools of soil organic carbon under maize-chickpea rotation, a carbon mineralization study was conducted for the duration of 90 days under laboratory condition. Cumulative carbon mineralized from 50 g of soil. The highest carbon mineralization (53.97 mg C-CO_2/50 g of soil) was recorded under the treatment of no till system with 90% retention of residues of previous crops. This was followed by 60, 30 and 0% of residue-retained treatments. The lowest carbon mineralization was recorded from conventionally tilled plot with no residue retained (42.87 mg C-CO_2/50 g of soil). Separation of active and slow pools was done using the double decomposition model. The size and turnover rates of each pool were estimated by curve fitting the CO_2 evolved per unit of time (C_t) using a two-component model (Paul et al., 1997) shown in Eq. (1)

$$C_t = C_a e^{-kat} + C_s e^{-kst} \quad (1)$$

where, C_t is sum of active (C_a) + slow pool carbon (C_s) pools; C_a and C_s are the sizes of the active and slow carbon pools and k_a, and k_s are the decay constants of respective pools. The double decomposition equations fitted with the non-linear regression (SPSS window version) were used in the Marquardt algorithm.

A significant difference in C concentration of the acid non-hydrolysable fraction occurred among treatments (Table 2.10). No till system with 90% residue retained treatment recorded the highest concentration of active pool of carbon (0.61 g/kg) and the lowest was recorded in CT with no residue retention treatment (0.47 g/kg). No till system resulted in a 32% improvement in carbon in the slow pool. Retention of residue hasgreater impact on soil carbon in slow pool. Retention of 90% of residue resulted in 89% improvement in carbon in the slow pool. The data of decay constant of active pool suggest that mean residence time (MRT) of active pool under different treatments ranged between 8-11 days where MRT of slow pool under different treatments ranged between 2-16 years.

Table 2.10: Carbon pool dynamics as affected by tillage and different levels of residue retention

RCER

Post-harvest soils of rice-mustard-cow pea cropping system of Chene, Jharkhand: pH in post-harvest soils of rice-mustard-cow pea varied from 4.71 to 4.86 and pH was non-significant among treatments. Organic carbon content was highest in the CA practices (0.62 and 0.63% in ZTDSR and ZTTR, respectively) (Table 2.11).

Table 2.11: Effect of CA practices on changes of soil properties in post-harvest soils of rice-linseed-greengram system of Chene, Jharkhand during 2023-24.

Treatments	**TC (%)**	**Ca (%)**	**Ka (days^{-1})**	**Cs (%)**	**Ks (days^{-1})**	**Cr (%)**
NT-0% Residue retention	1.28	0.050	0.105	0.37	0.00137	0.86
NT-30% Residue retention	1.38	0.048	0.113	0.38	0.00137	0.94
NT-60% Residue retention	1.42	0.059	0.090	0.43	0.00145	0.92
NT-90% Residue retention	1.51	0.061	0.101	0.53	0.00105	0.91
CT-0% Residue retention	1.08	0.047	0.109	0.28	0.000169	0.75

Treatment	**pH**	**Organic carbon (%)**
Crop establishment methods		
Rice-fallow	4.81	0.49
ZTDSR	4.83	0.62
CTDSR	4.71	0.58
ZTTR	4.86	0.63
FPTR	4.79	0.60
LSD ($p \leq 0.05$)	NS	0.064

ZTTR- zero-tillage transplanted rice, ZTDSR- zero-tillage direct seeded rice, CTDSR- conventional tillage direct seeded rice, FPTR - farmer’s puddled transplanted rice and rice-fallow

IARI

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 rice-wheat system in the Indo-Gangetic Plains (IGP) at ICAR-IARI, New Delhi (Table 2.12). The meta-analysis of global data set further revealed that soil organic C (SOC) content had a large difference in the surface, and significantly decreased down the profile, whereas SOC stock (0-60 cm) was marginally lower (1.1% only) in CA (Fig. 2.15).

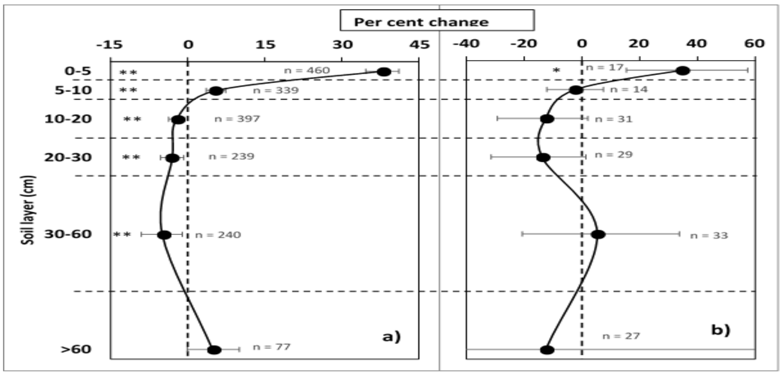


Fig 2.15: Meta-analysis of soil organic carbon and root growth under conventional vis-à-vis conservation agriculture practices

B. Active or KMnO4 oxidizable carbon

C) Soil Carbon Pools

IISS

The soil organic carbon buildup in CA-based maize-mustard and pigeon pea- wheat systems in light soil was studied after two cropping cycles. The percent increase in SOC under maize-mustard system ranges from 3.8-10.8%, whereas, it was 5.8-13.7% increase under pigeonpea-wheat system (Table 2.12). The data indicated that pigeonpea-wheat system buildup more SOC than maize-mustard system.

Table 2.12: Effect of cropping systems and tillage and crop residues on soil organic carbon after two cropping cycles

Soil organic carbon (Walkley and Black) (%) (0-5cm depth)			
Maize-mustard system	**Initial status**	**After two cropping cycle**	**% increase**
CTMz-CTMs	0.46	0.47	2.2
ZT Mz+25 MsR -ZTMs+25MzR	0.52	0.54	3.8
ZTMz + 50 MsR-ZTMs+50MzR	0.48	0.50	4.2
ZTMz+ 75 MsR-ZTMs+75MzR	0.46	0.51	10.8
Pigeonpea-wheat system			
CT pigeonpea-CT wheat	0.54	0.56	3.7
ZT pigeonpea+25 WR-ZT wheat+25 PR	0.51	0.54	5.8
ZT pigeonpea+ 50 WR-ZT wheat+50PR	0.60	0.64	6.7
ZT pigeonpea+ 75 WR-ZT wheat+75PR	0.51	0.58	13.7

There was improvement in the total organic carbon (TOC) concentration at 0-5 and 5-15 cm soil depth under CA by 19.2 and 2.2%, respectively compared to CT. The carbon stratification ratio under CA (1.56) was higher than that of CT. Among the CA practices, retention of residue could improve TOC concentration at 0-5 and 5-15 cm soil depth by 21.7 and 7.5%, respectively than that of residue removal. Among the CA practices maximum carbon sequestration was registered in ZT flat bed with residue retention and the carbon sequestration rate was 11.89 Mg C/ha (Fig. 2.16). Therefore, conservation agriculture practices have great potential for improving soil physical conditions and carbon sequestration in cotton-wheat system under sandy loam soil (Table 2.13).

Table 2.13: Total organic carbon concentration and carbon stratification ratio in cotton-wheat system as influenced by tillage and residue management

Treatments	**TOC (g/kg)**			**Carbon stratification ratio**
	0-5 cm	**5-15 cm**	**15-30 cm**	
Zero tillage (ZT)	12.18^{AB}	8.29^{A}	7.52^{BC}	1.62^{AB*}
ZT + Residue	14.72^{A}	9.29^{A}	7.03^{C}	2.09^{A}
BB + Residue	10.90^{BC}	8.94^{A}	7.86^{ABC}	1.39^{BC}

Broad bed (BB)	8.00^{C}	8.00^{A}	7.75^{ABC}	1.03^{C}
NB + Residue	9.89^{BC}	9.29^{A}	8.31^{ABC}	1.19^{BC}
Narrow bed (NB)	9.01^{C}	9.31^{A}	9.22^{A}	0.98^{C}
Flatbed	9.93^{BC}	8.97^{A}	9.01^{AB}	1.10^{BC}
Mean	10.66	8.87	8.10	1.34
P Value	0.0003	0.0586	0.0040	0.0001
Contrast CA vs CT				
CA	11.84	9.17	7.73	1.56
CT	9.93	8.97	9.01	1.10
P Value	0.0304	0.5825	0.0050	0.0040
Contrast Residue vs no-residue				
R+	11.84	9.17	7.73	1.56
R0	9.73	8.53	8.16	1.21
P Value	0.0024	0.0272	0.1280	0.0026
Contrast BB vs NB				
BB	9.45	8.47	7.81	1.21
NB	9.45	9.30	8.77	1.09
P Value	1.0000	0.0207	0.0115	0.3197

* Values in a column followed by same letter are not significantly different at p<0.01

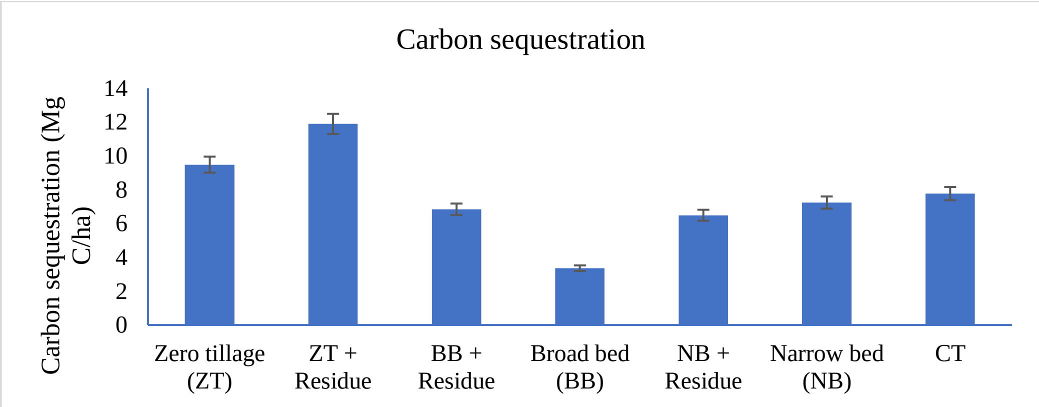


Fig 2.16: Carbon sequestration under cotton-wheat system at 0-15 cm soil depth as influenced by conservation agriculture practice

Soil organic carbon stabilization in bed planted cotton-wheat system under conservation agriculture: Plots under permanent broad bed+ residue (PBB+R) had 0.85 Mg $ha^{-1}yr^{-1}$ soil organic C (SOC) accumulation rate over conventionally tilled (CT) plots in the 0-30 cm soil depth under a cotton-wheat system in the Indo-Gangetic plains (IGP). Nearly 82% of the total SOC accumulation in the 0-60 cm was observed in the 0-30 cm soil depth. The SOC, labile C, water-soluble C and soil aggregation in the 0-5 cm depth were similar in beds to those in furrows, but were significantly more in beds than furrows in the 5-15 cm depth (Table 2.14). After ten years of cropping in the Indo-Gangetic plains (IGP), in the topsoil (0-5 cm depth), the PBB+R, PNB+R and ZT+R plots had ~39%, 34%, and 29% more total SOC storage than CT plots (4.84 Mg C ha^{-1}), respectively. Similarly, upto 30 cm depth, the effect of CA was significant with respect to SOC storage, beyond which it was not significant. The PBB+R had ~63% higher labile C than CT plots (2.85 g kg $^{-1}$) in the 0-5 cm soil depth. About 42 and 70% of total SOC accumulation was in the recalcitrant C pool in the 0-30 and 30-60 cm depths, respectively. The plots under PBB+R had 0.23 Mg macroaggregate-associated recalcitrant C $ha^{-1}yr^{-1}$ more than the control plots in the 0-15 cm soil depth.

Table 2.14: Paired t-test between bed and furrow

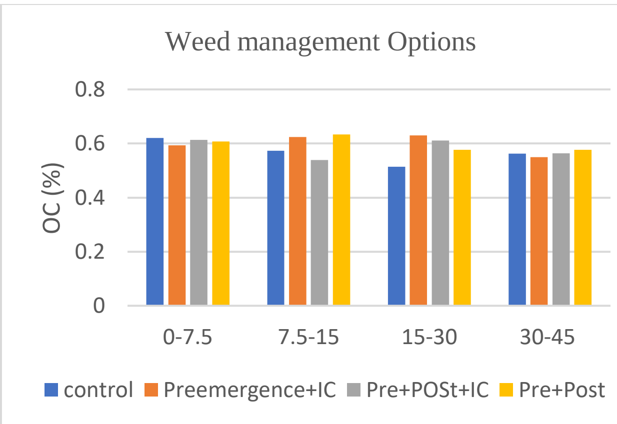
Parameters	0-5 cm	5-15 cm

	Bed	Furrow	t-calculated	Bed	Furrow	t-calculated
Total SOC (g kg^{-1})	7.90	7.34	1.67	7.11	6.66	2.74
Walkley-Black C (g kg^{-1})	5.80	5.55	1.57	5.42	5.01	2.41
Labile C of bulk soils (g kg^{-1})	4.07	3.74	1.84	3.12	2.71	2.53
Recalcitrant C of bulk soils (g kg^{-1})	3.80	3.69	0.77	3.59	3.23	2.32
Permanganate oxidizable C (g kg^{-1})	0.40	0.39	0.14	0.28	0.28	2.40
Water-soluble C (mg kg^{-1})	105	99.7	1.12	85.0	74.0	3.32
Labile C of macroaggregates (g kg^{-1})	4.20	3.96	1.71	3.51	3.12	4.01
Recalcitrant C of macroaggregates (g kg^{-1})	3.86	3.67	1.52	3.92	3.44	4.61
Total SOC within macroaggregates (g kg^{-1})	8.07	7.75	1.41	7.33	6.72	2.90
Labile C of microaggregates (g kg^{-1})	3.86	3.55	2.14	2.66	2.21	2.24
Recalcitrant C of microaggregates (g kg^{-1})	3.51	3.34	1.83	3.35	2.95	2.43
Total SOC within microaggregates (g kg^{-1})	7.38	7.10	1.98	6.57	6.04	2.54

Null hypothesis: Population mean of group A= Population mean of group B; T- table (0.05) value = 2.20

CRIDA

At CRIDA, Hyderabad, in Maize-pigeon pea system at 0-7.5 cm zero tillage with *in situ* moisture conservation (permanent bed and furrow) recorded 12%, 22% and 29 % higher soil organic carbon as compared to conservation agriculture (CA+ live dianch), ZTF, and conventional tillage respectively. Whereas at 7.5-15 cm CA treatment with in situ moisture conservation CA+ permanent conservation furrow or CA and CA (ZT+ dhaincha live mulch). The soil organic carbon beyond 15 cm. The organic carbon was not significantly influenced by the weed management treatments. (Fig. 2.17)



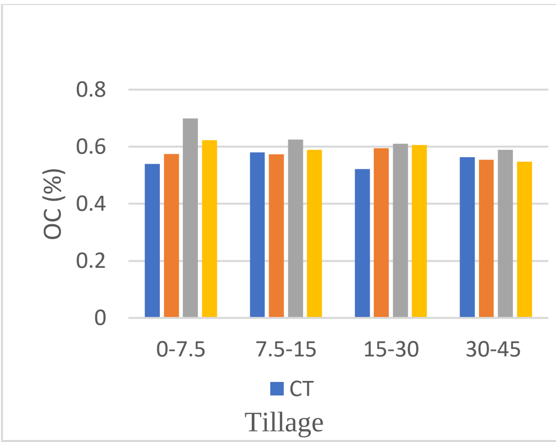


Fig 2.17: Impact of different treatments on Organic carbon (%)

In sorghum -blackgram cropping system with different tillage and residue levels Soil organic carbon in 0-7.5 cm were slightly higher with maximum residue retention, but did not differ with tillage. 7.5-15 cm and 15-30 cm soil did not differ significantly with tillage or residue retention (Fig. 2.18)

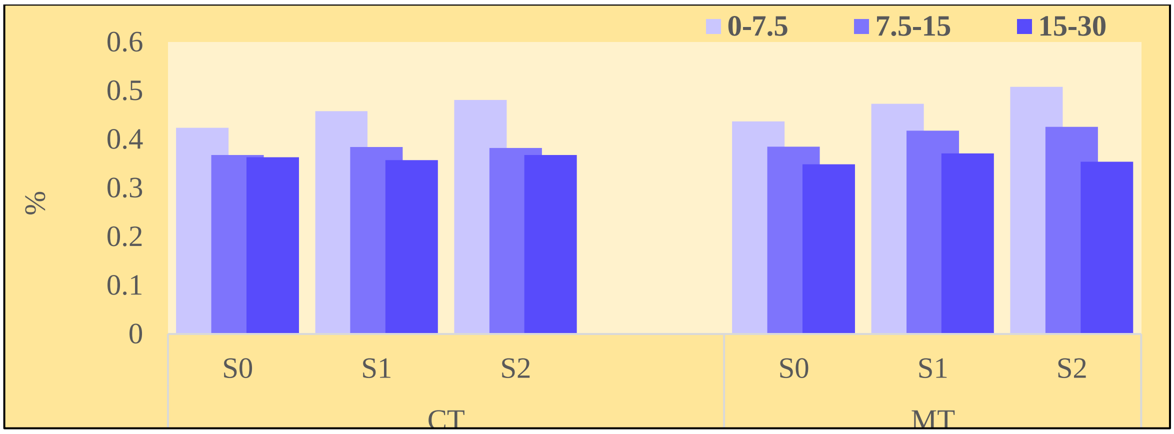


Fig 2.18: Influence of different tillage and residue levels on Soil Organic carbon

In Pearlmillet – Horsegram/ Pigeonpea system, significantly higher SOC was observed in ZT and MT (5.9 g/kg) as compared to CT. Significantly higher very labile and non-labile C was observed in ZT, higher labile C was observed in MT. Higher SOC was observed in 125% RDF due to higher biomass production and higher amount of residue retention.

In Soyabean-Chickpea cropping system, the organic carbon content of soil in different treatments was significant. However, significantly higher organic carbon content (0.66%) was recorded under reduced tillage (RT) – Pre sowing harrowing + Broad bed and furrow every year + Pre-emergence herbicide application + Crop residue mulch (T_3) and was on par with Conventional tillage (CT)- Pre sowing harrowing + One hoeing + One hand weeding + Crop residue mulch(T_1).The lowest organic carbon(0.58%)was recorded with Conventional tillage (CT) - Pre sowing harrowing + One hoeing + One hand weeding + No crop residue mulch(T_2) (Table 2.15).

Table 2.15: Organic carbon status of soil as influenced by different tillage treatments at 0-7.5 cm in soybean- chickpea system

Treatment	Organic carbon (%)
T_1	0.64
T_2	0.58
T_3	0.66
T_4	0.61
T_5	0.60
SE(m±)	0.01
CD (5%)	0.02

In fingermillet -pigeonpea cropping system the organic carbon was on par in reduced and zero tillage. These two treatments were superior over conventional tillage. The horsegram cover crop recorded significantly higher organic carbon over sunhemp and control (without cover crop) (Table 2.16).

Table 2.16: Effect of different tillage and cover crops on OC (%) at different depths

Treatments	OC%		
Depth	07.5 cm	7.5-15cm	15 -30cm
Tillage practice			
Conventional tillage	0.41	0.38	0.36
Reduced tillage	0.54	0.51	0.48
Zero tillage	0.55	0.52	0.50
CD (p=0.05)	0.03	0.05	0.02
Cover crops			
Control	0.41	0.39	0.38
Sunhemp	0.52	0.47	0.44

Horsegram	0.57	0.54	0.52
CD (p=0.05)	0.05	0.04	0.04

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

IIFSR

At IIFSR, Modipuram, incorporation of summer greengram in R-W-GG and M-M-GG both in CA and CT based cropping systems recorded 22.58%, 12.84% and 31.16% higher soil available N in R-W-GG (CA), M-M-GG (CT) and M-M-GG (CA) cropping systems over the R-W-GG (CT) treatment (Table 2.17). Among the different treatments sugarcane crop grown in reduced tillage (RT) recorded 89.52% higher available K over the R-W (CT). Among the treatments with summer mungbean with ZT ZTDSR-ZTW-ZTGG recorded 53.62% higher available K over the CT based treatment. All the treatments comprised of CA based management practices i.e. ZTDSR-ZTW, ZTDSR-ZTW-ZTGG, ZTM-ZTM-ZTGG and RTS-R-ZTW recorded 10.84%, 16.73%, 126.6% and 86.55% higher available S as compared 86.55% higher available S as compared to business as usual (PTR-CTW), respectively (Table 2.17).

Table 2.17: Influence of different CA based management practices on soil physicochemical properties in diverse cropping systems

	Tillage	Avail. N (kg/ha)	Avail P (kg/ha)	Avail. K (kg/ha)	Avail. S (mg/kg)
Cropping Systems					
R-W	PTR-CT	164.7	55.81	146.9	14.94
R-W	ZTDSR-ZT	205.9	57.16	165.0	16.56
R-W-GG	PTR-CT-CT	171.4	66.96	153.5	15.51
R-W-GG	ZTDSR-ZT-ZT	210.1	81.81	235.8	17.44
M-M-GG	CT-CT-CT	193.4	51.23	181.9	30.58
M-M-GG	ZT-ZT-ZT	224.8	53.63	174.8	33.86
S-R-W	CT-CT-CT	176.7	54.54	231.1	16.84
S+GG-R-W	RT-ZT-ZT	186.1	74.95	278.4	27.87
Sem (±)		13.69	1.523	3.58	1.113
C.D. (p<5%)		39.73	4.42	10.38	3.229
Soil Depth					
0-15 cm		197.0	70.12	237.9	20.68
15-30 cm		183.7	53.90	156.5	15.72
Sem (±)		6.845	0.762	1.79	0.556
C.D. (p<5%)		19.87	2.21	5.19	1.614

B.D.=bulk density; WHC=water holding capacity; EC=electrical conductivity; WBC=Walkley-Black carbon; PTR=puddled transplanted rice; ZTDSR=zero tilled direct seeded rice; CT=conventional tillage; ZT=zero tillage.

Plate 45: ZT wheat in R-W-GG cropping system

Plate 46: Plant growth parameters data collection

Plate 47: Greenseeker data collection in CA practices

Plate 48: GHG emission measurement in CA practices

NIASM

CSSRI

At CSSRI, Karnal, surface soil (0-15 cm), the ZT+R treatment exhibited the highest available N, recording a 25.08% increase compared to CT-R (Table 2.18). This trend persisted in the subsurface soil, where the ZT+R treatment also displayed 4.06% higher available N compared to CT -R. The addition of crop residues under ZT influenced the nutrient mineralization cycle, particularly enhancing N availability compared to conventional tillage. Available P and K ranged from 23.93-34.07 kg ha^{-1} and 236.53-271.45 kg ha^{-1}, respectively, at 0-15 cm soil depth. Maximum P content was reported in RT+R, showing a 23.77% and 17.75% increase compared to CT-R at surface and subsurface soil, respectively. This observed rise in soil available P content could be because of the release of organic acids during crop residue decomposition and the subsequent solubilization of native P. Additionally, reduced tillage treatments with retention of fresh crop residue minimized the mixing of applied soluble phosphatic fertilizers with soil and therefore reducing the chances of P fixation and enhancing its availability. However, in CT practice, availability of labile P is reduced because of maximum soil mixing and subsequent P fixation. The highest available K was consistently recorded in the ZT+R treatment, exhibiting 14.6% and 11.0% increase over CT-R at both depths. Contrast analysis highlighted significant differences in available macronutrients (N, P, and K content) among all tillage practices in surface soil. In subsurface soil, only available P exhibited contrasting results, increasing by 9.20 and 5.98% with RT and ZT compared to CT. Regardless of tillage practices, addition of crop residue significantly increased soil macronutrient content (N, P, and K) by 9.94,7.64 and 6.06% at 0-15 cm and 6.28, 14.09 and 3.24% at 15-30 cm soil depth.

Table 2.18: Soil available major and micronutrient after 15-years of tillage and residue management in rice-wheat system (2-years pooled average data)

Treatments/ scenarios	Available major nutrient (kg ha^{-1})

	N	P	K
0-15 cm soil layer			
CT-R	104.76^{d}	23.93^{d}	236.88^{c}
CT+R	109.21^{c}	26.48^{c}	254.85^{b}
RT-R	112.59^{c}	28.97^{b}	236.53^{c}
RT+R	119.99^{b}	34.07^{a}	243.76^{c}
ZT-R	110.41^{c}	27.01^{c}	252.68^{b}
ZT+R	131.04^{a}	33.42^{a}	271.45^{a}
Treatment	***	***	***
Year	***	***	***
Treatment × Year	***	***	***
Contrast			
-R *vs* +R	***	***	***
CT *vs* RT	***	***	*
CT *vs* ZT	***	***	***
RT *vs* ZT	*	**	***
15-30 cm soil layer			
CT-R	92.88^{b}	21.08^{b}	237.39^{c}
CT+R	98.71^{ab}	22.16^{b}	246.73^{ab}
RT-R	93.83^{b}	21.13^{b}	242.37^{bc}
RT+R	100.00^{a}	26.10^{a}	247.89^{ab}
ZT-R	96.89^{ab}	22.43^{b}	242.38^{bc}
ZT+R	102.71^{a}	23.40^{b}	250.93^{a}
Treatment	*	***	**
Year	NS	NS	*
Treatment × Year	***	***	*
Contrast			
-R *vs* +R	*	***	**
CT *vs* RT	NS	***	NS
CT *vs* ZT	NS	*	NS
RT *vs* ZT	NS	NS	NS

Treatment means within a column with dissimilar letters (lowercase) varied significantly ($P < 0.05$, Tukey's test) ***, **, * represent 0.1% (0.001), 1% (0.01), and 5% (0.05) level of significance, and NS represent non-significant. CT, RT and ZT represent conventional, reduced and zero tillage, respectively. -R and +R represent no crop residues and 1/3rd crop residue addition, respectively.

IISS

Under the maize- chickpea and soybean-wheat systems at ICAR-IISS, Bhopal, the data on available N at various soil depths is given in Table 2.19. There was no significant effect of tillage and nutrient management on soil available nutrient under soybean–wheat system. Under maize-chickpea cropping system, significantly higher value of available N was observed under T_2 (NT 60 cm residue) at 0-10 cm soil depth, while both T_2 and T_4 (RT with 60 cm residue height) had similar and higher values of available N in deeper layers. Nutrient management treatments had a significant effect on available N as the highest value was recorded under N_3 (STCR) treatment at 0-10 soil depth.

Table 2.19: Effect of conservation agriculture on Available Nitrogen value under different tillage and nutrient management practices at different soil depths.

Treatments	Available N (Maize-Chickpea) kg/ha			Available N (Soybean-Wheat) kg/ha		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
T1	272.33	118.96	102.02	146.98	129.62	112.20
T2	274.64	122.29	103.40	148.11	134.50	108.72

T3	260.59	121.44	101.72	151.12	133.80	108.72
T4	263.49	122.90	110.16	151.12	135.89	120.56
T5	260.29	117.80	101.28	155.53	117.78	102.44
CD	**6.348**	**NA**	**4.502**	**NA**	**NA**	**NA**
N100	267.96	121.37	104.21	149.37	128.37	111.64
N75	258.97	117.27	102.73	147.24	130.04	105.37
STCR 150	271.88	123.40	104.22	155.11	132.55	114.57
CD	**5.813**	**1.854**	**NA**	**NA**	**NA**	**NA**

The data on available phosphorus in soil are given in Table 2.20. Values of available P in soil was found higher in the upper layer of the soil i.e. 0-10 cm under both the cropping systems. Under soybean–wheat cropping system,a significant higher value of available P was observed under T_2 (NT 60 cm residue) at 0-10 cm soil depth, while in deeper layers, higher amount was found under both T_2 and T_4 (RT 60 cm residue) treatments. Nutrient management treatments had no significant effect on available P, while the highest value was recorded under N_3 (STCR) treatments at 0-10 soil depth under soybean –wheat cropping system.

Under maize-chickpea cropping system, non-significant higher value of available P was observed under T_2 (NT 60 cm residue) at 0-10 cm soil depth, while both T_2 and T_4 (RT with 60 cm residue height) had similar and higher values of available P in deeper layers. Nutrient management treatments had significant effect on available P as the highest value was recorded under N_3 (STCR) treatments at 0-10 soil depth, while the 75% of RDF treatment had the lowest available P content.

Under maize-chickpea cropping system,non-significant higher value of available P was observed under T_2 (NT 60 cm residue) at 0-10 cm soil depth, while both T_2 and T_4 (RT with 60 cm residue height) had similar and higher values of available P in deeper layers. Nutrient management treatments had significant effect on available P ast the highest value was recorded under N3 (STCR) treatments at 0-10 soil depth, while the 75% of RDF treatment had the lowest available P content.

Table 2.20: Effect of conservation agriculture on Available Phosphorus under different tillage and nutrient management practices at different soil depths.

Treatments	**Available P (Maize-Gram) kg/ha**			**Available P (Soybean-Wheat) kg/ha**		
	0-10 cm	**10-20 cm**	**20-30 cm**	**0-10 cm**	**10-20 cm**	**20-30 cm**
T1	26.43	22.23	5.46	25.80	17.50	14.96
T2	30.24	23.46	5.49	26.61	17.92	15.44
T3	24.62	23.63	5.39	25.80	17.70	15.30
T4	27.12	24.67	5.56	26.44	18.34	17.49
T5	23.91	20.09	5.07	21.48	16.28	12.94
CD	**NA**	**2.062**	**NA**	**2.309**	**NA**	**1.763**
N100	27.57	23.27	5.43	25.09	17.72	15.37
N75	24.06	20.02	4.79	24.18	16.09	14.65
STCR 150	27.77	25.15	5.96	26.40	18.83	15.66
CD	**2.29**	**1.935**	**0.485**	**NA**	**NA**	**NA**

The data on available K content are given in Table 2.21. The uppermost layer was found to be rich in available K content under both the cropping systems. Under soybean –wheat cropping system, significantly higher value of available K was observed under T_2 (NT 60 cm residue) at 0-10 cm soil depth. Nutrient management treatments had significant effect on available K as the highest value was recorded under N_1 (100% RDF) treatments at 0-10 soil depth. Under maize-chickpea system, the significantly higher value of available K was observed under T_1 (NT 30 cm residue) at all soil depths. Nutrient management treatments had significant effect on available K as highest value was recorded under N_1 (100% RDF) treatments at 0-10 soil depth.

Table 2.21: Effect of conservation agriculture on Available Potassium value under different tillage and nutrient management practices at different soil depths

Treatments	Available K (Maize-Gram) kg/ha			Available (Soybean-Wheat) kg/ha		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
T1	593.58	292.44	221.84	524.94	260.34	215.34
T2	536.29	262.86	187.42	548.95	267.29	222.28
T3	566.89	268.02	175.27	515.25	249.50	204.50
T4	533.22	266.86	209.02	545.96	249.01	204.01
T5	510.61	244.65	187.32	511.81	262.61	217.61
CD	**19.943**	**3.306**	**21.31**	**22.57**	**NA**	**NA**
N100	575.05	294.13	206.53	540.04	263.41	218.41
N75	565.16	263.77	192.17	534.00	259.24	214.24
STCR 150	504.14	242.99	189.82	514.11	250.59	205.59
CD	**4.547**	**6.15**	**NA**	**13.784**	**NA**	**NA**

Soil nutrients dynamics under different levels of residue retention under no-till system in central India

After the lapse of 8 cropping cycles, soil samples from 0-10 cm and 10-20 cm collected from no till experiment with different levels of residue retention in soybean-wheat and maize-chickpea rotations. Samples were analyzed for total carbon, total nitrogen and available nitrogen, phosphorus and potassium concentration. Under maize chickpea rotation, retention of residue significantly improved soil total carbon concentration in 0-10 cm of depth. It was observed that retention of 60% and more of residues of previous crops resulted in significant increase in soil carbon concentration. Retention of 60 and 90 % of residue of previous crops resulted in improvement of total carbon concentration to the extent of 32 and 41%, respectively. The trend was similar for total N concentration. Here also, retention of residue resulted in improvement in soil total N concentration. However, significant improvement was noticed only where 60% or more of residues were retained. Retention of 60 and 90 % of residue of previous crops resulted in improvement of total nitrogen concentration to the extent of 21 and 24%, respectively in comparison to conventionally tilled agriculture.

Under soybean wheat rotation, here also retention of residue along with no tillage improved soil total carbon and nitrogen content in 0-10 cm of soil depth. Here, retention of 90% of residues of previous crops could only make significant change in soil total carbon concentration. It was observed that retention of 90% of residues resulted in 19% increase in soil total carbon concentration in comparison to conventionally tilled plot. Retention of 30 and 60% of residues of previous crop could not make any significant change in soil total carbon concentration. The similar trend was also observed for total N concentration. Retention of 90% of residues of previous crop increased total N concentration by 16% as compared to no residue retained plot. In 10-20 cm of depth, no significant impact of no tillage and residue retention was observed on changes on soil total carbon and nitrogen concentrations in soybean-wheat cropping system.

Table 2.22: Effect of soil nutrients dynamics under different levels of residue retention under no-till system with different levels of residue retention in soybean-wheat and maize-chickpea rotations

Treatments	Maize-chickpea rotation				Soybean-wheat cropping system			
	0-10 cm		10-20 cm		0-10 cm		10-20 cm	
	TC (%)	TN (%)	TC (%)	TN (%)	TC (%)	TN (%)	TC (%)	TN (%)
NT-0% Residue retention	1.30ab	0.134ab	0.84a	0.094a	1.15a	0.115a	0.74a	0.079a
NT-30% Residue retention	1.37ab	0.135ab	0.80a	0.085a	1.14a	0.113a	0.77a	0.085ab
NT-60% Residue retention	1.44b	0.143b	0.72a	0.074a	1.25ab	0.124ab	0.72a	0.078a

NT-90% Residue retention	1.54b	0.146b	0.77a	0.079a	1.36b	0.134b	0.76a	0.077a
CT-0% Residue retention	1.09a	0.118a	0.81a	0.082a	1.14a	0.122ab	0.80a	0.0917b

An effort was made to understand the nutrient dynamics after adoption of 8 years of conservation agriculture. Soil available N, P and K was measured in 0-10 cm and 10-20 cm of soil depths under soybean wheat and maize-chickpea rotation. Under maize- chickpea rotation, no significant impact of no till system with residue retention on soil available nutrient status was noticed in either of the two depths. However, under soybean-wheat copping system, retention of 90% of residues of previous crops resulted in significant improvement in soil available N in comparison to conventionally tilled agriculture. Regarding available P and K, no significant impact of residue retention as observed.

Table 2.23: Effect of soil nutrients dynamics under different levels of residue retention under no-till system with different levels of residue retention in Maize-chickpea rotation

Treatments	0-10 cm			10-20 cm		
	AN (kg/ha)	AP (kg/ha)	AK (kg/ha)	AN (kg/ha)	AP (kg/ha)	AK (kg/ha)
NT-0% Residue retention	217.4a	33.6a	563.8a	179.8a	5.2a	304.2a
NT-30% Residue retention	211.2a	30.6aa	659.2a	184.0a	5.2a	310.3a
NT-60% Residue retention	209.1a	25.3a	667.1a	179.8a	3.7a	273.2a
NT-90% Residue retention	207.0a	22.4a	658.1a	177.7a	5.2a	304.7a
CT-0% Residue retention	196.5a	19.4a	611.5a	175.6a	5.2a	273.1a

However, under soybean-wheat copping system, retention of 90% of residues of previous crops resulted in significant improvement in soil available N in comparison to conventionally tilled agriculture. Regarding available P and K, no significant impact of residue retention as observed (Table 2.24)

Table 2.24: Effect of soil nutrients dynamics under different levels of residue retention under no-till system with different levels of residue retention in Soybean-wheat cropping system

Treatments	0-10 cm			10-20 cm		
	AN (kg/ha)	AP (kg/ha)	AK (kg/ha)	AN (kg/ha)	AP (kg/ha)	AK (kg/ha)
NT-0% Residue retention	199.7ab	29.1a	663.9a	172.5a	8.2a	333.9a
NT-30% Residue retention	196.5ab	23.5a	568.9a	167.2a	9.0a	321.1a
NT-60% Residue retention	200.7ab	26.9a	681.1a	170.4a	8.2a	322.4a
NT-90% Residue retention	211.1b	30.6a	735.35a	165.2a	8.6a	315.6a
CT-0% Residue retention	190.2a	25.4a	658.1a	177.7a	5.2a	318.4a

RCER

Post-harvest soils of rice-linseed-green gram cropping system of Chene, Jharkhand during 202-24. Available-P content was the highest of 19.78 kg/ha in ZTTR treatment and found significantly higher over CTDSR & rice-fallow treatment. Available-K content was the highest of ZTDSR (table-2.25).

Table 2.25: Effect of CA practices on changes of soil properties in post-harvest soils of rice-linseed-greengram system of Chene, Jharkhand

Treatment	**Available N (kg/ha)**	**Available P (kg/ha)**	**Available K (kg/ha)**
Crop establishment methods			
Rice-fallow	171.1	14.45	156.7
ZTDSR	190.6	18.83	183.1
CTDSR	178.4	16.20	171.0

ZTTR	194.4	19.78	181.9
FPTR	181.6	18.23	173.8
SEm (±)	4.86	0.76	4.09
LSD (p≤0.05)	14.97	2.34	12.61

ZTTR- zero-tillage transplanted rice, ZTDSR- zero-tillage direct seeded rice, CTDSR- conventional tillage direct seeded rice, FPTR - farmer's puddled transplanted rice and rice-fallow

CRIDA

Soil Available nutrients

At ICAR- CRIDA Hyderabad, in Maize-pigeonpea cropping system with in situ moisture conservation and weed management options ZT+ PB (Permanent bed and furrow) recorded higher available phosphorus over other ZTS (CA+ live mulch), ZT+ permanent CF and CT up to 45 cm. Whereas CA+CF recorded lowest available phosphorus. (Fig. 2.19). Pre+post emergence herbicide application recorded higher available phosphorus in the surface layers but beyond 15 cm there was no significant difference among weed management options.

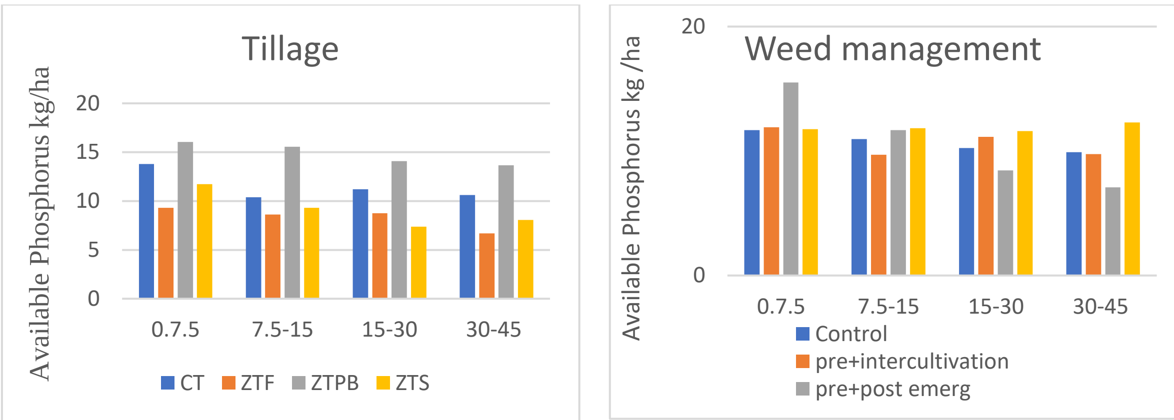


Fig 2.19: Impact of different treatments on Available Phosphorus

In pearlmillet – horsegram/ pigeonpea system, significantly higher available nitrogen, phosphorus and potassium were recorded in conventional tillage (220, 31 and 224 kg/ha, respectively) compared to zero tillage. In cotton-pigeonpea system, significantly higher available N after harvest of cotton was observed in MT (128 kg/ha) and ZT (124 kg/ha) compared to the CT (103 kg/ha). Whereas in nutrient management higher available N was observed in 125% RDF (134 kg/ha) and 100% RDF (114 kg/ha) compared to the 75% RDF (107 kg/ha). With increasing depth either increases or decreases. Significantly higher available K after harvest of cotton was observed in MT (226 kg/ha) and ZT (226 kg/ha) as compared to CT (193 kg/ha). Whereas in nutrient management higher available K was observed in 125% RDF (244 kg/ha) and 100% RDF (219 kg/ha) compared to the 75% RDF (182 kg/ha). With increasing depth either increases or decreases.

In sorghum- blackgram system the available nitrogen was slightly higher in 0-7.5 cm with residue levels but tillage treatments did not significantly influenced the available nitrogen. However available P, K and micronutrients did not show any significant difference in any of the depths, either with tillage or residue retention

In soyabean-chickpea cropping system, the available nutrients were significantly influenced by different tillage and residue treatments. Available nitrogen content in soil was influenced by various treatments. Higher available nitrogen content (190.18 kg ha^{-1}) was recorded under reduced tillage (RT) – Pre sowing harrowing + Broad bed and furrow every year + Pre-emergence herbicide application + Crop residue mulch (T_3) and was on par with Conventional tillage (CT)- Pre sowing harrowing + One hoeing + One hand weeding + Crop residue mulch(T_1).The lowest available nitrogen (182.19kg ha^{-1}) was recorded with Conventional tillage (CT) - Pre sowing harrowing + One hoeing + One hand weeding + No crop residue mulch(T_2).

The available phosphorus content in soil was significantly higher under reduced tillage (RT) – Pre-sowing harrowing + Broad bed and furrow every year + Pre-emergence herbicide application + Crop residue mulch (T_3) and was on par with conventional tillage (CT)- pre sowing harrowing + one hoeing + one hand weeding + Crop residue mulch(T_1). The lowest available phosphorus (19.60kg ha^{-1}) was recorded with Conventional tillage (CT) - Pre sowing harrowing + One hoeing + One hand weeding + No crop residue mulch(T_2).

The available potassium content was significantly higher in reduced tillage (RT) – Pre sowing harrowing + Broad bed and furrow every year + Pre-emergence herbicide application + Crop residue mulch (T_3) and was on par with Conventional tillage (CT)- Pre sowing harrowing + One hoeing + One hand weeding + Crop residue mulch(T_1).The lowest available potassium (297.58kg ha^{-1})was recorded with Conventional tillage (CT) - Pre sowing harrowing + One hoeing + One hand weeding + No crop residue mulch(T_2). In general, reduced tillage with BBF and crop residue mulch helped in slight build up in organic carbon and available nutrients in soil (Table 2.26).

Table 2.26: Available nutrient status of soil as influenced by various treatments during 2023-24

Treatment	Available Nutrients (kg ha^{-1})		
	N	P	K
T_1	188.11	21.93	301.44
T_2	182.19	19.60	297.58
T_3	190.18	22.94	302.90
T_4	183.70	20.72	298.46
T_5	185.39	20.53	300.04
SE(m±)	0.73	0.38	0.63
CD (5%)	2.24	1.16	1.94

In finge rmillet-pigeonpea cropping system reduced tillage recorded significantly higher available N at all the depths. Whereas available phosphorus and potassium was higher in reduced tillage but this was on par with zero tillage and these two treatments were significantly superior over conventional tillage. In general, available nutrients (NPK) were higher with the cover crops. Among the intercrops horse gram recorded higher available NPK as compared to sunhemp and no cover crops (Table 2.27).

Table 2.27: Effect of different tillage levels and cover crops on available nutrients

Treatments	**Nitrogen (kg ha^{1})**			**Phosphorus (kg ha^{-1})**			**Potassium (kg ha^{-1})**		
Depth	**0-7.5**	**7.5-15**	**15-30**	**0-7.5**	**7.5-15**	**15-30**	**0-7.5**	**7.5-15**	**15-30**
Conventional tillage	203	178	171	73.2	73.73	71.33	152	134	124
Reduced tillage	314	291	256	113.5	104.2	99.06	197	184	175
Zero tillage	248	225	209	104.7	98.05	93.11	190	173	164
CD (p=0.05)	22.94	9.65	21.02	12.65	13.92	4.3	24.09	14.16	13.59
Control	213	194	187	76.1	73.78	72.64	148	132	124
Sunhemp	247	219	206	102.2	95.4	91.9	201	184	174
Horsegram	304	280	242	113.1	106.8	98.96	191	175	165
CD (p=0.05)	20.96	17.62	19.85	8.02	7.81	5.48	14.98	15.49	14.58

C. pH and EC

IISS

The data pertaining to soil pH at various soil depths under maize-chickpea and soybean –wheat system at ICAR-IISS, Bhopal, is given in Table 2.28. Under both the cropping systems, soil pH value increased with soil depth. Deeper layer showed higher amount of pH which was similar to T_4 (RT with 60 cm residue height) under soybean –wheat cropping system. Among different nutrient management systems, 100% RDF and STCR N doses had higher soil pH at 10-20 cm soil depth over 75% RDF N. The pH value of the upper soil (0-10 cm) in the maize-chickpea cropping system for STCR N dose was found comparable with 100% RDF and 75 % RDF. Among the tillage system, thenon-significant higher value of pH was observed under T_4 and T_1 (RT 60 cm residue and NT 30 cm residue) at 0-10 cm soil depth, while the deeper layers had higher pH which was found similar in T_4 (RT with 60 cm residue height) and T_5 (Conventional tillage) under maize-chickpea cropping system.

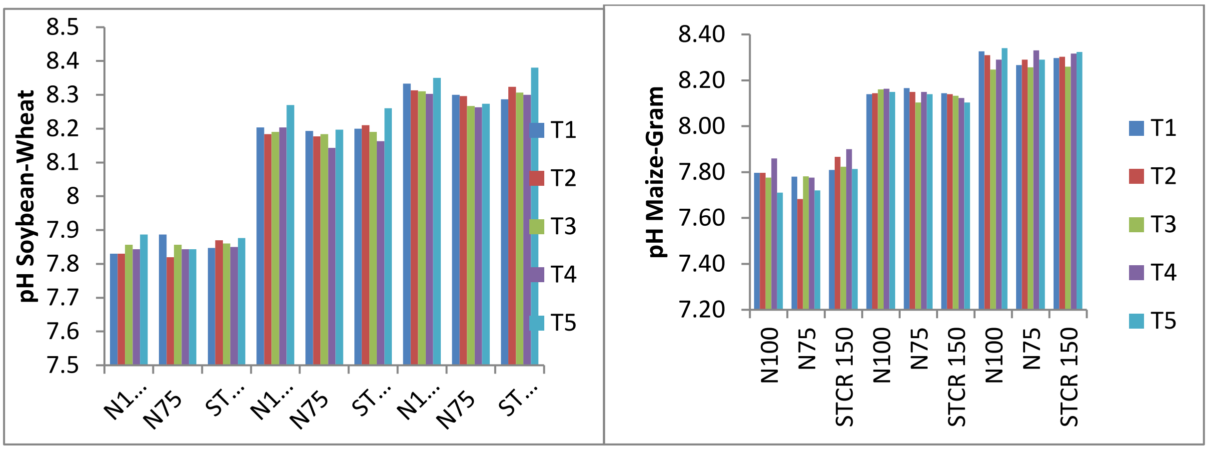


Fig 2.20: Soil pH as influenced by conservation tillage and nutrient management under soybean-wheat and maize – chickpea cropping system

T_1- No tillage + 30 cm. crop residue, **T_2-** No Tillage + 60 cm crop residue, **T_3** – Reduced tillage (RT) + 30cm crop residue **T_4-** Reduced tillage (RT) + 60cm crop residue, **T_5-** Conventional tillage (CT) **N_{100}-** 100% Recommended dose of nutrient, **N_{75}-** 75% of Recommended dose of nutrient, **STCR $_{150}$-** 150% of recommended dose of fertilizer.

Table 2.28: Effect of conservation agriculture on soil pH value under different tillage and nutrient management practices at different soil depths

Treatments	pH (Maize-Gram)			pH (Soybean-Wheat)		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
T1	7.80	8.15	8.30	7.85	8.20	8.31
T2	7.78	8.14	8.30	7.84	8.19	8.31
T3	7.79	8.13	8.25	7.86	8.19	8.29
T4	7.85	8.15	8.31	7.85	8.17	8.29
T5	7.75	8.13	8.32	7.87	8.24	8.33
CD	**NA**	**NA**	**NA**	**NA**	**0.024**	**NA**
N100	7.79	8.15	8.30	7.85	8.21	8.32
N75	7.75	8.14	8.29	7.85	8.18	8.28
STCR 150	7.84	8.13	8.30	7.86	8.21	8.32
CD	**0.047**	**NA**	**NA**	**NA**	**0.022**	**0.036**

Observed values of soil electrical conductivity are given in Table 2.29. The values of electrical conductivity decreased with increasing depth of the soil under both the cropping systems. Under soybean–wheat cropping system, tillage had non-significant effect on soil EC. Nutrient management treatments were found to have significant effect on EC. Highest value was recorded under N_3 (STCR) at 0-10 soil depth under soybean–wheat cropping system.

In the maize-chickpea cropping system, the significant higher value of EC was observed under T_1 (NT 30 cm residue) at 0-10 cm soil depth. Nutrient management treatments had significant effect on EC as the highest value was recorded under N_1 (100% RDF) treatments at 0-10 soil depth.

Table 2.29: Effect of conservation agriculture on EC value under different tillage and nutrient management practices at different soil depths

Treatments	EC (Maize-Chickpea)			EC (Soybean-Wheat)		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm

T1	278.16	168.15	158.08	233.80	179.51	146.98
T2	262.67	165.13	149.20	237.50	186.81	148.11
T3	210.31	154.04	145.56	239.77	178.46	151.12
T4	269.49	177.06	152.00	241.93	178.46	151.12
T5	236.56	181.87	139.62	229.90	196.47	155.53
CD	**19.91**	**9.121**	**5.752**	**N/A**	**N/A**	**N/A**
N100	285.45	169.87	152.13	234.86	189.69	149.37
N75	244.71	175.15	149.53	235.52	184.28	147.24
STCR 150	224.15	162.73	145.01	239.36	177.85	155.11
CD	**13.475**	**6.213**	**2.825**	**2.267**	**8.296**	**N/A**

D. NH4 – N, NO3 – N, and Mineral-N Concentration (mg kg – 1)

IARI

Spatial and temporal distribution of soil nitrogen release were carried out in pigeon pea (*Cajunus cajan* L.) crop under conservation agriculture (CA) based pigeon pea-wheat system. The treatment includes, conventional tillage (CT); permanent narrow bed (PNB); PNB with residues of previous crop (PNB+R); permanent broad bed (PBB), PBB with residues (PBB+R), flat bed (FB) and FB with residues (FB+R). Soil samples were collected from pre-flowering, flowering, pod filling and harvest stage of pigeon pea from two depths (0-15 and 15-30 cm).

Ammonium-N (NH_4-N)
In general, adoption of CA practices (after 10 years) increased ammonium nitrogen concentration in soil at different growth stages of crop (Table 2.30). At all physiological crop growth stages highest NH_4-N concentration in soil was recorded in PBB+R plots and it was 131, 100, 77 and 73% higher than CT plots at pre-flowering, flowering, pod filling and harvesting stage, respectively in 0-15 cm of soil depth. Continuous residue retention along with zero tillage in different bed system (crop establishment method) increased the NH_4-N content from 6.7 mg kg^{-1} (CT) to 15.7 mg kg^{-1} (PBB+R) at the pre-flowering stage of crop and this trend was also recorded in other physiological crop growth stages. The highest concentration of NH_4-N in soil was noticed at flowering stage and it was 145% higher than pre-flowering stage of crop. However, the concentration of NH_4-N in soil decreased at pod filling (16.6 mg kg^{-1}) and harvesting stages (8.5 mg kg^{-1}) compared to flowering stage (25.4 mg kg^{-1}). Residues of crops have sufficient amount of C and N that can act as convenient substrate for soil microorganisms, hence it significantly improved mineralization of N in soil. In addition to this, CA practices have relatively less soil disturbance in combination of residue retention, which also stimulated ammonification process and resulted increased NH4-N concentration in CA plots as compared to CT plots. Crop establishment methods (without residue plots) were also positively affected NH_4-N concentration in soil although the effect was marginal in some of the treatment as compared to conventional tillage. Among zero tilled without residues retained plots, at pre-flowering and flowering stages, PBB plots recorded significantly highest NH_4-N concentration, which was 52 and 38% higher than CT plots. The mean NH_4-N concentration of residue retained plots was statistically at par, although it was higher than that of without residue retained and CT plots. Lower concentration NH_4-N at pre-flowering stage compared to flowering and pod-filling stages might be due to immobilization of N during initial phase of crop residue decomposition.
As like 0-15 cm, residue retention and crop establishment methods had significant impact on NH_4-N concentration of soil at different growth stage of pigeon pea in 15-30 cm depth, although the intensity of effect was less (Table 2.31). In 15-30 cm of soil depth, NH_4-N concentration in PBB+R plots at different crop growth stage was 177, 102, and 71% higher as compared to CT plots at pre-flowering, flowering and pod filling stage, respectively. Most importantly, NH_4-N concentration in soil was not significantly altered by crop establishment methods as well as crop residue retention at harvesting stage crop. The average soil NH_4-N concentration increased by 35% from pre-flowering (6.2 mg kg^{-1}) to flowering (8.4 mg kg^{-1}), and decreased by 33 and 58%, respectively, at the pod filling, and harvesting stage.

Table 2.30: Ammonium nitrogen (mg kg^{-1} soil) concentration in 0-15 cm depth of soil at different growth stage of pigeon pea under conservation agriculture.

Treatments	Pre-flowering	Flowering	Pod filling	Harvest	Mean
CT	6.8^{d}	17.4^{d}	12.2^{e}	6.6^{b}	10.7^{d}
PNB	7.8^{d}	23.0^{c}	16.3^{cd}	7.9^{b}	13.8^{bcd}
PNB+R	10.0^{c}	29.7^{b}	16.8^{c}	8.7^{ab}	16.3^{abc}
PBB	10.3^{c}	24.1^{c}	15.7^{cd}	7.3^{b}	14.3^{bcd}
PBB+R	15.7^{a}	34.8^{a}	21.6^{a}	11.4^{a}	20.9^{a}
FB	8.7^{cd}	18.0^{d}	14.8^{d}	7.7^{b}	12.3^{cd}
FB+R	13.2^{b}	31.0^{ab}	19.4^{b}	9.9^{ab}	18.4^{ab}
Mean	10.3	25.4	16.6	8.5	15.2
Tukey's HSD ($p \leq 0.05$)	2.1	4.1	1.9	3.4	NA

Table 2.31: Ammonium nitrogen (mg kg^{-1} soil) concentration in 15-30 cm depth of soil at different growth stage of pigeon pea under conservation agriculture.

Treatments	Pre-flowering	Flowering	Pod filling	Harvest	Mean
CT	3.8^{e}	6.1^{d}	4.4^{c}	3.8	4.5^{b}
PNB	4.5^{de}	5.0^{d}	5.3^{bc}	3.2	4.5^{b}
PNB+R	4.6^{de}	9.2^{bc}	5.8^{b}	2.9	5.6^{ab}
PBB	6.0^{c}	7.9^{c}	4.8^{bc}	3.6	5.6^{ab}
PBB+R	10.5^{a}	12.5^{a}	7.4^{a}	3.7	8.5^{a}
FB	5.6^{cd}	8.2^{c}	5.4^{bc}	3.5	5.7^{ab}
FB+R	8.5^{b}	9.8^{b}	6.0^{ab}	3.6	7.0^{ab}
Mean	6.2	8.4	5.6	3.5	5.9
Tukey's HSD ($p \leq 0.05$)	1.1	1.3	1.4	1.1	NA

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; FB: Planting on flat bed with ZT; FB+R: FB with residue retention. Means followed by same letters within a column are not significantly different at $p < 0.05$ according to Tukey's HSD test.

Nitrate nitrogen (NO_3-N)

As like NH_4-N concentration, NO_3-N concentration in soil was significantly affected by crop residue retention (Table 2.32 and 2.33). In general, higher NO_3-N concentration was noticed in PBB+R plots and lower in CT plots irrespective of soil depth and crop growth stages. Among crop residue retained plots, PBB+R at flowering and pod-filling stages recorded significantly higher NO_3-N than other residue retained plots. Among the treatments at various crop growth stages NO_3-N was highest at pre-flowering stage (44.2 mg kg^{-1} soil) under PBB+R plots, which was 81, 55, 48, 34, 14 and 6%, higher over CT, PNB, FB, PBB, PNB+R and FB+R plots, respectively. It is evident from the data that NO_3-N was 61, 57 and 95% higher in PBB+R plots than CT plots at flowering, pod filling and harvesting stage respectively.

Maximum mean NO_3-N concentration was noticed at pre-flowering stage followed by pod filling > flowering > harvest stage in both the depth of soil. At pre-flowering stage residue retained PBB, PNB, FB recorded 40, 34 and 35 % higher NO_3-N than without residue retained plots with same crop establishment methods plots, respectively. At the time of pod filling stage, NO_3-N was found highest in treatment PBB+R and it was statistically at par with PNB+R treatment whereas superior over other treatments. Higher NO_3-N also related to the preferential oxidation of AOA to ammonia from organic nitrogen (derived from long-term retention of crop residues) mineralization, and AOA possesses a high affinity to ammonia, especially if the ammonia oxidation rate exceeds the mineralization rate. In 15 - 30 cm of soil depth, the average NO_3-N concentration decreased by 69, 72, 73 and 75% at pre-flowering, flowering, pod filling and harvesting stages respectively, compared to 0-15 cm soil depth (Table 2.32). In 15-30 cm soil depth, the mean NO_3-N at different crop growth stage was highest under PBB+R (10.3

mg kg^{-1}) plots which was 49, 46, 42, 37, 23 and 11 % higher over CT, PNB, FB, PBB, PNB+R, and FB+R plots, respectively (Table 2.33). It appears that higher NO_3-N availability at pod filling stages in residues retained plots because of increased NH_4-N concentration at flowering stage, which stimulated nitrification process, as requirement of N at this particular crop growth stage is too high.

Table 2.32: Nitrate nitrogen (mg kg^{-1} soil) concentration in 0-15 cm depth of soil at different growth stage of pigeon pea under conservation agriculture.

Treatments	Pre-flowering	Flowering	Pod filling	Harvest	Mean
CT	24.4^{d}	22.9^{c}	22.8^{d}	13.7^{d}	20.9^{e}
PNB	28.5^{cd}	25.5^{bc}	30.6^{c}	18.0^{c}	25.7^{d}
PNB+R	38.6^{ab}	27.9^{b}	36.1^{bc}	23.3^{ab}	31.5^{bc}
PBB	32.9^{bc}	26.5^{bc}	33.3^{bc}	21.0^{bc}	28.4^{cd}
PBB+R	44.2^{a}	36.9^{a}	43.5^{a}	26.7^{a}	37.8^{a}
FB	29.8^{cd}	26.7^{bc}	30.7^{c}	19.2^{c}	26.6^{d}
FB+R	41.6^{a}	34.6^{a}	39.1^{ab}	24.8^{a}	35.0^{ab}
Mean	34.3	28.7	33.7	21.0	29.4
Tukey's HSD ($p \leq 0.05$)	6.0	4.6	6.7	3.7	NA

Table 2.33: Nitrate nitrogen (mg kg^{-1} soil) concentration in 15-30 cm depth of soil at different growth stage of pigeon pea under conservation agriculture.

Treatments	Pre-flowering	Flowering	Pod filling	Harvest	Mean
CT	9.4^{b}	7.9^{abc}	6.3^{d}	4.19	7.0^{c}
PNB	9.2^{b}	7.3^{bc}	7.3^{cd}	4.66	7.1^{bc}
PNB+R	10.9^{ab}	8.5^{ab}	9.3^{bc}	4.90	8.4^{abc}
PBB	8.9^{b}	6.7^{c}	9.1^{bc}	5.72	7.6^{bc}
PBB+R	12.8^{a}	9.3^{a}	13.5^{a}	5.87	10.4^{a}
FB	9.2^{b}	7.2^{bc}	8.1^{cd}	4.74	7.3^{bc}
FB+R	12.4^{a}	8.8^{ab}	10.4^{b}	5.87	9.3^{ab}
Mean	10.4	8.0	9.14	5.14	8.2
Tukey's HSD ($p \leq 0.05$)	2.3	1.7	2.13	2.41	NA

Mineral nitrogen (Mineral-N)

Mineral-N accounts approximately 2% of the nitrogen in soil. In 0-15 cm soil depth, at pre flowering stage, mineral-N was recorded highest (59.9 N mg kg^{-1} soil) under PBB+R treatment and it was 92, 65, 56, 38, 23 and 9% more than CT, PNB, FB, PBB, PNB+R and FB+R treatments, respectively. FB+R, PBB+R and PNB+R plots recorded 42, 38 and 34 % higher mineral-N as compared to irrespective without residues retained plots in 0-15 cm of soil depth at pre-flowering stage (Fig 2.21). Almost similar trends of mineral-N were recorded at the flowering, pod filling and harvesting stage of crop. Among different crop growth stages, average mineral-N increased from pre flowering to flowering and then starts decreasing and minimum value was recorded at harvesting stage. Mineral-N of soil was found decreased with increased in soil depth from 0-15 to 15-30 cm under different crop establishment methods (Fig 2.22). In 15-30 cm soil depth, best land configuration at pre- flowering stage was PBB+R (23.4 N mg g^{-1} soil) and it was 76, 70, 58, 57, 51 and 12 % higher over conventional tillage, PNB, FB, PBB, PNB+R, and FB+R plots, respectively. In 15-30 cm soil depth, significant positive impact of residues was recorded on mineral-N concentration but the intensity of impact was less as compared to 0-15 cm soil depth. Most importantly, drastic reduction mineral N was recorded in 15-30 cm, over 0-15 cm soil and that was -167.7, -231, -242 and -248 % at pre-flowering, flowering, pod filling and harvest stage, respectively (Fig 2.22).

In a nutshell, conservation tillage resulted in increased NH_4-N, NO_3-N and mineral-N in soil even upto 30 cm of soil depth. Highest available N fractions (NH4-N, NO3-N and mineral-N) were noticed in PBB+R plots, although in some of the stages and soil depths it was statistically similar with other residue retained plots but always superior over ZT without residue retained (ZT) and CT plots. In pigeon pea crop, pre-flowering stage and harvesting stage was most appropriate to estimate NH_4-N and NO_3-N respectively.

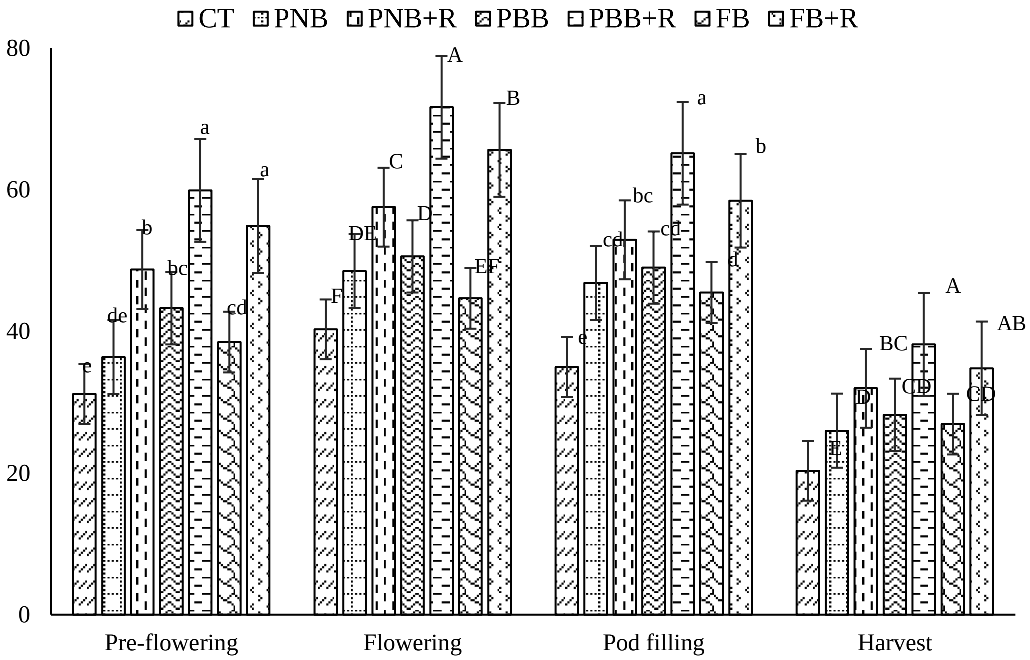


Fig 2.21: Mineral nitrogen (mg kg^{-1} soil) concentration in 0-15 cm depth of soil at different growth stage of pigeon pea under conservation agriculture.

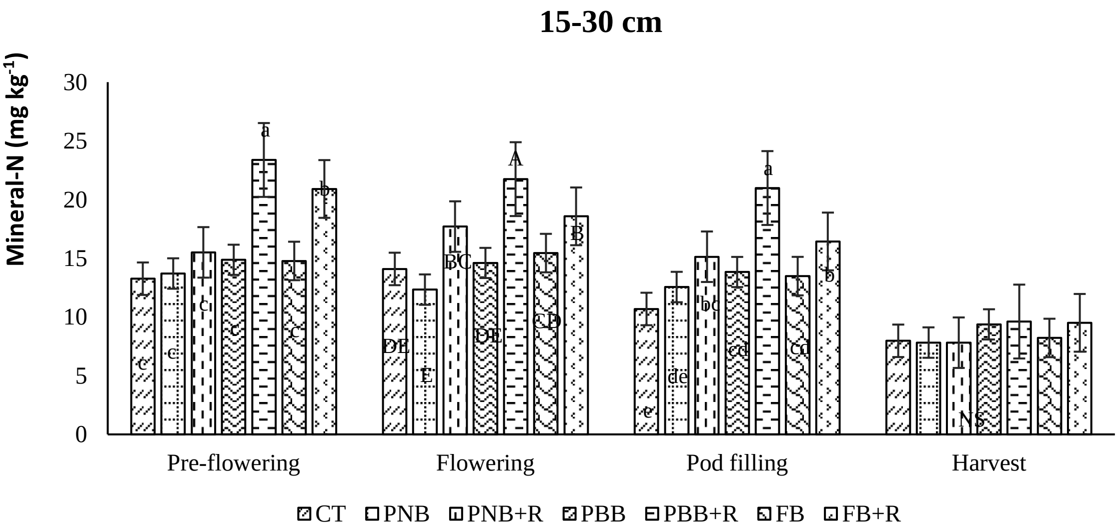


Fig 2.22: Mineral nitrogen (mg kg^{-1} soil) concentration in 15-30 cm depth of soil at different growth stage of pigeon pea under conservation agriculture

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; FB: Planting on flat bed with ZT; FB+R: FB with residue retention.

E. Decomposition

IARI

Another separate experiment was conducted together with the above-mentioned experiment to study the residue decomposition kinetics at ICAR-IARI, Delhi (Table 2.34). Here, certain amount of wheat residues was taken in a nylon mesh bag and kept in field for observing the mass remaining of residues in a periodical interval. Nylon mesh bags with residue were kept on the surface in case of conservation agriculture, organic farming and natural farming plots, but it was incorporated in conventional tillage production system. The result of this study depicted that decomposition rate was more where residues are incorporated compared to where it was retained. However, among the treatments where it was retained organic farming resulted highest decomposition rate hence the days to decompose 50% of the residue is lowest.

Table 2.34: Treatment wise residue decomposition rate, avg $t_{0.50}$ and avg $t_{0.95\ (days)}$

Treatments	AVG K (per day)	AVG $t_{0.50}$ (days)	AVG $t_{0.95\ (days)}$
CT	0.0103	69.4	290.84
NF-CT	0.0074	93.64	404.82
OF-CT	0.0082	84.51	365.33
CA-PFB	0.0064	115.9	468.08

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

IIFSR

Data pertaining to DTPA extractable Fe content at the harvest of rabi season crops in 2023 presented in table 6 shows that long-term adoption of CA based management practices significantly influenced the Fe content both in surface and subsurface soil layers. Treatments ZTDSR-ZTW, ZTDSR-ZTW-ZTGG, ZTM-ZTM-ZTGG and RTS-R-ZTW recorded 31.7%, 36.4%, 49.9% and 39.8% higher DTPA extractable Fe over the PTR-CTW treatment, respectively. Similarly, DTPA extractable Cu, Zn and Mn were also found superior in these treatments over the PTR-CTW treatment both in surface (0-15 cm) and sub-surface (15-30 cm) soil depths (Table 2.35).

Table 2.35: Influence of CA based management practices on DTPA extractable micronutrients mg kg^{-1}

Treatments	Tillage	Fe	Cu	Zn	Mn
Cropping systems					
R-W	PTR-CT	13.55	2.544	4.273	13.34
R-W	ZTDSR-ZT	17.84	3.256	5.732	15.62
R-W-GG	PTR-CT-CT	14.54	2.336	4.789	14.67
R-W-GG	ZTDSR-ZT-ZT	18.48	3.063	5.513	16.47
M-M-GG	CT-CT-CT	16.89	2.842	6.473	17.24
M-M-GG	ZT-ZT-ZT	20.31	4.572	7.273	19.34
S-R-W	CT-CT-CT	17.72	2.685	5.526	12.19
S+GG-R-W	RT-ZT-ZT	18.94	3.085	6.249	19.64
Sem (±)		0.840	0.264	0.441	0.758
C.D. (p<5%)		2.439	NS	1.281	2.199
Soil Depth					
0-15 cm		17.41	2.922	5.617	14.55
15-30 cm		9.31	2.419	3.400	11.08
Sem (±)		0.421	0.132	0.221	0.379
C.D. (p<5%)		1.219	NS	0.641	1.099

CSSRI

Soil micronutrients (Zn, Fe, and Mn) availability were significantly affected by TRM practices; however, availability of Cu remains unaffected and varied from 1.95 to 2.04 mg kg^{-1} at surface soil (0-15 cm) (Table 2.36).

Table 2.36: Soil available major and micronutrient after 15-years of tillage and residue management in rice-wheat system (2-years pooled average data)

	Micro nutrient (mg kg^{-1})

Treatments/ scenarios	Zn	Cu	Fe	Mn
0-15 cm soil layer				
CT-R	3.07[c]	1.95	16.14[b]	12.39[c]
CT+R	3.92[b]	1.98	16.77[a]	13.05[bc]
RT-R	4.11[ab]	2.02	17.50[a]	13.02[bc]
RT+R	4.01[b]	2.06	17.55[a]	14.13[a]
ZT-R	4.45[ab]	2.06	17.26[a]	13.99[a]
ZT+R	4.65[a]	2.04	17.63[a]	13.77[ab]
Treatment	***	NS	*	**
Year	***	NS	NS	***
Treatment × Year	**	**	***	***
Contrast				
-R *vs* +R	**	NS	NS	NS
CT *vs* RT	**	NS	**	**
CT *vs* ZT	***	NS	*	*
RT *vs* ZT	***	NS	NS	NS
15-30 cm soil layer				
CT-R	1.71[c]	1.52	12.44[b]	8.45
CT+R	1.83[bc]	1.62	13.26[ab]	8.53
RT-R	1.84[bc]	1.32	14.62[a]	9.25
RT+R	2.12[ab]	1.38	14.13[a]	8.97
ZT-R	1.99[bc]	1.42	14.04[a]	8.85
ZT+R	2.43[a]	1.50	14.53[a]	9.07
Treatment	***	NS	*	NS
Year	***	NS	***	***
Treatment × Year	**	NS	***	**
Contrast				
-R *vs* +R	**	NS	NS	NS
CT *vs* RT	NS	NS	***	NS
CT *vs* ZT	**	NS	*	NS
RT *vs* ZT	*	NS	NS	NS

Treatment means within a column with dissimilar letters (lowercase) varied significantly ($P < 0.05$, Tukey's test)

***, **, * represent 0.1% (0.001), 1% (0.01), and 5% (0.05) level of significance, and NS represent non-significant.

CT, RT and ZT represent conventional, reduced and zero tillage, respectively. -R and +R represent no crop residues and 1/3[rd] crop residue addition, respectively.

G. GHG emission and Energy budgeting

IARI

Measurement of greenhouse gas emission was carried out in cotton wheat system with residue retention. The nitrous oxide and carbon dioxide emissions were measured using close chamber technique during the crop growth period in cotton and wheat. The emissions of the greenhouse gases are shown in Table 2.37. The emissions were higher in zero flatbed as compared to permanent narrow bed and permanent broad bed. The Global warming potential reduced by 30% in the PNB treatment, however the retention of residue increased the emission of both carbon dioxide and nitrous oxide. The GWP in treatments with 25% reduced N fertilizer with residue retention were at par with the 100% N no residue retained treatment under PBB and FB treatments (Table 2.37).

Table 2.37: Measurement of GHG emission from cotton wheat system with residue retention

Treatment	Notation	Cotton		Wheat		System GWP
		CO_2-C (kg/ha)	N_2O-N g/ha	CO_2-C (kg/ha)	N_2O-N g/ha	kg CO_2 equiv./ha
Conventional Tillage	CT	838	636	504	798	1939a
Permanent narrow bed	PNB	482	604	380	551	1343h

Permanent narrow bed+ Residue +75% N	PNBR75%N	556	573	468	546	1490g
Permanent narrow bed+ Residue +100% N	PNBR100%N	609	710	349	612	1508fg
Permanent broad bed	PBB	510	656	435	764	1536ef
Permanent broad bed+ Residue +75% N	PBBR75%N	562	598	482	678	1576e
Permanent broad bed+ Residue +100% N	PBBR100%N	706	756	450	680	1754c
Zero-till flatbed	ZTFB	716	689	360	859	1721cd
Zero-till flat bed+residue +75% N	ZTFBR75%N	766	620	346	814	1709d
Zero-till flatbed+ Residue +100% N	ZTFBR100%N	813	719	351	892	1835b

CRIDA

The GHG fluxes were measured using a vented insulated non steady state closed chamber technique. The data on GHG emissions in conservation agriculture with different in situ moisture conservation practices and weed management strategies. The study revealed that CT and ZT + live mulch has recorded higher GHG emissions as compared to ZT + permanent conservation furrow (ZTF) and ZT+ permanent bed (ZTPB). The GHGI also was in similar trend. CT recorded the lowest GHGI. Among the weed management treatments control recorded lowest N_2O emissions and GHGI emissions. Pre emergence +post emergence herbicide recorded higher N_2O emissions but the GHGI emissions were higher in this treatment. (Table 2.38)

Table 2.38: Influence of different tillage and residue levels on GHG emissions.

Treatments	**N_2O kg ha^{-1}**	**GHGI (kg yield/kg N_2O)**
CT	0.77	1.33
ZTF	0.60	2.18
ZTPB	0.61	2.03
ZT+ live mulch	0.68	1.68
Control	0.66	0.96
pre+ intercultivation	0.69	1.77
pre+ post emergence	0.69	2.43
pre+post+intercultivation	0.61	2.03

In Pearlmillet – Horsegram/ Pigeonpea system, significantly higher N_2O emission was observed in CT followed by MT and ZT. Higher N_2O emission was observed in 125% RDF followed by 100% RDF and 75% RDF.

Energy balance studies: In Soyabean-Chickpea cropping system, It is observed that the energy input (EI) is more in conventional tillage (CT) with crop residue mulch treatment (T_1) followed by conventional tillage (CT) without crop residue mulch treatment (T_2), Reduced tillage (T_3), Permanent BBF furrow after every 4 rows + crop residue mulch treatment (T_5) and Zero tillage + crop residue treatment (T_4). However, the energy output (EO) was highest in Reduced tillage (T_3) followed by conventional tillage (CT) with crop residue mulch treatment (T_1), conventional tillage (CT) without crop residue mulch treatment (T_2), Permanent BBF furrow after every 4 rows + crop residue mulch treatment (T_5) and Zero tillage + crop residue treatment (T_4). The energy use efficiency (5.52) and energy productivity (2.57) were found highest in Reduced tillage treatment (T_3) (Table 2.39).

Table 2.39: Energy Balance as influenced by different treatments during 2023

Treatments	**Energy Input (EI)**	**Energy output (EO)**	**Energy use efficiency (EUE)**	**Specific energy**	**Energy productivity**
T_1	11045	50162	4.54	7.24	2.08
T_2	10877	48130	4.42	7.40	2.03
T_3	9429	52141	5.52	5.71	2.57
T_4	8673	38764	4.47	7.09	2.07

T_5	8707	40925	4.70	6.74	2.18

NIASM

A long term (six-year) impact of tillage, surface trash retention and fertigation strategies on productivity and water-energy-carbon nexus in drip irrigated sugarcane was assessed. The plant crop included three treatments of tillage (CT: Conventional tillage + 10% RDF basal and 90% fertigation; RT_1: Reduced tillage (RT) + 10% RDF basal and 90% fertigation, and RT_2: RT+10% RDF basal, 40% band placement and 50% fertigation) in main plots and (ii) soil surface trash retention practices, namely mulching (M) and non-mulching (NM), in subplots. The sub-plots were further divided to sub-sub plots to adjust three nutrient levels (N_1: 25% RDF as basal and rest through fertigation, N_2: 50% RDF as basal using multifunctional SORF (stubble shaving, off-barring, root pruning and band placement of fertilisers) drill and rest 50% through fertigation, and N_3: SORF with 75% RDF as basal using SORF drill and rest 25% through fertigation). The plant crop exhibited higher GHG loss (9.0–10.4 Mg CO_2-eq ha^{-1}) and lower energy use efficiency (EUE, 22.8–33.5) than the ratoon crop (6.5–7.7 Mg CO_2-eq ha^{-1} and 24.7–56.5).

3. Soil Biological Properties

A. Glomalin and soil enzyme activities under CA-based system

IARI

The soil biological properties such as, glomalin protein, soil microbial biomass carbon, dehydrogenase activity, β- glucosidase activity and phenoloxidase activity were significantly influenced by conservation agriculture practices (Table 2.40, 2.41, 2.42, 2.43 and 2.44). Treatment PBB+R, PNB+R and FB+R resulted in significantly higher glomalin protein, soil microbial biomass carbon, dehydrogenase activity and β- glucosidase activity in bulk soil, macroaggregates and microaggregates than CT, whereas, phenoloxidase activity was higher in CT.

Table 2.40: Effect of long-term conservation agriculture on glomalin (mg g^{-1}) related soil protein in soils and within macro and micro- aggregates under a cotton-wheat cropping system in an Inceptisol

Treatments*	Bulk soils		Macroaggregates		Microaggregates	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
CT	3.27	2.48	2.58	2.15	2.03	2.03
PNB	4.01	2.52	3.47	2.79	3.18	3.18
PNB+R	4.63	3.43	3.90	3.26	3.32	3.32
PBB	4.29	2.61	3.49	2.75	3.22	3.22
PBB +R	4.95	3.74	3.95	3.29	3.35	3.35
ZT+R	4.90	3.41	3.86	3.22	3.25	3.25
ZT	3.88	2.51	3.44	2.86	3.15	3.15
LSD (P=0.05)	0.21	0.43	0.30	0.31	0.33	0.33

Table 2.41: Effect of long-term conservation agriculture on soil microbial biomass carbon (mg kg^{-1}) in soils under a cotton-wheat cropping system in an Inceptisols

Treatments*	Bulk soils		Macroaggregates		Microaggregates	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
CT	389	283	314	213	226	160
PNB	436	383	344	254	237	242
PNB+R	569	408	426	329	321	279
PBB	502	388	343	275	242	233
PBB +R	595	423	433	381	349	298
ZT+R	562	426	436	299	326	283
ZT	510	390	334	251	235	236
LSD (P=0.05)	42.1	37.1	33.6	32.4	24.5	25.3

Table 2.42: Effect of long-term conservation agriculture on dehydrogenase activity (µg TPF g^{-1} day^{-1}) in soils under a cotton-wheat cropping system in an Inceptisol

Treatments*	Bulk soils		Macroaggregates		Microaggregates	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
CT	10.0	6.89	4.88	3.10	4.36	3.08
PNB	10.3	8.09	5.02	4.11	4.75	4.09
PNB+R	17.4	14.1	11.2	8.33	7.79	5.25
PBB	10.6	8.11	5.40	4.09	5.04	3.94
PBB +R	19.0	15.4	12.3	8.86	8.27	5.85
ZT+R	16.8	15.5	12.4	9.13	8.07	5.98
ZT	11.0	8.33	6.51	4.29	5.00	4.03
LSD (P=0.05)	1.93	0.99	1.35	0.31	0.46	0.40

Table 2.43: Effect of long-term conservation agriculture on β- glucosidase activity (µg PNP-g^{-1} h^{-1}) in soils under a cotton-wheat cropping system in an Inceptisol

Treatments*	Bulk soils		Macroaggregates		Microaggregates	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
CT	4.91	2.19	2.25	1.16	1.28	1.03
PNB	6.78	2.92	2.70	1.40	1.55	1.31
PNB+R	8.71	4.11	3.64	1.61	1.83	1.58
PBB	6.83	3.31	2.68	1.41	1.56	1.25
PBB +R	9.30	6.14	4.97	1.73	1.88	1.58
ZT+R	9.73	5.95	5.01	1.81	1.83	1.58
ZT	6.57	3.32	3.24	1.46	1.68	1.25
LSD (P=0.05)	0.87	0.43	0.38	0.20	0.15	0.23

Table 2.44: Effect of long-term conservation agriculture on phenoloxidase activity (µg DOPA g^{-1} h^{-1}) in soils under a cotton-wheat cropping system in an Inceptisol

Treatments*	Bulk soils		Macroaggregates		Microaggregates	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
CT	0.36	0.21	0.47	0.22	0.18	0.13
PNB	0.27	0.18	0.30	0.20	0.14	0.12
PNB+R	0.16	0.16	0.16	0.17	0.13	0.12
PBB	0.23	0.18	0.24	0.19	0.12	0.13
PBB +R	0.14	0.13	0.18	0.13	0.13	0.13
ZT+R	0.14	0.11	0.19	0.11	0.14	0.11
ZT	0.24	0.19	0.29	0.19	0.14	0.12
LSD (P=0.05)	0.11	ns	0.10	ns	ns	ns

An earthworm study was conducted in the same experiment by counting the number of earthworms per m^2 area during different stages of crop growth such as tillering, flowering and maturity stages of wheat and branching, squaring and maturity stages of cotton which indicates the organic matter content of soil, thereby soil health and quality (Table 2.45). The study revealed the highest no. of earthworms were found during flowering stage followed by tillering and maturity in wheat crop, and in cotton crop highest population of earthworm were recorded in the squaring stage followed by branching and maturity stages. In both wheat and cotton crop during all the stages of crop growth the highest count of earthworm were recorded by PBB+R+100N followed by ZTFB+R+100N, PNB+R+100N and the lowest were recorded in the conventional tillage plot.

Table 2.45: Earthworm population (No./m^2) at different stages of the crops

		TLS	FLS	MTS
Wheat	CT	32.7	60.7	23.7
	PNB+R+100N	94.3	146	70.3
	PBB+R+100N	98	180.3	72

	ZTFB+R+100N	96.7	178.7	77
Cotton	CT	38.3	52.6	30.6
	PNB+R+100N	102.4	144.3	61.2
	PBB+R+100N	112.5	172	68.4
	ZTFB+R+100N	107	168.4	66.1
Wheat-Cotton system	CT	71	113.3	54.3
	PNB+R+100N	196.7	290.3	131.5
	PBB+R+100N	210.5	352.3	140.4
	ZTFB+R+100N	203.7	347.1	143.1

IIFSR

Soil samples (0-15 cm) were collected at the harvest of rabi season crops in 2023. The bulk soil microbial communities differed significantly among the different cropping systems and tillage practices (Table 2.46). The fungal and bacterial biomass differed significantly with highest biomass consistently found in ZT maize-mustard-greengram (7.7×10^7 and 5.5×10^4 CFU/g dry soil) and lowest in PTR-CTW (1.8×10^7 and 2.3×10^4 cfu/g dry soil). Actinomycetes, free living N fixers and Trichoderma followed the same pattern.

Table 2.46: Effect of long-term CA based management practices on soil microbial population

Treatments	**Microbial population on different growth media (CFU/g dry soil)**						
	Bacteria (NA)	**Fungi**	**Actinomycetes**	**Bacteria (KingsB)**	**Free living N fixers (Jensen Media)**	**Trichoderma (Trichoderma Selective Media)**	**Rhizobium (CRYEMA)**
PTR-CTW	1.8×10^7	2.3×10^4	2.5×10^5	5.3×10^6	1.2×10^5	7.3×10^3	2.7×10^4
ZTDSR-ZTW	2.6×10^7	3.8×10^4	2.6×10^5	6.3×10^6	1.5×10^5	9.3×10^3	3.5×10^4
PTR-CTW-CTGG	3.4×10^7	3.0×10^4	2.9×10^5	5.6×10^6	1.3×10^5	12.7×10^3	2.9×10^4
ZTDSR-ZTW-ZTGG	2.0×10^7	4.7×10^4	4.1×10^5	8.0×10^6	1.5×10^5	25.7×10^3	3.7×10^4
CTM-CTM-CTGG	4.4×10^7	4.6×10^4	4.1×10^5	6.7×10^6	1.7×10^5	27.7×10^3	4.7×10^4
ZTM-ZTM-ZTGG	7.7×10^7	5.5×10^4	5.3×10^5	10.2×10^6	1.8×10^5	28.3×10^3	5.4×10^4
CTS-R-CTW	3.2×10^7	3.5×10^4	2.1×10^5	6.4×10^6	1.1×10^5	6.0×10^3	3.2×10^4
RTS+GG-R-ZTW	3.3×10^7	3.8×10^4	3.0×10^5	7.9×10^6	1.5×10^5	15.7×10^3	3.4×10^4

Significant variation in DHA was observed both in CA and CT treatments over the business as usual (PTR-CTW) treatment (Table 2.47). The CA based treatments ZTDSR-ZTW, ZTDSR-ZTW-ZTGG, ZTM-ZTM-ZTGG and RTS-R-ZTW recorded significantly 32.0%, 43.5%, 50.9% and 34.2% higher DHA activity over the PTR-CTW treatment, respectively. Phosphatases enzyme plays a crucial role in mineralization of organic phosphate compounds and release inorganic phosphorus in soil. Significant variation in acid and alkaline phosphatase activity was observed irrespective of scenarios and sampling depths. In RTS-R-ZTW significantly higher acid phosphatase enzyme (37.5%) was observed as compared to PTR-CTW. Similarly, ZTDSR-ZTW-ZTGG, ZTDSR-ZTW and ZTM-ZTM-ZTGG recorded 23.7%, 17.7% and 12.1% higher acid phosphatase over the PTR-CTW, respectively.

Incorporation of summer greengram residue along with ZT in ZTDSR-ZTW-ZTGG, ZTM-ZTM-ZTGG and STS+GG-R-ZTW treatments recorded significantly 4.64%, 15.68% and 4.79 higher alkaline phosphatase enzyme activity over the PTR-CTW-CTGG treatment, respectively (Table 2.47). Microbial biomass carbon (MBC) is the measurement of the carbon contained within the living component of soil organic matter (SOM). Treatments comprised of CA based management practices showed significant improvement in MBC over the PTR-CTW treatment. Treatments ZTDSR-ZTW, ZTDSR-ZTW-ZTGG, ZTM-ZTM-ZTGG and RTS+GG-R-ZTW observed 4.8%, 10.6%, 12.4% and 7.9% higher MBC content over the PTR-CTW treatment, respectively.

Fluorescein diacetate (FDA) is the simple and accurate technique to measure the total microbial activity of soil. Significantly highest (276.7 µg F g^{-1} dry soil h^{-1}) FDA activity was recorded ZTM-ZTM-ZTGG treatment followed by ZTDSR-ZTW-ZTGG (273.3 µg F g^{-1} dry soil h^{-1}) and CTM-CTM-

CTGG (260.9 µg F g^{-1} dry soil h^{-1}) treatments, respectively (Table 2.47). Glomalin is a hypothetical glycoprotein produced abundantly on hyphae and spores of arbuscular mycorrhizal (AM) fungi in soils and in roots. Long-term adoption of CA based management practices significantly improved the total glomalin content over the CT based treatments. Treatments ZTDSR-ZTW, ZTDSR-ZTW-ZT-GG, ZTM-ZTM-ZTGG and RTS+GG-R-ZTW recorded 5.1%, 11.9%, 31.8% and 9.5% higher total glomalin content over the PTR-CTW treatment, respectively.

Table 2.47: Effect of crop diversification and CA based management practices on soil carbon, nitrogen and phosphorus cycling enzymes.

Cropping systems	Tillage	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})	MBC (mg kg^{-1})	Total Glomalin (mg kg^{-1})	FDA (µg F g^{-1} dry soil h^{-1})
R-W	PTR-CT	188.1	109.3	306.8	242.6	284.2	230.8
R-W	ZTDSR-ZT	248.3	128.6	335.6	254.3	298.7	242.7
R-W-GG	PTR-CT-CT	224.6	128.7	327.8	261.1	302.9	243.1
R-W-GG	ZTDSR-ZT-ZT	269.9	135.2	343.0	268.2	317.9	273.3
M-M-GG	CT-CT-CT	249.9	117.4	359.5	254.3	315.0	260.9
M-M-GG	ZT-ZT-ZT	283.8	122.5	379.2	272.7	373.4	276.7
S-R-W	CT-CT-CT	207.3	109.3	292.2	239.7	292.7	244.8
S+GG-R-W	RT-ZT-ZT	252.5	150.3	343.5	261.8	311.3	204.7
Sem (±)		12.75	6.50	17.05	9.864	23.06	11.62
C.D.		37.05	18.86	50.79	28.62	NS	33.74
Soil Depth							
0-15 cm		288.9	148.9	374.4	256.9	316.5	301.0
15-30 cm		192.2	110.6	281.7	161.4	309.3	195.8
Sem (±)		6.375	3.25	8.75	4.932	11.53	5.812
C.D.		18.503	9.433	NS	NS	NS	16.87

DHA=dehydrogenase; ACP=acid phosphatase; ALP=alkaline phosphatase; MBC=microbial biomass carbon; FDA=fluorescein diacetate

CSSRI

The results of MBC, dehydrogenase activity, and alkaline phosphatase activity presented in Table 2.48 demonstrates the profound effect of TRM. These properties, essential for soil microbial activity and biochemical processes, are intricately linked to SOC and vary significantly with various soil management practices. The higher MBC values were consistently recorded in ZT treatment with residue retention, registering values of 271.63 and 186.56 in surface and subsurface soil layer, respectively. Conversely, the lowest MBC levels were recorded in the CT-R treatment, indicating a strong association between MBC and the quantity of crop residues present. Greater crop residue amounts under zero tillage gradually accumulate organic matter on the soil surface, contributing to increased MBC levels. This aligns with the assertion that MBC serves as an indicator of soil's capacity to effectively accumulate and recycle essential nutrients and soil organic matter. A similar pattern emerged for alkaline phosphatase and dehydrogenase activities, with peak values in the ZT with residue retention treatment and minimum values in the CT-R treatment in both surface and sub-surface layers. Residue retention with no tillage practice promotes the slow decomposition of crop residues leading slow release of labile organic matter, therefore, supply nutrient for a longer period for soil microbes. Additionally, the increased soil moisture availability resulting from ZT and residue retention in the surface soil likely contributes to heightened enzyme activity.

Table 2.48: Soil biological parameters after 15-years of tillage and residue management in rice-wheat system (2-years pooled average data)

Treatments/scenarios	**Microbial biomass carbon (mg kg^{-1} soil)**	**Alkaline phosphatase (µmol p-nitrophenol g^{-1} h^{-1})**	**Dehydrogenase activity (µg TPF g^{-1} 24 h^{-1})**
0-15 cm soil layer			
CT-R	135.50^{e}	110.73^{e}	76.36^{e}
CT+R	219.50^{d}	143.88^{d}	100.19^{bc}
RT-R	176.88^{c}	140.63^{d}	91.47^{d}
RT+R	254.00^{b}	172.73^{b}	104.85^{b}

ZT-R	248.50[b]	158.30[c]	99.29[c]
ZT+R	271.63[a]	187.08[a]	122.00[a]
Treatment	***	***	***
Year	***	***	***
Treatment × Year	***	**	**
Contrast			
-R vs +R	***	***	***
CT vs RT	***	***	***
CT vs ZT	***	***	***
RT vs ZT	***	**	***
15-30 cm soil layer			
CT-R	109.90[c]	90.94[e]	66.95[e]
CT+R	152.58[b]	118.01[d]	80.06[c]
RT-R	172.93[a]	117.70[d]	74.54[d]
RT+R	182.49[a]	142.82[b]	86.88[b]
ZT-R	174.41[a]	129.02[c]	80.93[c]
ZT+R	186.56[a]	151.56[a]	100.12[a]
Treatment	***	***	***
Year	***	***	*
Treatment × Year	***	***	**
Contrast			
-R *vs* +R	**	***	***
CT *vs* RT	**	***	**
CT *vs* ZT	***	***	***
RT *vs* ZT	NS	**	***

Treatment means within a column with dissimilar letters (lowercase) varied significantly (P < 0.05, Tukey's test)
***, **, * represent 0.1% (0.001), 1% (0.01), and 5% (0.05) level of significance, and NS represent non-significant.
CT, RT and ZT represent conventional, reduced and zero tillage, respectively. -R and +R represent no crop residues and 1/3[rd] crop residue addition, respectively.

Contrast analysis revealed that the addition of crop residue significantly improved biological properties across all the tillage practices. With the retention of crop residue, 61.99, 43.60 and 9.31% increase in MBC values were recorded at surface soil under CT, RT and ZT in comparison to the treatments without crop residue. Alkaline phosphatase activity increased with residue addition by 29.94% in CT, 22.83% in RT, and 18.18% in ZT in surface soil (0-15 cm) depth. At subsurface (15-30 cm depth), almost similar pattern with comparatively lower values from upper surface soil are recorded for alkaline phosphatase activity. Similarly, significant increase in dehydrogenase activity, ranged from 19.78 to 59.77% and 11.34 to 49.54 % was recorded at 0-15 and 15-30 cm depth, respectively. ZT showed significantly higher MBC compared to RT and CT in both the upper and lower soil layer whereas difference between ZT and RT became non-significant at sub-surface layer (15-30). Tillage practices significantly influenced the alkaline phosphatase and dehydrogenase activities. Highest alkaline phosphatase and dehydrogenase activity was recorded in ZT (172.69 and 110.64) followed by RT (156.68 and 98.16) and CT (127.305 and 88.275) in surface soil depth. Almost similar pattern (CT < RT < ZT) was recorded in the sub-surface (15-30 cm) soil.

RCER

Post-harvest soils of rice-linseed-green gram cropping system of Chene, Jharkhand: Soil microbial biomass carbon was significantly highest of 270 mg C/kg soil in ZTTR compared to rice-fallow, CTDSR and FPTR, while it showed non-significant with ZTDSR

CRIDA

In Sorghum-Blackgram system, Soil biological properties, viz., microbial biomass carbon in the 0-7.5 cm and 7.5-15 cm soil layers were monitored during crop growth. No differences were observed in soil microbial biomass carbon with tillage and residue management (Fig. 2.23, 2.24).

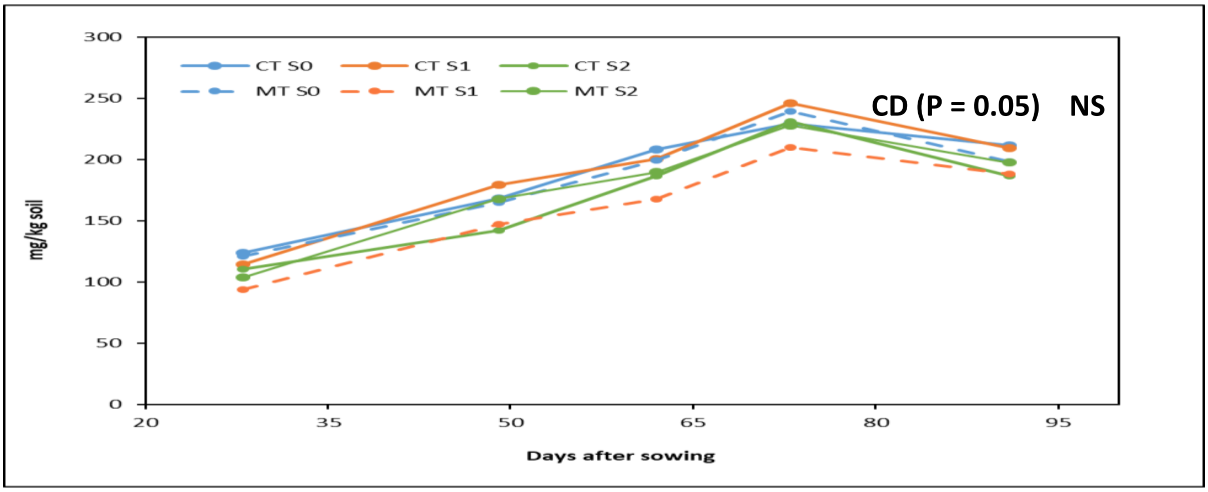


Fig 2.23: Effect of tillage and residue management on soil microbial biomass carbon (SMBC) in 0-7.5 cm soil layer

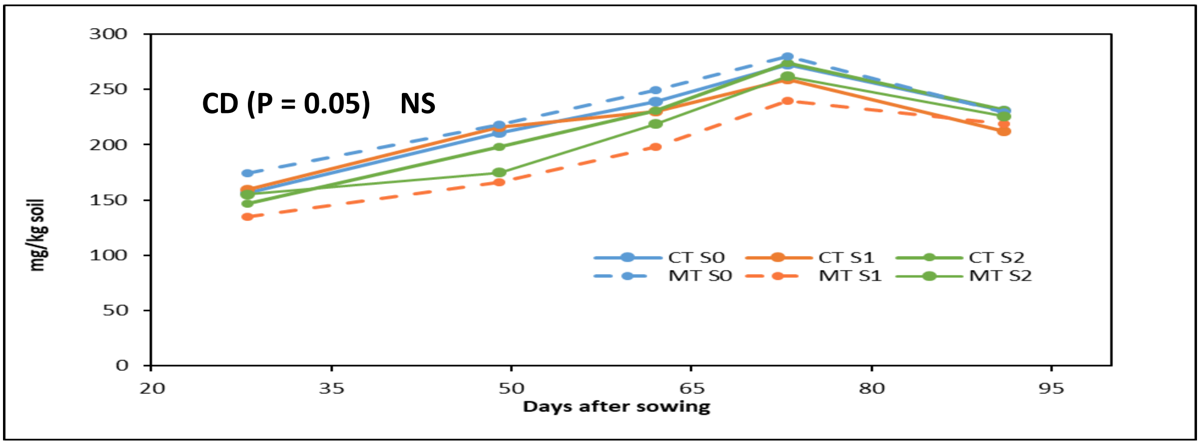


Fig 2.24: Effect of tillage and residue management on soil microbial biomass carbon (SMBC) in 7.5-15 cm soil layer

RCER

Field trials were initiated during the rainy season of 2016 at the ICAR Research Complex for Eastern Region in Patna, Bihar (25°35' N, 85°05' E, and 51 m above mean sea level), situated in a sub-tropical humid region. Average annual precipitation for region is 1213 mm. The monthly distribution of rainfall, evaporation, and minimum and maximum temperatures during the experiment is provided in. The mean precipitation during winter season (November to April) was 49 mm, categorizing it as a 'dry' period. In contrast, mean precipitation during rainy season (June to October) was 936 mm, classifying it as a 'wet' period for cropping season. Average pan evaporation (Epan) varied between 46.4 mm in January (the lowest) and 187.6 mm in May (highest). Soil at the experimental site exhibited a silty-clay loamy texture (with sand: 10.7%, silt: 53.3%, and clay: 36%) and was slightly alkaline in nature (pH: 7.58). In upper soil layer (0-15 cm), bulk density was 1.63 g cm^{-3}, and soil organic carbon (SOC) content was 5.6 g kg^{-1}. Experimentation was conducted in split-plot with treatment of crop establishment-cum-residue management (CERM) as main-plot & post-rainy crops as sub-plots (13 m × 4.5 m). Droughts-tolerant short duration rice cultivars "*Swarna Shreya*" (115-120 day) was taken in rainy cropping. In winter season, main plot was divided into sub-plot, wherein treatment of post-rainy crops was imposed. Six CERM treatment [zero-till-direct-seeded rice (ZTDSR), conventional-till-DSR(CTDSR), transplanted puddled rice (TPR), ZTDSR with residue retention ($ZTDSR_{R+}$), CTDSR with residue retention ($CT\text{-}DSR_{R+}$) & TPR with residue retention (TPR_{R+})] were laid out in main-plot, while five potential winter crops [chickpea, lentil, safflower, linseed, mustard] were in sub-plots. In treatment having residue retention ($ZTDSR_{R+}$, $CTDSR_{R+}$, TPR_{R+}), crops harvested manually by leaving~20 cm crop stubble, while crops harvested close to ground level in treatment without residue (ZTDSR, CTDSR, TPR).

CERM-based management practices had a significant impact on earthworm casting (EC) & earthworm burrowing counts (EBC). Our result confirmed that ZTDSR systems had 35.6 and 27.3%

higher EC and EBC in comparison to TPR (Table 2). Similarly, CTDSR had 12.1 and 13.8% higher EC & EBC than that of TPR. Irrespective of CERM-based management, markedly higher EC & EBC were noted with pulse-based systems (47 and 31.1/0.5 m^2) compared to oilseed-based sequences. Among the cropping systems, rice-safflower system had a significantly higher number of EC and EBC. In the present study, CA-based systems had higher EC & EBC than farmer's practices which might be due to crop residue retention which acts as an organic source of food for earthworms. This is obvious from strong & positive correlations with EWs counts (Table 2.49).

Earthworm (EW) is a potential indicator of soil biology and agri-food production systems. The influence of CA-management i.e., ZT, crop rotation, and crop residue on diversity, abundance, live biomass of EWs in rice fallow of eastern India had been investigated during the present study. In rainy season, EW diversity was distinctly higher compared to winter season (Table 3). On average, total EWCs were 0.92 and 6.5 times higher in rainy and post-rainy seasons in CA/ZTDSR in comparison to TPR. Earthworm species diversity was more intense in CA-based system (ZTDSR) than in CT. Three dominant earthworm species: *Metaphire formosae, Amynthas morrisi* and *Eisenia fetida* in rainy season, and only one earthworm species i.e., *E. fetida* in post-rainy season were observed. Among earthworm species, *E. fetida* was most dominant & frequent species in all crop management systems across seasons. Oilseed-based system (89.36/cft) was more EWCs compared to pulse-based sequences (80.78/cft). Among cropping system, rice-linseed system was the maximum EWCs (103.32/cft) followed by rice-chickpea sequence (87/cft). However, a reverse trend was noted during post-rainy cropping, where pulse-based system was 41.1% more EWCs than that to oilseed-based systems. Among the cropping system, rice-lentil system (7.5/cft) was maximum EWCs. In case of earthworm biomass (EWB), CA and pCA-based system had 0.73 and 0.6 times more EWB than TPR. Oilseed-based cropping systems had higher EWB compared to pulses-based systems. Among cropping system, rice-linseed system had maximum EWB (2.52 g/cft).

Table 2.49: Earthworm species diversity and their total biomass in rice during rainy and winter cropping as affected by diverse crop-establishment-cum-residues-management (CERM) in rice fallows agroecosystem of eastern India

CERM		**Earthworm species counts (no./cft) in rice**											
		Metaphire formosae						***Amynthas morrisi***					
		R-C	R-L	R-S	R-Li	R-M	Mean	R-C	R-L	R-S	R-Li	R-M	Mean
[ZTDSR-ZT] R-	CA	3.19 (9.70)	2.19 (4.30)	1.79 (2.70)	2.05 (3.70)	1.67 (2.30)	2.18^{B} (4.54)	0.89 (0.30)	1.10 (0.70)	2.12 (4.00)	1.58 (2.00)	1.22 (1.00)	1.38^{B} (1.60)
[ZTDSR-ZT] R+		3.29 (10.30)	2.49 (5.70)	1.87 (3.00)	2.34 (5.00)	1.79 (2.70)	2.36^{A} (5.34)	1.48 (1.70)	1.10 (0.70)	2.05 (3.70)	1.95 (3.30)	1.58 (2.00)	1.63^{A} (2.28)
[CTDSR-ZT] R-	pCA	1.79 (2.70)	1.22 (1.00)	1.58 (2.00)	1.58 (2.00)	1.48 (1.70)	1.53^{D} (1.88)	1.22 (1.00)	1.22 (1.00)	1.67 (2.30)	1.22 (1.00)	1.10 (0.70)	1.29^{D} (1.20)
[CTDSR-ZT] R+		1.67 (2.30)	1.95 (3.30)	1.34 (1.30)	1.67 (2.30)	1.79 (2.70)	1.68^{C} (2.38)	0.89 (0.30)	0.71 (0.00)	1.95 (3.30)	1.48 (1.70)	1.58 (2.00)	1.32^{C} (1.46)
[TPR-ZT] R-	FP	0.89 (0.30)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.710 (0.00)	0.75E (0.60)	1.34 (1.30)	0.71 (0.00)	0.71 (0.00)	0.710 (0.00)	0.71 (0.00)	0.84^{E} (0.26)
[TPR-ZT] R+		0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.1 (0.70)	0.79^{E} (0.14)	0.89 (0.30)	0.71 (0.00)	0.71 (0.00)	0.71(0.00 ±0.00)	0.71 (0.00)	0.75^{F} (0.06)
Mean		1.92^{A} (4.22)	1.55^{B} (2.38)	1.33^{D} (1.50)	1.51^{B} (2.17)	1.42^{C} (1.68)		1.12^{D} (0.82)	0.93^{E} (0.40)	1.54^{A} (2.22)	1.28^{B} (1.33)	1.15^{C} (0.95)	
P Value		CERM		WC	CERM* WC		CERM		WC		CERM* WC		
		<0.0001		<0.0001	<0.0001		<0.0001		<0.0001		<0.0001		
CERM		*Eisenia fetida*						Total earthworm counts (g/cft)					
		R-C	R-L	R-S	R-Li	R-M	Mean	R-C	R-L	R-S	R-Li	R-M	Mean
[ZTDSR-ZT] R-	CA	8.14 (66.30)	8.72 (76.0)	9.05 (82)	9.86 (97.30)	9.45 (89.3)	9.04^{B} (82.18)	8.73 (76.3)	9.00 (81.00)	9.42 (88.70)	10.15 (103)	9.62 (92.7)	9.38^{B} (88.34)
[ZTDSR-ZT] R+		10.15 (103.0)	10.25 (105)	9.76 (95.3)	11.75 (138.00)	10.26 (105.30)	10.43^{A} (109.32)	10.72 (115)	10.55 (111.30)	10.10 (102.00)	12.09 (146.30)	10.49 (110)	10.79^{A} (116.92)
[CTDSR-ZT] R-	pCA	8.72 (76.00)	8.35 (69.7)	9.36 (87.7)	10.01 (100.30)	9.20 (84.70)	9.13^{B} (83.68)	8.93 (79.7)	8.47 (71.70)	9.59 (92)	10.16 (103.30)	9.32 (87)	9.29^{B} (86.74)
[CTDSR-ZT] R+		9.36 (87.70)	10.00 (100)	11.54 (133.3)	11.31 (128.00)	10.72 (115.00)	10.59^{A} (112.80)	9.50 90.30)	10.16 (103.30)	11.75 (138)	11.49 (132.00)	10.94 (119.7)	10.77^{A} (116.66)
[TPR-ZT] R-	FP	8.20 (67.30)	5.745 (33.0)	5.77 (33.3)	7.50 (56.30)	5.48 (30.00)	6.54^{D} (43.98)	8.30 (69.00)	5.74 (33.00)	5.77 (33.30)	7.50 (56.30)	5.47 (30)	6.56^{D} (44.32)
[TPR-ZT] R+		9.55 (91.30)	6.85 (47.0)	6.83 (46.7)	8.89 (79.00)	6.93 (48.00)	7.81^{C} (62.40)	9.58 (91.7)	6.85 (47.00)	6.83 (46.70)	8.88 (79.00)	6.98 (48.7)	7.82^{C} (62.62)
Mean		9.02^{B} (91.83)	8.32^{D} (71.78)	8.72^{C} (79.82)	9.89^{A} (99.82)	8.67^{C} (78.72)		9.29^{B} (87.0)	8.46^{D} (74.55)	8.91^{C} (83.45)	10.05^{A} (103.32)	8.80^{C} (81.35)	
P Value		CERM		WC	CERM* WC		CERM		WC		CERM* WC		
		<0.0001		<0.0001	<0.0001		<0.0001		<0.0001		<0.0001		
CERM		Earthworm biomass (g/cft)						*Eisenia fetida counts (no./cft)* in winter crops					
		R-C	R-L	R-S	R-Li	R-M	Mean	R-C	R-L	R-S	R-Li	R-M	Mean
[ZTDSR-ZT] R-	CA	1.22 (1.93)	0.97 (1.43)	1.40 (2.30)	1.65 (2.80)	1.14 (1.77)	1.28^{C} (2.05)	2.12 (4.00)	2.92 (8.00)	2.74 (7.00)	2.55 (6.00)	2.91 (8.00)	2.65^{C} (6.60)
[ZTDSR-ZT] R+		1.79 (3.07)	1.52 (2.53)	1.94 (3.37)	2.0 (3.50)	1.60 (2.70)	1.77^{A} (3.03)	3.39 (11.0)	3.81 (14.00)	2.92 (8.00)	2.12 (4.00)	2.34 (5.00)	2.92^{A} (8.40)

[CTDSR-ZT] R-	pCA	1.04 (1.57)	1.10 (1.7)	1.59 (2.67)	1.44 (2.37)	1.14 (1.77)	1.26^{C} (2.02)	2.35 (5.00)	2.74 (7.00)	2.55 (6.00)	1.58 (2.00)	1.22 (1.00)	2.09^{D} (4.20)
[CTDSR-ZT] R+		1.42 (2.33)	1.57 (2.63)	1.84 (3.17)	1.57 (2.63)	1.57 (2.63)	1.59^{B} (2.68)	3.39 (11.)	3.24 (10.00)	4.18 (17.00)	2.34 (5.00)	0.71 (0.00)	2.77^{B} (8.60)
[TPR-ZT] R-	FP	1.02 (1.53)	0.64 (0.77)	0.49 (0.47)	0.75 (1.00)	0.57 (0.63)	0.69^{E} (0.88)	0.71 (0.00)	2.34 (5.00)	0.71 (0.00)	1.22 (1.00)	0.71 (0.00)	1.14^{E} (1.20)
[TPR-ZT] R+		1.22 (1.93)	0.97 (1.43)	1.40 (2.30)	1.65 (2.80)	1.14 (1.77)	1.28^{C} (2.05)	1.87 (3.00)	1.22 (1.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.04^{F} (0.80)
Mean		1.29^{B} (2.68)	1.13^{C} (1.75)	1.44^{A} (2.38)	1.51^{A} (2.52)	1.19^{C} (1.88)		2.31^{C} (5.67)	2.71^{A} (7.50)	2.30^{C} (6.33)	1.43^{B} (3.00)	1.75^{A} (2.33)	
P Value		CERM		WC	CERM* WC		CERM		WC		CERM* WC		
		<0.0001		<0.0001	<0.0001		<0.0001		<0.0001		<0.0001		

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CERM:crop establishment-cum-residue management; WC: winter crops; FP: farmers practices; pCA: partial conservation agriculture; CA: conservation agriculture; ZT: zero-till; ZTDSR: zero-till-direct seeded rice; CTDSR: conventional-till-direct seeded rice; TPR: transplanted puddle rice; R+: crop residue (30% RT); R-: without residue/control; R-C: rice-chickpea; R-L: rice-lentil; R-S: rice-safflower; R-Li: rice-linseed; R-M: rice-mustard; cft: cubic feet; Different capital letters (vertical) indicate significant variations in different CERM; Different capital letters (horizontal) indicate significant variations in different cropping systems; Values after ± symbol represent standard error of mean; Values in parentheses are means of three replications before performing square root transformation ($\sqrt{x+0.5}$)

Objective 3: Adapting and mainstreaming available best bet location specific CA practices for enhanced productivity and profitability in rainfed and irrigated eco-systems
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, conventional-till wheat. The results on crop yields, system productivity (wheat equivalent yield, WEY), and net returns were compared (Table 3.1). In all the districts, the zero till wheat exhibited higher yield than the conventional tilled wheat while DSR yield was little lower but comparable to TPR yield. The DSR-ZTW system performed slightly better in terms of system productivity (wheat equivalent yield, WEY) with TPR-CTW. With respect to net returns, CA based system gave approximately 18.3% higher net returns at Karnal and 16.4% higher net returns at Bareilly 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 (Rs./ha) at farmers field at Karnal (Haryana) and Bareilly (U.P.)

Farmer (No.)	District	Conservation agriculture (CA) practices				Conventional tillage (CT) practices			
		Rice grain yield (t/ha)	Wheat grain yield (t/ha)	RW system productivity (WEY) (t/ha)	Net returns (Rs./ha)	Rice grain yield (t/ha)	Wheat grain yield (t/ha)	RW system productivity (WEY) (t/ha)	Net returns (Rs./ha)
5	Karnal	4.94	5.56	10.36	176478	5.01	5.27	10.1	149216
5	Bareilly	4.67	5.64	10.16	173603	4.76	5.33	9.93	149198

CRIDA, Hyderabad

1. Demonstration on minimum tillage Begalgram in Setaria + Redgram Intercropping
The results indicated that highest redgram equivalent yield (1923 kg/ha) and net returns were obtained with sowing of Bengalgram in Korra+ Redgram intercropping after harvesting korra (Rs 1,49,803/ha) than Korra+ Redgram intercropping (1548kg/ha) (Rs 50310ha). The additional net income of the farmers was also increased in minimum tillage Bengalgram in Korra+ Redgram intercropping. Rs 27115/- more than the in Setaria+ Redgram Intercropping.

Table 3.2: Effect of minimum tillage on Begalgram in Setaria + Redgram Intercropping

Treatments	Yield (q/ha)*	Net returns (Rs./ha)	B:C Ratio	Total Productivity (Kg/ha/day
Redgram+Setaria- Bengalgram	19.23	149803	4.23	5.27
Redgram+Setaria	15.48	122688	4.18	4.24


Plate 49: Demonstration on minimum tillage Begalgram in Setaria + Redgram Intercropping

2. Demonstration Setaria- Bengalgram cropping sequence with minimum Tillage

The results indicated that highest net returns was obtained with Korra-bengalgram sequence (Rs. 146454 /ha) than fallow –Bengalgram (Rs. 24153 /ha). The additional net income of the farmers was also increased in Korra- Bengalgram sequence which is calculated as Rs. 122301/ha- more than the Fallow- bengalgram. This shows the increased profitability through Setaria-Bengalgram sequence with minimum tillage. Foxtail millet (korra), crop being its short duration may fit well in double cropping sequence under rainfed situation in black soils. Inorder to increase net returns Rs/ha and cropping intensity.

Table 3.3: Setaria- Bengalgram cropping sequence with minimum Tillage

Particulars	Yield Kg/ha	Cost of cultivation	Gross returns Rs/ha	Net returns Rs/ha	Addl Returnns (Rs/ha)	Total Productivity (Kg/ha/day
Setaria-Bengalgram	2675-1161	72653	219107	146454	122301	9.67 3.93
Bengalgram	1437	48500	89094	24153		

Plate 50: Demonstration Setaria- Bengalgram cropping sequence with minimum Tillage

3. Demonstration on Soyabean- Bengalgram cropping sequence with minimum Tillage

The results indicated that highest net returns was obtained with Soyabean- Bengalgram sequence (Rs. 66390 /ha) than fallow –Bengalgram (Rs. 38044 /ha). The additional net income of the farmers was also increased in Soyabean- Bengalgram sequence which is calculated as Rs. 28346 more than the Fallow-Bengalgram

Table 3.4: Soyabean- Bengalgram cropping sequence with minimum Tillage

Treatments	Locations (No)	Farmers visited (Nos)	Yield (q/ha)*	Net returns (Rs./ha)	B:C Ratio
Soybean-Bengalgram	10	28	25.53	66390	1.80
Bengalgram	10	10	14.00	38044	1.78

Plate 51: Demonstration on Soyabean- Bengalgram cropping sequence with minimum Tillage

4. Demonstration on conservation furrow in Setaria + Redgram Intercropping

The results indicated that highest Redgram equivalent yield (1576 kg/ha) and net returns was obtained with conservation furrow in Korra+ Redgram intercropping (Rs 1124939/ha) than Redgram sole crop without conservation furrow (769kg/ha) (Rs 55063ha). The additional net income of the farmers was also increased with conservation furrow in Korra+ Redgram intercropping which is calculated as Rs. Rs 69876 more than sole crop of Redgram.

Table 3.5: conservation furrow in Setaria + Redgram Intercropping

Treatments	Locations (No)	Farmers visited (Nos)	Yield (q/ha)*	Net returns (Rs./ha)	B:C Ratio	Total Productivity (Kg/ha/day
Redgram+Setaria with conservation furrow at 30-35DAS	10	28	15.76	124939	4.48	4.31
Redgram without conservation furrow(FP)	10	10	7.69	55063	3.35	2.10

Plate 52: Demonstration on conservation furrow in Setaria + Redgram Intercropping

IIWBR, Karnal

Field demonstrations on *in-situ* rice residue management in wheat under rice-wheat system were conducted at farmers' field in Taroarivillage of Karnal district.Paddy was harvested using straw management system (SMS) fitted combine harvester.Wheat was sown using a seed rate of 100 kg/ha with the Turbo Happy Seeder (THS). Results showed that rice residue can be effectively managed withTHS machines with a lesser time and energy requirement compared to conventional system. The wheat yield was similar under CA (59.0 q/ha) and CT (57.8 q/ha) system. 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. The reduced tillage cost in CA has resulted in economics in favour of CA system.

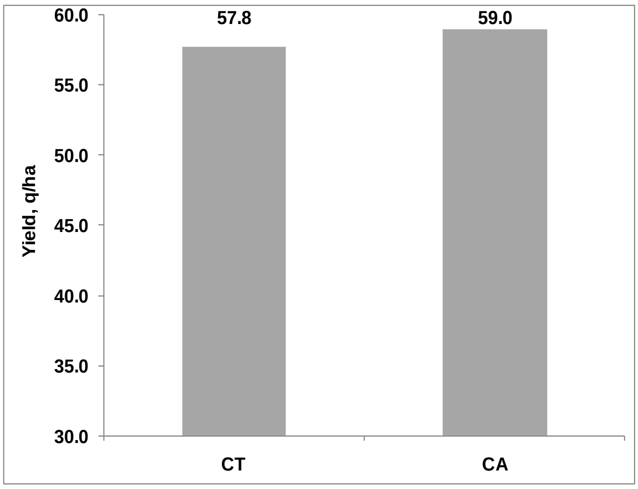

Plate 53: Wheat sowing with Turbo Happy

Fig 3.1: Performance of wheat under CA and CT in rice-wheat system

Wheat seeded in sugarcane ratoon crop with full trash using Rotary Disc Drill After the harvest of sugarcane, fields were selected in three villages namely Johar Majra, Mundoghari and Laxamanpurafor seeding of wheat in ratoon crop of sugarcane. The growing of wheat or other crops like green gram in sugarcane ratoon will be additional crops for the farmers and will enhance the profitability of the farmers as well as the wheat production. Moreover, this will promote the conservation agriculture with better environmental health by reducing the pollution with no straw/trash burning.The wheat variety DBW 187 was sown using a seed rate of 150 kg/ha during the month of December (Laxamanpura) and January (Johar Majra and Mundoghari). The new version of RDD was used for seeding in full trash of sugarcane. The wheat yield obtained ranged from 32.6 to 53.1 q/hawhen sown using RDD. Whereas, 1000 grains weight ranged 30-38 g due to delayed sowing. These results clearly showed that an additional crop of wheat can be taken in sugarcane ratoon using RDD.

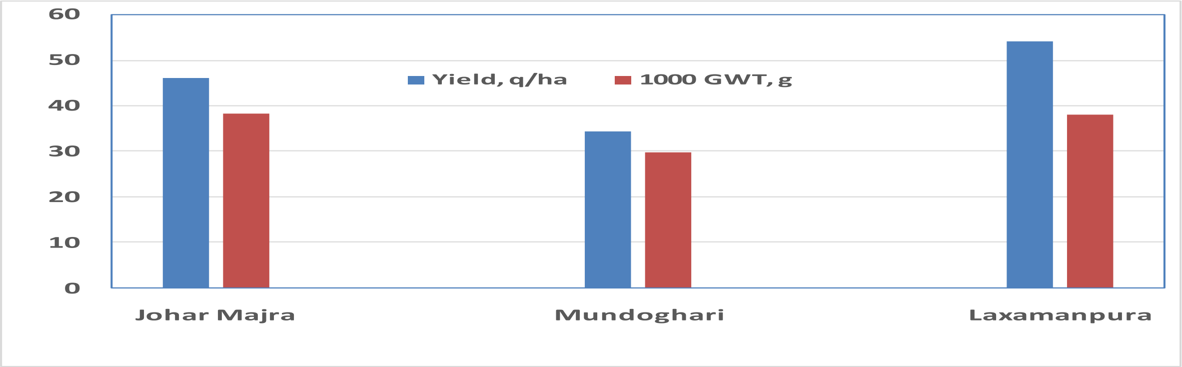

Fig 3.2: Performance of wheat seeded in sugarcane ratoon using Rotary Disc Drill

Plate 54: Wheat seeding in sugarcane ratoon using Rotary Disc Drill

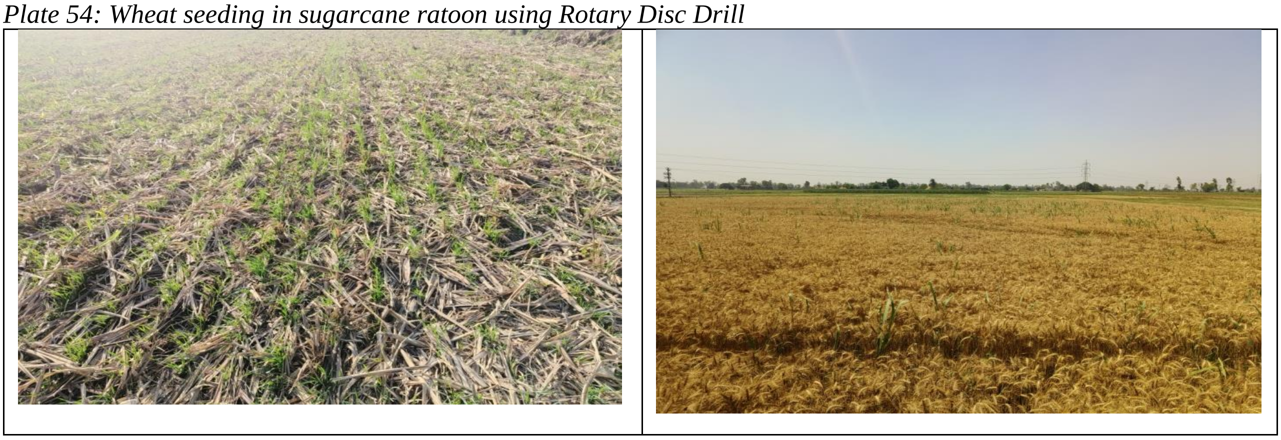

Plate 55: Wheat crop in sugarcane ratoon

Efficacy of pre-emergence herbicides in conservation tillage wheat

Pot studies were conducted to determine the effect of residue retention on efficacy of pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin against *P minor*. The soil for filling pots (of size 4.5 kg soil capacity) was taken from field having no previous infestation of *P. minor*. The soil after passing through 2 mm sieve was filled in pots. Hundred seeds/pot were sown at about 2 cm. depth. After sowing pots were heavy irrigated for seed germination and thereafter half of the pots were covered with chopped rice residue @ 8t/ha. Two days after sowing graded doses of herbicides (pyroxasulfone 6.25, 12.5,25,50,100, 200 g/ha; pendimethalin 62.5, 125,250,500,1000 and 2000 g/ha; and pyroxasulfone + pendimethalin 6.25 + 62.5, 12.5+ 125, 25+250, 50+500, 100+1000, 200+2000 g/ha) were applied. The herbicides were sprayed with knap sack sprayer fitted with flat fan nozzles delivering 450 lit/ha of spray solution.One month after herbicide application, fresh weight/pot of *P. minor* was taken and based on which per cent *P. minor* biomass reduction compared to control was worked out and which was further used for calculating GR90 values using probit analysis (Finney, 1971). The experiment was conducted twice with four replications

The effect of residue retention on efficacy of pre-emergence herbicides was studied in pot experiment. Based on the fresh biomass reductions, GR90 values were calculated and results showed differential response under with (+R) and without (-R) residue retention conditions (Table 3.6). Under the residue retention system, the dose of pyroxasulfone needed to suppress 90% of *P. minor* biomasswas increased by a factor of 6.29 times compared to the system without residue. GR_{90} values recorded for pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin under rice residue retention condition were 62.85, 226.41 and 291.11 g/ha, respectively, whereas without residue retention the respective values were 10.00, 184.09 and 97.18 g/ha. There were 528.5, 23.0 and 199.6%higher doses requirement of pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin, respectively with residue retention compared to without residue retention conditions. The rice residue retention reduced the efficacy of pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin against *P. minor*. The higher reduction was observed for pyroxasulfone efficacy.

Table 3.6: Effect of rice residue management on GR_{90} values of *P. minor* for pyroxasulfone, pendimethalin and pyroxasulfone + pendimethalin in a pot study

Residue management	Herbicide	GR_{90} values (g/ha)
Residue retention (+R)	Pyroxasulfone	62.85
	Pendimethalin	226.41
	Pyroxasulfone + Pendimethalin (1:10)	291.11
Without residue (-R)	Pyroxasulfone	10.00
	Pendimethalin	184.09
	Pyroxasulfone + Pendimethalin (1:10)	97.18

Plate 56: Efficacy of pre-emergence herbicides affected by residue retention

DWR, Jabalpur

Demonstration of weed management technologies in rice/maize-wheat/chickpea-greengram cropping system under conservation agriculture

Wheat (*Rabi* 2022-23)

In wheat crop, twenty on-farm research trials cum demonstrations on weed management were undertaken at ten villages of Panagar and Sihora localityunder conservation agriculture during *Rabi* 2022-23. The major weed flora observed in the field were *Phalaris minor* (21%), *Avena ludoviciana* (20%), *Vicia sativa* (17%), *Medicago polymorpha* (15%), *Chenopodium album* (12%), *Lathyrus aphaca* (11%)andothers (4%). Improved crop production practice includes use of recommended dose of fertilizer NPK (120:60:40 kg/ha) under conservation agriculture and improved weed management with application of clodinafop+metsulfuron 60+4 g/ha at 30 DAS. This practice resulted in lowest weed density and biomass alongwith highest grain yield of 5.18 t/ha. Further, this treatment recorded highest net returns of Rs. 76614/ha and higher incremental cost benefit ratio (ICBR) of 5.72 compared to other treatments (Table 3.7).

Table 3.7: Weed management, productivity and economics of OFR treatments in wheat during *Rabi*, 2022-23

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	Grain yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	ICBR
Improved package of practice + Improved weed management	3.24(10.71)^d	4.07(16.77)^d	5.18^a	110045	76614	5.72
Farmers' package of practice + Improved weed management	4.47(20.29)^c	5.27(28.26)^c	4.85^b	103062	66968	3.74
Improved package of practice + Farmers practice of weed management	5.27(28.14)^b	6.74(45.8)^b	4.29^c	90929	57598	1.35
Farmers' package of practice + Farmers practice of weed management	6.35(41.43)^a	8.08(65.97)^a	3.94^d	83179	47085	-

Chickpea (*Rabi*, 2022-23)

In chickpea, ten OFR trials cum demonstrations were conducted with four treatments under conservation agriculture at five villages of Panagar and Sihora locality during *Rabi* 2022-23. The major weed flora observed was *Medicago polymorpha* (25%), *Lathyrus aphaca* (22%), *Vicia sativa* (20%), *Chenopodium album* (16%) and others (17%). Chickpea grown with improved packages of practices including recommended fertilizer (20:60:40 N, P_2O_5, K_2O kg/ha) and herbicide (pendimethalin 750 g/ha as pre-emergence) under CA recorded lower weed density and biomass than other treatments (Table 3.8). The average seed yield of chickpea was obtained to the tune of 2.41 t/ha in this practice. The higher ICBR of 7.16 was also recorded with the same treatment as compared to farmers' practice of weed management. An increase of 43% in the net returns was recorded through improved practice as compared to farmer's practice.

Table 3.8: Weed management, productivity and economics of OFR treatments of chickpea during *Rabi*, 2022-23

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	Seed yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	ICBR
Improved package of practice + Improved weed management	4.30(18.83)^d	4.83(23.48)d	2.41^a	128485	95445	7.16
Farmers' package of practice + Improved weed management	5.20(27.17)^c	6.115(37.4)^c	2.18^b	115814	79861	5.19
Improved package of practice + Farmers practice of weed management	6.25(39.17)^b	7.16(51.33)^b	1.90^c	101143	65436	1.05
Farmers' package of practice + Farmers practice of weed management	7.49(56.17)^a	8.18(66.9)^a	1.68^d	89806	53853	-

Greengram (Summer 2023)

Similarly, during summer 2023, sixteen OFR cum demonstrations were conducted on weed management in greengram under conservation agriculture at farmers' fields in six villages of Panagar and Sihora localities. The major weed flora observed was *Echinochloa colona* (39%), *Euphorbia geniculata*(15%), *Alternanthera sessilis* (12%), *Cyperus rotundus* (20%), *Sporobolus* sp. (8%) and others (6%).Results obtained from OFR trials revealed that recommended package of practices under CA along with improved weed management (imazethapyr 100 g/ha as post-emergence) was effective and provided broad-spectrum weed control and seed yield of 1.49 t/ha, as compared to 1.15 t/ha under FP (conventional tillage + 1 hand weeding); and provided an net returns of Rs. 77806/ha with higher ICBR of 4.13 over farmers practice (Table 3.9). Crop raised under CA by using Happy seeder facilitated early sowing of crop by utilizing the residual soil moisture content in addition of effective management of crop residue and reduction in excessive tillage operation and operational cost.

Table 3.9: Weed management, productivity and economics of OFR treatments in greengram during summer, 2023

Treatment	Weed density (no./m²)	Weed biomass (g/m²)	Seed yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	ICBR
Improved package of practice + Improved weed management	3.54(15.59)[c]	2.68(7.43)[c]	1.49[a]	105705	77806	4.13
Farmers' package of practice + Farmers practice of weed management	4.54(23.18)[b]	4.13(18.12)[b]	1.15[ab]	80981	48368	-
Improved package of practice + Weedy	6.41(44.24)[a]	5.98(37.30)[a]	0.73[b]	50821	22845	-
LSD (p=0.05)	0.55	0.506	0.63	-	-	-

Rice (*Kharif* 2023)

In rice crop, fourteen on-farm research trials cum demonstrations on weed management were undertaken at villages viz. Jetna, Bahmnoda, Porua villages of Panagar locality and Jujhari, Gosalpur, Khajri, Ghutna, Mandovar and Deori villages of Sihora locality under conservation agriculture during *Kharif* 2023. The major weed flora observed in the field were *Echinochloa colona, Cyperus spp, Dinebra reteroflexa, Alternanthera sessilis, Physalis minima, Commelina communis, Eclipta alba,* etc. Improved crop production practice includes use of recommended dose of fertilizer NPK (120:60:40 kg/ha) and improved weed management with application of pyrazosulfuron 25 g/ha as PE *fb* bispyribac-sodium 25 g/ha as PoE at 18 DAS. Improved practice of weed management and other agricultural practices resulted in lowest weed density and biomass along with highest grain yield of 5.21 t/ha. Further, this treatment recorded highest net returns of Rs. 84053/ha and higher cost benefit ratio of 3.54 compared to other treatments (Table 3.10).

Table 3.10: Weed management, productivity and economics of OFR treatments in rice at Panagar and Sihora localities during *Kharif*, 2023

Treatment	Weed density (no./m²)	Weed biomass (g/m²)	Grain yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C
Improved package of practice + Improved weed management	3.36(12.3)[c]	4.27(20.1)[c]	5.21[a]	117191	84053	3.54
Farmers' package of practice + Improved weed management	5.20(28.6)[b]	6.20(39.0)[b]	4.87[b]	110278	73949	3.04
Improved package of practice + Farmers practice of weed management	5.79(38.6)[b]	6.64(49.7)[b]	4.27[c]	95615	62477	2.88
Farmers' package of practice + Farmers practice of weed management	7.39(59.3)[a]	8.89(79.6)[a]	4.00[d]	87902	51573	2.42

Plate 57: Weed management in rice at Panagar and Sihora localities during Kharif, 2023

Maize (*Kharif*, 2023)

In maize, five OFR trials were conducted on weed management during *Kharif*, 2023 at villages Khirheni and Porua villages of Panagar locality. The major weed flora observed was *Commelina benghalensis, Cyperus* spp., *Dinebra retroflexa, Echinochloa colona, Eclipta alba* and *Euphorbia geniculata*. Lower weed density (7.8 no./m^2) and biomass (17.6 g/m^2) were observed in application of atrazine 750 g/ha as PE *fb* tembotrione + atrazine (120+500 g/ha) at 30 DAS with RDF (120:60:40 N, P_2O_5, K_2O kg/ha) (Table 3.11). Grain yield of maize was observed as 5.68 t/ha in improved practice with improved weed management technique. Higher net returns (Rs. 79382/ha) and B: C (3.17) was recorded with the same treatment as compared to the farmers' practice. It was also observed that, the improved weed management practice under farmer practice controlled the weeds effectively compared to the farmer practice of weed management.

Table 3.11: Weed management, productivity and economics of OFR treatments in maize at Panagar locality during *Kharif*, 2023

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	Grain yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C
Improved package of practice + Improved Weed management	2.74(7.8)^d	4.12(17.6)^d	5.68^a	118628	79382	3.17
Farmers' package of practice + Improved weed management	4.47(20.2)^c	5.48(30.1)^c	5.26^b	109934	67031	2.56
Improved package of practice + Farmers practice of weed management	5.83(34.2)^b	6.83(46.9)^b	4.66^c	97394	58148	2.48
Farmers' package of practice + Farmers practice of weed management	7.54(57.2)^a	8.41(71.0)^a	4.01^d	83767	40864	2.01

Plate 58: Weed management and productivity of OFR treatments in maize at Panagar locality during Kharif, 2023

Herbicide residues under conservation agriculture experiments

Plant samples (seed/grain/straw) were collected at harvest in*Rabi* summer and *Kharif*crops during 2023 for the determination of terminal residues. The presence of herbicide residues in grain and straw samples were determined by standardized UFLC methods using a PDA detector. The UFLC methods make use of Phenomenex C-18 (ODS) column (3.5 µm particle size, 5×3.5 mm i.d.) and acetonitrile: H_3PO_4 0.01% (70:30 v/v) as mobile phase at a flow rate of 0.35 ml/min.10 µl of the aliquot of standards and samples was injected by using microsyringe.

- In rice-wheat/chickpea-greengram cropping system, clodinafop, metsulfuron, mesosulfuron and iodosulfuron residues in wheat, pendimethalin, imazethapyr and topramezone residues in chickpea and pendimethalin, quizalofop and imazethapyr residues in greengram, pyrazosulfuron, pretilachlor, bispyribac sodium, fenoxaprop, chlorimuron and metsulfuron residues in rice, were found below the detection limit (0.01 µg/g).
- In maize-wheat/chickpea-greengram cropping system, clodinafop, metsulfuron, mesosulfuron and iodosulfuron residues in wheat, pendimethalin, imazethapyr and topramezone residues in chickpea and pendimethalin, quizalofop and imazethapyr residues in greengram, atrazine, topramezone and tembotrioneresidues in maize, clodinafop, metsulfuron, mesosulfuron and iodosulfuron residues in wheat, pendimethalin, imazethapyr and topramezone residues in chickpea and pendimethalin and imazethapyr residues in greengram were found below the detection limit (0.01 µg/g).

NIASM, Baramati

1. Organized One Month Inplant Training on “Abiotic Stresses in Agriculture, Management Strategies and Engineering Interventions” from September 4 to October 3, 2023 held at ICAR–NIASM. Total 22 students (UG, PG, and PhD) of different agricultural disciplines from MPKV, Rahuri; VNMKV, Parbhani and IARI–NIASM, Baramati were participated. The course was enunciated in such a way those students would have hands-on experience with the latest conservation agriculture/ climate-resilient technologies/strategies and their application for transforming and reorienting agricultural development under new realities of climate change.

2. Organized two frontline demonstrations of multifunctional ratoon drill for resources conservation in ratoon sugarcaneat ICAR–NIASM, Baramati. Total 75 farmers, students and extension functionaries were benefited.

SCSP Activities:

Organized the three-awareness program on conservation agriculture and distributed household inputs, sewing machines, and flour mills to scheduled caste (SC) beneficiaries from Malegaon, Mekhali, Pimpali, and Nimon villages in BaramatiTahsil and Ahmednagar District under the CRP-CA project. More than 35 beneficiaries (140 family members) were benefited during the year 2023–24.

लोकमत

महिलांना गृहोपयोगी साहित्य वाटप

आर्थिक दुर्बल घटकातील महिलांना गृहपयोगी साहित्यांचे मोफत वाटप

पुण्यनगरी

बारामतीत महिलांना गृहोपयोगी साहित्यांचे वाटप

बारामती : तालुक्यातील पिंपळी-लिमटेक, मेखळी, माळेगाव भागातील आर्थिकदृष्ट्या मागास असलेल्या महिलांना गृहोपयोगी साहित्य, शिलाई मशीन, पीठगिरणी व संपूर्ण भांडी संचाचे मोफत वाटप राष्ट्रीय अजैविक तान प्रबंधन संस्थेच्या वतीने करण्यात आले. या वेळी बोलताना डॉ. के. एस. रेड्डी म्हणाले, ग्रामीण भागातील आर्थिकदृष्ट्या मागास असलेल्या पात्र महिलांना गरजेनुसार राष्ट्रीय अजैविक तान प्रबंधन संस्थान मार्फत गृहोपयोगी साहित्यांचे मोफत वाटप केले. या साहित्यांचा वापर उत्तम करावा, असे त्यांनी सांगितले. या प्रसंगी संवर्धन कृषी प्रकल्प अधिकारी डॉ. गोरक्ष वाकचौरे म्हणाले, सर्व पात्र लाभार्थींचे त्यांनी अभिनंदन करून पीठगिरणी व शिलाई मशीनचा वापर घरगुती आणि स्वयंरोजगारासाठी करावा, तसेच सर्व गृहोपयोगी साहित्याचा उपयोग करावा. या योजनेचा सर्व पात्र लाभार्थींना लाभ मिळण्याकामी सावित्री महिला प्रशिक्षण संस्था पिंपळीच्या वतीने संस्थेच्या अध्यक्षा स्नेहा थोरात यांनी प्रयत्न केले होते. या वेळी आभार राष्ट्रीय अजैविक तान प्रबंधन संस्थानचे प्रमुख अधिकारी डॉ. के. के. पाल यांनी मानले.

RCER, Patna

01-day training program on *"Rice-fallow Management by CA Technologies"* sponsored by Consortia Research Project of SCSP Fund GoI held at KVK, Chatra, Jharkhand, 1st March, 2024.


प्रमंडल

कृषि विज्ञान केंद्र में धान-परती प्रणाली प्रबंधन पर एक दिवसीय प्रशिक्षण शिविर का आयोजन

चतरा : आधुनिक तरीके से खेती करके अपनी आमदनी बढ़ा सकते है किसान : डॉ. धर्मा उरांव

किसानों को दी गई जल प्रबंधन की जानकारी

रांची, शनिवार 02.03.2024

किसानों को दिया धान परती प्रणाली प्रबंधन पर प्रशिक्षण

धान-परती प्रणाली प्रबंधन पर एक दिवसीय प्रशिक्षण का हुआ आयोजन

सदर प्रखंड के सोनबिगहा ग्राम में ड्रोन से नैनो यूरिया का छिड़काव किया गया

भास्कर न्यूज | चतरा

जिले के सदर प्रखंड के सोनबिगहा गांव के खेतों में शुक्रवार को ड्रोन के माध्यम से खेतों में नैनो यूरिया का छिड़काव किया गया। यह कार्यक्रम भारतीय कृषि अनुसंधान परिषद के अनुसंधान केन्द्र पलांडु एवं कृषि विज्ञान केन्द्र चतरा के द्वारा ड्रोन द्वारा किसानों के खेत मे नैनो यूरिया का छिड़काव प्रदर्शन कार्यक्रम के तहत की गई। ड्रोन से नैनो यूरिया का छिड़काव कार्यक्रम चतरा प्रखण्ड के सोनबिगहा गांव में सफलता पूर्वक सम्पन्न हुवा। यह कार्यक्रम संस्था के वरिष्ठ कृषि वैज्ञानिक ड्रा. संतोष संभाजी माली के देख-रेख में किया गय।इस दौरान डॉ. संतोष ने किसानों को कृषि में ड्रोन का उपयोग से अवगत कराते हुए इसका प्रदर्शन किया । किसान कृषि में विज्ञान एवं आधुनिक विधि से अवगत होकर काफी उत्साहित थे। कार्यक्रम मे ड्रोन के माध्यम से किसानों के खेतों मे नैनो यूरिया का छिड़काव प्रदर्शन सफलता पूर्वक सम्पन्न किया गया। ग्रामीण किसानों ने कार्यक्रम को सराहा और किसानों को विज्ञान से जुड़ने एवं आधुनिक विधि को अपनाने की आवश्यकता पर जोर दिया।

धान-परती प्रणाली का दिया गया प्रशिक्षण

संवाद सूत्र, चतरा : स्थानीय कृषि विज्ञान केंद्र में शुक्रवार धान-परती प्रणाली प्रबंधन विषय पर एक दिवसीय प्रशिक्षण कार्यक्रम का आयोजन किया गया। जिसका उद्घाटन प्रमुख वैज्ञानिक एवं परियोजना के सह-अन्वेशक डा. बाल कृष्ण झा ने दी प्रज्वलित कर किया। कार्यक्रम को संबोधित करते हुए उन्होंने कहा कि झारखंड प्रदेश में एकल फसल वर्षा आधारित धान की खेती किसान करते हैं।

रबी और गरमा फसलों की खेती नहीं करते है परती छोड देते हैं, जिससे किसानों को खेती से पूरा लाभ नहीं मिल पाता है। उन्होंने बताया कि रांची स्थित अनुसंधान संस्थान में विगत सात वर्षों के संरक्षित कृषि आधारित धान-परती प्रणाली पर किए गए अनुसंधान से धान की कटाई के पश्चात संरक्षण तकनीक द्वारा शून्य जुताई एवं फसलों के अवशेष प्रबंधन पलवार के साथ-साथ जल संरक्षण की तकनीक द्वारा खेतों की न्यूनतम जुताई कर बची हुई नमी का उपयोग सिंचाई में कर सकते है। कहा कि वर्तमान जलवायु परिवर्तन के परिप्रेक्ष्य में संरक्षण कृषि तकनीक द्वारा धान-परती प्रणाली के प्रबंधन में काफी लाभदायक है। इसे अपनाकर किसान अपनी आमदनी दोगुनी कर सकते हैं। प्रशिक्षण के उपरांत सोनबिगहा गांव में ड्रोन के द्वारा नैनो यूरिया का छिड़काव किया गया। प्रशिक्षण में केंवीके के उपेंद्र कुमार सिंह, मो. जुनैद आलम, अभिजित घोष, अभिषेक घोष सहित अन्य ने अहम भूमिका निभाई।

ड्रोन से नैनो यूरिया का छिड़काव की जानकारी देते प्रशिक्षक • जागरण

चतरा में अब ड्रोन से किसानो के खेत में यूरिया का हो रहा है छिड़काव

ग्रामीण चहल पहल | गया/आसपास

संरक्षण कृषि प्रौद्योगिकी द्वारा धान-परती प्रणाली प्रबंधन पर एक दिवसीय प्रशिक्षण

Plate 59: Press and Media Coverage

CIAE, Bhopal

Under SCSP component of CRP on CA demonstration cum train102 numbers of CIAE developed fuel cooking stove, were demonstrated and distributed to 102 farmers of village Manakhedi, Sewaniya, Napaniya and Dhabla Rai of Sehore district of MP. These tools are helpful in drudgery reduction, saving in time and cost of cultivation. The detail is given in table below.

S. No.	Programme detail	Date	District	Beneficiaries
1.	Field day-cum-demonstration and distribution of CIAE made hand tool to farmers of Manakhedi village	11.01.2023	Sehore, MP	51

2.	"Hands-on training and demonstration of improved agricultural implements suitable for conservation agriculture"from Sewaniya and Napaniya village of Sehore district of Madhya Pradesh.	01/03/2023 to 03/03/2023	Sehore, MP	25
3.	"Hands-on training and demonstration of improved agricultural implements suitable for conservation agriculture" from Dhabla Rai village of Sehore district of Madhya Pradesh.	08/03/2023 to 10/03/2023	Sehore, MP	

Plate 60: Demonstration of promising CA machinery to farmers for enhancing their confidence

To popularize the suitable CA machinery among the stakeholders through various skill development programs the institute developed technology (Slit till drill) was demonstrated in three villages (9 farmer's field) for sowing of wheat in irrigated field after harvesting of paddy crop. The crop germinated was satisfactory and farmers were happy with saving in operational cost. Farmers name, their village, mobile number along with date of sowing is listed below: -

S. No.	Farmer name	Village	Mobile no.	Area in acre	Sowing date
1	Chain Singh Jat	Rasla khedi	9827437705	1	04/12/2023
2	Jeevan Singh Jat	Rasla khedi	9753334316	1	05/12/2023
3	Hemraj Yadav	Kham kheda	9098419953	1	06/12/2023
4	Nandlal Yadav	Kham kheda	8458902592	1	06/12/2023
5	Rajnarayan Yadav	Kham kheda	8889287739	1	06/12/2023
6	Himmat Singh Lodhi	Karond khurd	9981113024	1	10/12/2023
7	Naval Singh Lodhi	Karond khurd	8319594419	1	10/12/2023
8	Ram Singh Lodhi	Karond khurd	9754222053	1	11/12/2023
9	Azad Singh	Karond khurd	9981337923	1	12/12/2023

Plate 61: Sowing of wheat crop at farmers field and interaction with farmers.

IIFSR

As a part of the project the activities under SCSP scheme were initiated in the Laldhang cluster, Bahadrabad block of Haridwar district of Uttarakhand state to improve the livelihood of the farmers belonging to the Scheduled caste category. A total number of 325 farm families of Schedule Caste (SC) from Dalupuri, Rasoolpur Mithiberi and Chamariya villages of Laldhang cluster were adopted under the scheme. To identify the suitability of integrated farming system component, conservation agriculture and organic farming among the farmers of small and marginal farmers' category the basic data related to socio-economic status of the adopted farmers were collected using the standard survey proforma. As per the survey, the selected villages are dominated by the marginal farmers' category (44%) owning 55.6%marginal; >36.3% small farmers; >22.9% medium and large farmers. The mean level of cropping intensity of adopted villages is 164%. Fig. 3.3 contains the data related to comparison of effect of improved wheat varieties and introduction of poultry component on nutritional and livelihood security of the adopted farm families.

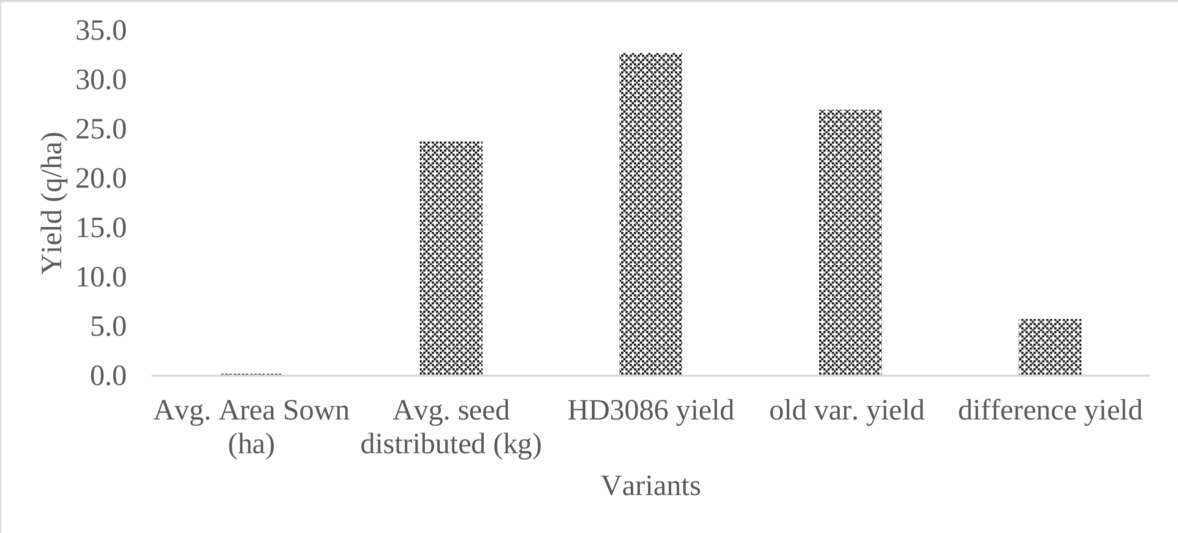

Fig 3.3: Comparison of farmers practices and improved wheat cultivar on yield enhancement among the adopted farm families.

The data depicted in fig 3.4 showed that the average area shown by individual farmers under wheat crop was 0.20 ha in the studied area. The improved HD 3086 variety of wheat produced on an average 32.71 q ha^{-1} yield as compared to the traditional cultivar used by the farmers. Data depicted in Fig 3.5 shows that an average of 29 birds were distributed among the farmers. The mortality rate was 6.5 birds per farm family. At the same time, the live birds produced on an average of 19 egg per bird which in turn produced a total of 67.67 eggs per farm family.

Fig 3.4: Introduction of commercial poultry birds among the SC farmers for nutritional and livelihood security.

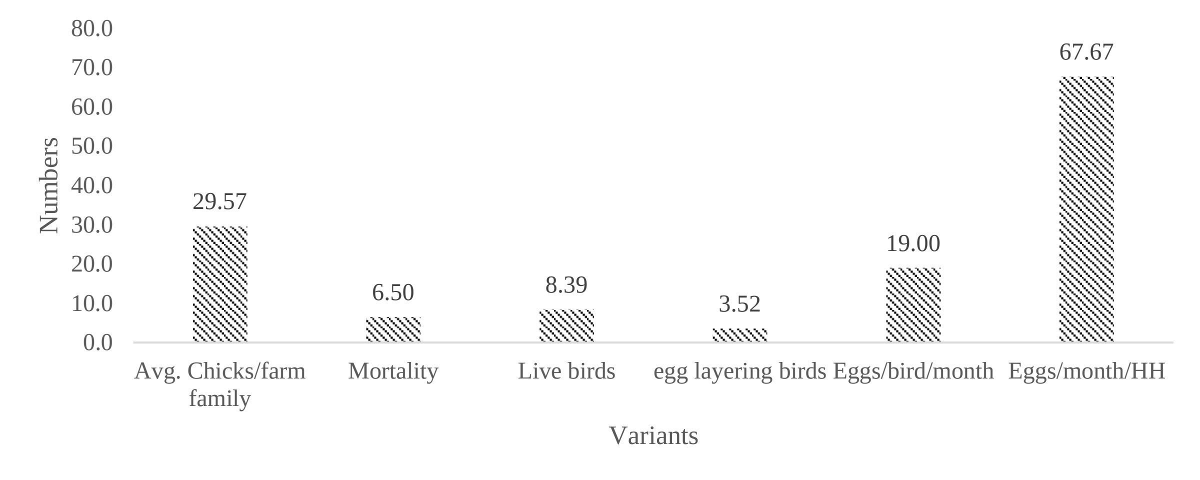

Fig 3.5: Introduction of commercial poultry birds among the SC farmers for nutritional and livelihood security.

Plates 61: (a) Demonstration of Vermicomposting technique and (b) Use of Pusa decomposer for rice straw management among the SCSP farmers

Plates 62: (a) Demonstration of improved rice seed and commercial poultry bird among the SCSP farmers

ISS, Bhopal

Farmers field experiments were conducted in a participatory mode in adopted villages *viz*., Khamkheda, Raslakhedi, Raipur and Karodkhurd using soybean (JS 2029), wheat (HI 1544) and chickpea (RVG 202) as test crops to evaluate the different crop establishment techniques such as zero tillage (ZT), reduced tillage (RT) and conventional tillage (CT) at 20 farmers field during kharif and rabi season of 2023. The standard agronomic protocols were followed to raise the crops at farmers' fields at different villages. Besides, the recommended herbicides were adopted under different treatments to check the growth of weeds.

Soybean

Twenty farmers field demonstrations (Table 3.12) under zero tillage, reduced tillage and conventional tillage were conducted during kharif season 2023 withsoybean as test crop under CRP on CA. Average data revealed that zero tillage recorded higher grain and biological yields of soybean at most of the farmers' fields as compared to reduced and conventional tillage. However, reduced and conventional tillage also improved the grain and biological yield of soybean at some farmers field as compared to the zero till farming. Maximum harvest index was recorded in zero tillage (43.1) of soybean at most of farmers field as compared to reduced tillage (43.0) and conventional tillage (41.5).

Table 3.12: Farmers field demonstrations under zero tillage, reduced tillage and conventional tillage were conducted during kharif season 2023 as soybean test crop under CRP on CA

S. No.	Name of Farmer	Zero Tillage			Reduced Tillage			Conventional Tillage		
		Biological yield (kg/ha)	Grain yield (kg/ha)	HI	Biological yield (kg/ha)	Grain yield (kg/ha)	HI	Biological yield (kg/ha)	Grain yield (kg/ha)	HI
1	Parvat Yadav	4125.0	1875.0	45.5	3775.0	1700.0	45.0	4325.0	1475.0	34.1
2	Nandlal Yadav	3625.0	1575.0	43.4	3600.0	1700.0	47.2	3950.0	1800.0	45.6
3	Karan Singh Yadav	3475.0	1475.0	42.4	3100.0	1400.0	45.2	2825.0	1225.0	43.4
4	Hemraj Yadav	3575.0	1550.0	43.4	3375.0	1525.0	45.2	3400.0	1500.0	44.1
5	Naval Singh Yadav	2787.5	1225.0	43.9	2625.0	1250.0	47.6	2625.0	1125.0	42.9
6	Deepak Yadav	4450.0	1875.0	42.1	3875.0	1700.0	43.9	3500.0	1525.0	43.6
7	Raj Narayan Yadav	5375.0	2200.0	40.9	5125.0	1800.0	35.1	4625.0	1600.0	34.6
8	Jagjeevan Ahirwar	4125.0	1750.0	42.4	3925.0	1775.0	45.2	3950.0	1625.0	41.1
9	Ram Singh Lodhi	3700.0	1550.0	41.9	3400.0	1425.0	41.9	3075.0	1375.0	44.7
10	Himmat Singh Lodhi	3125.0	1225.0	39.2	3275.0	1425.0	43.5	3200.0	1362.5	42.6
11	Naval Singh Lodhi	2875.0	1400.0	48.7	3200.0	1500.0	46.9	2775.0	1300.0	46.8
12	Azad Singh	3600.0	1575.0	43.8	4500.0	1400.0	31.1	2350.0	1200.0	51.1
13	Santosh Yadav	3025.0	1500.0	49.6	3625.0	1550.0	42.8	3300.0	1325.0	40.2
14	Chain Singh Jat	4050.0	1725.0	42.6	3750.0	1625.0	43.3	3550.0	1275.0	35.9
15	Jeevan Singh Jat	3775.0	1800.0	47.7	3625.0	1700.0	46.9	3500.0	1475.0	42.1
16	Badam Singh Jat	3875.0	1525.0	39.4	3075.0	1350.0	43.9	2375.0	1050.0	44.2

17	Ram Singh Jat	3087.5	1525.0	49.4	3375.0	1450.0	43.0	2875.0	1250.0	43.5
18	Vijay Malviya	3625.0	1450.0	40.0	3275.0	1550.0	47.3	3375.0	1300.0	38.5
19	Phul Singh	3550.0	1312.5	37.0	3025.0	1225.0	40.5	2450.0	900.0	36.7
20	Goverdhan	3625.0	1525.0	42.1	3450.0	1450.0	42.0	3375.0	1475.0	43.7
Average		**3672.5**	**1581.9**	**43.1**	**3548.8**	**1525.0**	**43.0**	**3270.0**	**1358.1**	**41.5**

Plate 63: View of Soybean crop in farmers' field under conservation agriculture in kharif season 2023

Wheat

12 demonstrations (Table 3.13) with wheat crop were conducted during rabi season 2023. A perusal of the average data revealed that zero tillage recorded higher seed yield (5160.4 kg/ha) and biological yield (11968.8 kg/ha) of wheat as compared to reduced tillage and conventional tillage, however, the differences in grain yield could not attain the level of significance. Maximum harvest index was recorded in zero tillage (43.1) of soybean at most of the farmers' field as compared to reduced tillage (41.5) and conventional tillage (41.3).

Table 3.13: Farmers field demonstrations with wheat crop conducted during rabi season 2023.

S. No.	Name of Farmer	Zero Tillage			Reduced Tillage			Conventional Tillage		
		Biological yield (kg/ha)	Grain yield (kg/ha)	HI	Biologica lyield (kg/ha)	Grain yield (kg/ha)	HI	Biological yield (kg/ha)	Grain yield (kg/ha)	HI
1	Parvat Yadav	10875.0	4625.0	42.5	10125.0	4400.0	43.5	10000.0	4300.0	43.0
2	Nandlal Yadav	12000.0	5800.0	48.3	11375.0	5525.0	48.6	11500.0	5400.0	47.0
3	Karan Singh Yadav	11750.0	5125.0	43.6	12125.0	5025.0	41.4	11625.0	4800.0	41.3
4	Hemraj Yadav	12750.0	5525.0	43.3	12375.0	5000.0	40.4	12875.0	5300.0	41.2
5	Naval Singh Yadav	11625.0	5625.0	48.4	12000.0	4800.0	40.0	11875.0	4450.0	37.5

6	Deepak Yadav	12000.0	5000.0	41.7	12875.0	4875.0	37.9	13000.0	4975.0	38.3
7	Raj Narayan Yadav	13375.0	5425.0	40.6	12250.0	5250.0	42.9	13500.0	5375.0	39.8
8	Jagjeevan Ahirwar	11500.0	4500.0	39.1	11375.0	4375.0	38.5	11625.0	4625.0	39.8
9	RamSingh Lodhi	10375.0	4575.0	44.1	10500.0	4400.0	41.9	10125.0	4550.0	44.9
10	Himmat Singh Lodhi	13375.0	5750.0	43.0	13000.0	5375.0	41.3	12750.0	5250.0	41.2
11	Naval Singh Lodhi	11375.0	4750.0	41.8	11250.0	4625.0	41.1	10750.0	4500.0	41.9
12	Azad Singh	12625.0	5225.0	41.4	12125.0	5050.0	41.6	11700.0	4825.0	41.2
Average		**11968.8**	**5160.4**	**43.1**	**11781.3**	**4891.7**	**41.5**	**11777.1**	**4862.5**	**41.3**

Plate 64: View of wheat crop in farmers' field under conservation agriculture in rabi season 2023

Chickpea

8 demonstrations (Table 3.14) with wheat crop were conducted during rabi season 2023. A perusal of the average data revealed that zero tillage recorded higher seed yieldand biological yield of chickpea as compared to reduced tillage and conventional tillage, however, the differences in grain yield and biological yield could not attain the level of significance. Maximum harvest index was recorded in reduced tillage (43.6) of soybean at most of farmers' field as compared to conventional tillage (42.3) and zero tillage (41.7).

Table 3.14: Farmers field demonstrations with wheat crop conducted during rabi season 2023.

S. No	Name of Farmer	Zero Tillage			Reduced Tillage			Conventional Tillage		
		Biological yield kg/ha.	**Grain yield kg/ha.**	**HI**	**Biological yield kg/ha.**	**Grain yield kg/ha**	**HI**	**Biological yield kg/ha.**	**Grain yield kg/ha**	**HI**
1	Santosh Yadav	3200.0	1400.0	43.8	2975.0	1350.0	45.4	2450.0	1050.0	42.9
2	Chain Singh Jat	3250.0	1325.0	40.8	2725.0	1200.0	44.0	2225.0	900.0	40.4
3	Jeevan Singh Jat	3125.0	1300.0	41.6	3200.0	1400.0	43.8	2375.0	1075.0	45.3
4	Badam Singh Jat	2850.0	1200.0	42.1	2650.0	1100.0	41.5	2200.0	925.0	42.0

5	Ram Singh Jat	3075.0	1200.0	39.0	2625.0	1125.0	42.9	2325.0	900.0	38.7
6	Vijay Malviya	3275.0	1325.0	40.5	2725.0	1200.0	44.0	2600.0	1125.0	43.3
7	Phul Singh	3550.0	1550.0	43.7	3150.0	1375.0	43.7	2850.0	1200.0	42.1
8	Govardhan	3775.0	1600.0	42.4	3250.0	1425.0	43.8	3200.0	1400.0	43.8
Average		**3262.5**	**1362.5**	**41.7**	**2912.5**	**1271.9**	**43.6**	**2528.1**	**1071.9**	**42.3**

Plate 65: View of Chickpea crop in farmers' field under conservation agriculture in rabi season 2023

Activities under SCSP

Under SCSP program, distribution of farm implements, vermicompost and seedlings of high yielding varieties of Lime, Guava and Mango were made to the farm families (40 nos.) of the villages of RasuliaPathar, Kham Kheda, Raipur and Kalakhedi.