



INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Consortia Research Platform on Conservation Agriculture

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Principles of Conservation Agriculture

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1. Background

Agriculture plays a vital role in India's economy contributing to GVA of the country by 18-19 % and employing nearly 60 % of the labour force. The country achieved a record-breaking food grain production of 357.73 million tonnes in the agricultural year 2024–25, the highest in its history. The significant growth has been attributed to favourable climatic conditions, the adoption of modern agricultural technologies, improved crop management practices, and continued government support through farmer-focused initiatives. This achievement reflects steady progress in India's agricultural sector and strengthened food security. The mission of increasing food grain production, though somehow realized at present, is yet under risk due to climatic aberrations and reduced availability of land, water, nutrients along with 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 them from the processes of soil degradation like erosion, compaction, aggregate breakdown, loss of organic matter, leaching of nutrients, and processes that are accentuated 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 them 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 for 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 agriculture 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 and in India it is also seen as an effective strategy against the crop-residue burning. South American countries (e.g. Brazil, Argentina, Colombia etc) and many other countries in different continents including Asia, who are practicing conservation agriculture reported a remarkable positive effect on carbon and water footprints of agriculture. Although adopting CA practices presents certain challenges particularly for large-scale conventional farmer's modern agricultural technologies, yet provide significant support and opportunities in transition of conventional agriculture into energy savior and climate smart.

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-ecological regions 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, and alternatives to rice–wheat cropping system in relation to CA technologies. The area planted with wheat using zero-tillage drill has been increasing rapidly in recent years. It is estimated that over the past few years, adoption of Zero-tillage in India has expanded to cover about 2 m ha and CA (including partial CA) has expanded in about 3.5 m ha.

The rapid adoption and spread of zero tillage are 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. The adoption of 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 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. Research 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 low 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) regions, 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. needs 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. 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 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 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 m³ 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.

Farmer's 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 cropped 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 by exploring changes in community structure and the dynamics of microbial population and microbial mediated processes.
- Quantifying tangible and intangible 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 specially 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 Highlights of CRP on Conservation Agriculture (2024)

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

A. Tillage and Residue Management Practices

1. Rice-Wheat Cropping System

IARI

A long-term 14-year experiment on CA revealed that a Triple-cropping system involving ZT DSR with summer mung bean (SMB) residue (MBR), ZT wheat (ZTW) with rice residue (RR) – ZT, and summer mung bean (ZTSMB) with wheat residue (WR) was superior to the conventional puddled transplanted rice (TPR) - conventional till wheat (CTW) system in terms of wheat yield, system productivity (SP), and net returns. CA-based DSR had a lower yield than TPR. But the TZT+R had 21% higher wheat yield and 29% higher system yield, although it had 19% lower rice yield than TPR-CTW (Fig 1). This CA system led to building up 44% and 37% higher SOC at 0-5 and 5-15 cm soil layers and higher C-sequestration than CT. This triple cropping ZT system with residue is a superior alternative to the TPR-CTW system and an adaptation-mitigation co-benefit strategy to cope with climate change effects (Plate 1).

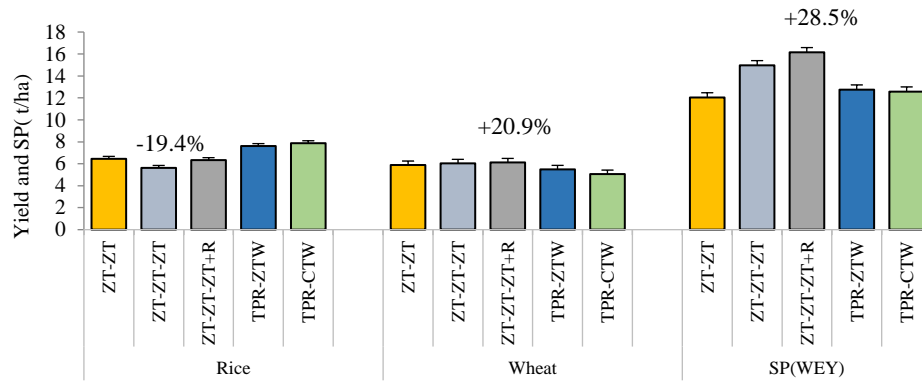


Fig 1. Rice yield, wheat yield and system productivity under conservation agriculture (CA)-based rice-wheat system



Plate 1. Conservation agriculture (zero till direct seeded rice; zero till wheat with rice residue)

CSSRI

Rice crop during *Kharif* 2024

a) Puddled transplanted rice (PTR)

The highest grain yield was recorded in puddled transplanted rice (PTR: 6.86 t ha⁻¹), followed by puddled transplanted rice with 1/3 wheat residue incorporation (PTR+RI: 6.83 t ha⁻¹).



Plate 2. Sowing of direct seeded rice with reduced tillage

b) Reduced tillage direct seeded rice with wheat residue incorporation

Direct-seeded rice under reduced tillage (RTDSR) produced a grain yield of 5.69 t ha⁻¹, while RTDSR with residue incorporation (RTDSR+RI) yielded 5.44 t ha⁻¹, which were 16.96% and 20.69% lower, respectively, compared to puddled transplanted rice (PTR: 6.86 t ha⁻¹) (Fig 2).

c) Zero tillage direct seeded rice with wheat residue retention

Grain yield under zero-tilled DSR with anchored wheat residue (ZTDSR+RR) was 5.20 t ha⁻¹ which was 24.21 % lower than the PTR (6.86 t ha⁻¹) and 1.76% lower than the zero-tillage direct seeded rice without wheat residue retention (ZTDSR; 5.11 t ha⁻¹) (Fig 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.

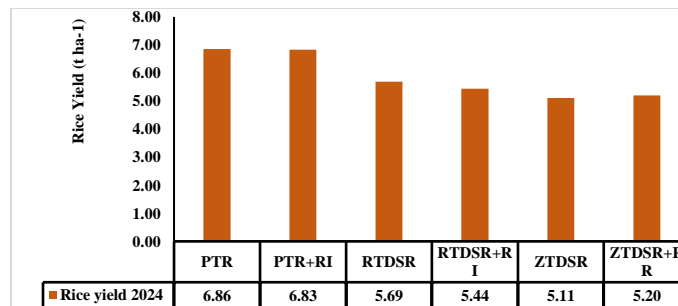


Fig 2. Effects of different tillage and residue management practices on rice grain yield during *kharif* 2024

(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)

Wheat crop during *rabi* 2023-24

a) Conventional tilled wheat (CTW)

Conventional tilled wheat with residue incorporation (CTW+RI) produced a grain yield of 4.59 t ha⁻¹ recording a 5.60 % yield gain over conventional tilled wheat without residue incorporation (CTW; 4.35 t ha⁻¹) (Fig 2).

b) Reduced tilled wheat with rice residue

Reduced tilled wheat (RTW) recorded a grain yield of 4.58 t ha⁻¹, which increased by 3.55% with residue incorporation (RTW+RI; 4.74 t ha⁻¹). RTW and RTW+RI showed an increased yield gain of 5.17 and 8.91 % in comparison to (CTW; 4.35 t ha⁻¹) (Figure 2).



c) Zero tilled wheat with anchored rice residue

Zero tilled wheat with anchored rice residue (ZTW+RR) produced wheat yield of 5.27 t ha⁻¹ which was 22.41% higher in comparison to CTW (4.35 t ha⁻¹) and 1.06% lower in comparison to zero tilled wheat without rice residue retention (ZTW; 5.33 t ha⁻¹) (Fig 3). 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 it 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 loss in wheat yield.

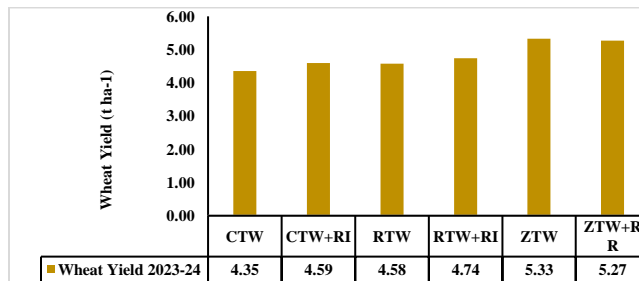


Fig 3. Effects of tillage and residue management practices on wheat grain yield during *rabi* 2023-24.

(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)

Rice-Wheat Cropping System during 2023-24

a) PTR/CTW

Higher grain yield (11.43 t ha⁻¹) was recorded under conventional puddled transplanted rice/conventional tilled wheat with residue incorporation (PTR+RI/CTW+RI) and 11.21 t ha⁻¹ in PTR/CTW without residue incorporation. So, residue incorporation in conventional PTR rice enhanced the grain yield by 1.95% (Figure 3).

b) RTDSR+RI/RTW+RI

Reduced tillage direct seeded rice and reduced tilled wheat with residue incorporation (RTDSR+RI/RTW+RI) produced grain yield of 10.18 t ha⁻¹, which was 0.91 and 9.20% lower in comparison to PTR/CTW (11.21 t ha⁻¹) and reduced tillage direct seeded rice / reduced tilled wheat without residue incorporation (RTDSR/RTW) (10.27 t ha⁻¹), respectively (Fig 4).

c) ZTDSR+RR/ZTW+RR

Zero tillage direct seeded rice/zero tilled wheat with residue retention (ZTDSR+RR/ZTW+RR) produced grain yield of 10.47 t ha⁻¹ with a yield gain of 0.32% over Zero tillage direct seeded rice/zero tilled wheat without residue retention (ZTDSR/ZTW; 10.43 t ha⁻¹) and a reduction of 6.61% from PTR/CTW (11.21 t ha⁻¹) (Fig 4).

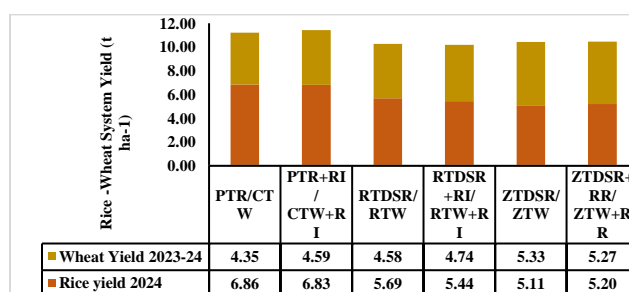


Fig 4. Effects of tillage and residue management practices on rice-wheat cropping system grain yield during 2023-24.

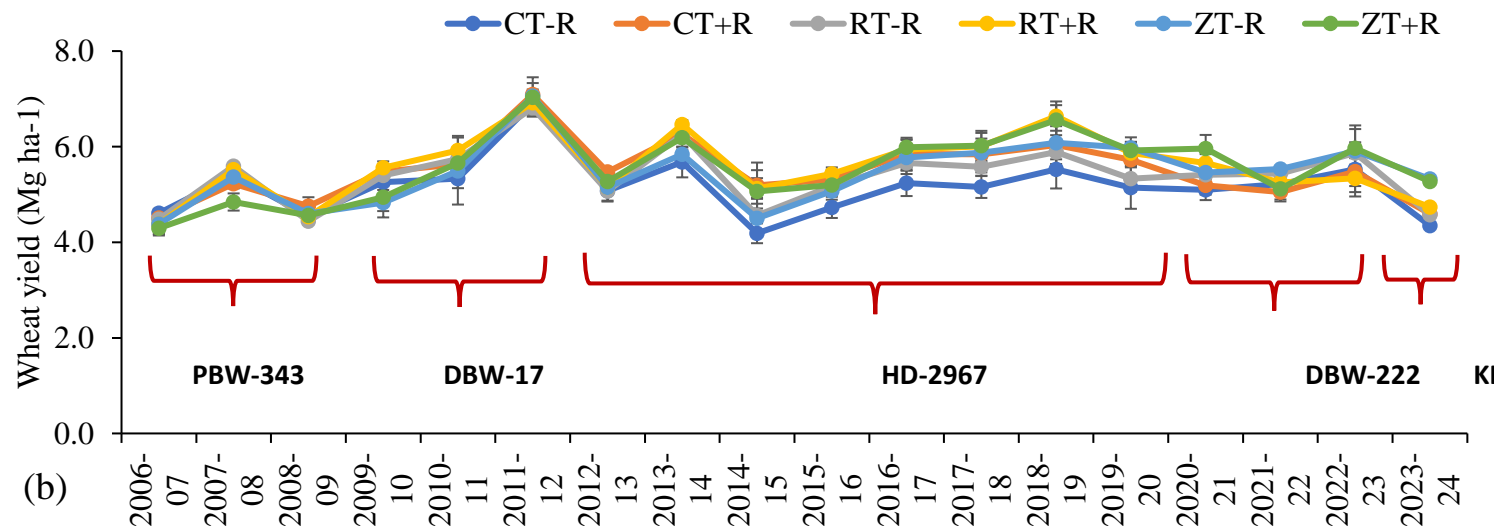
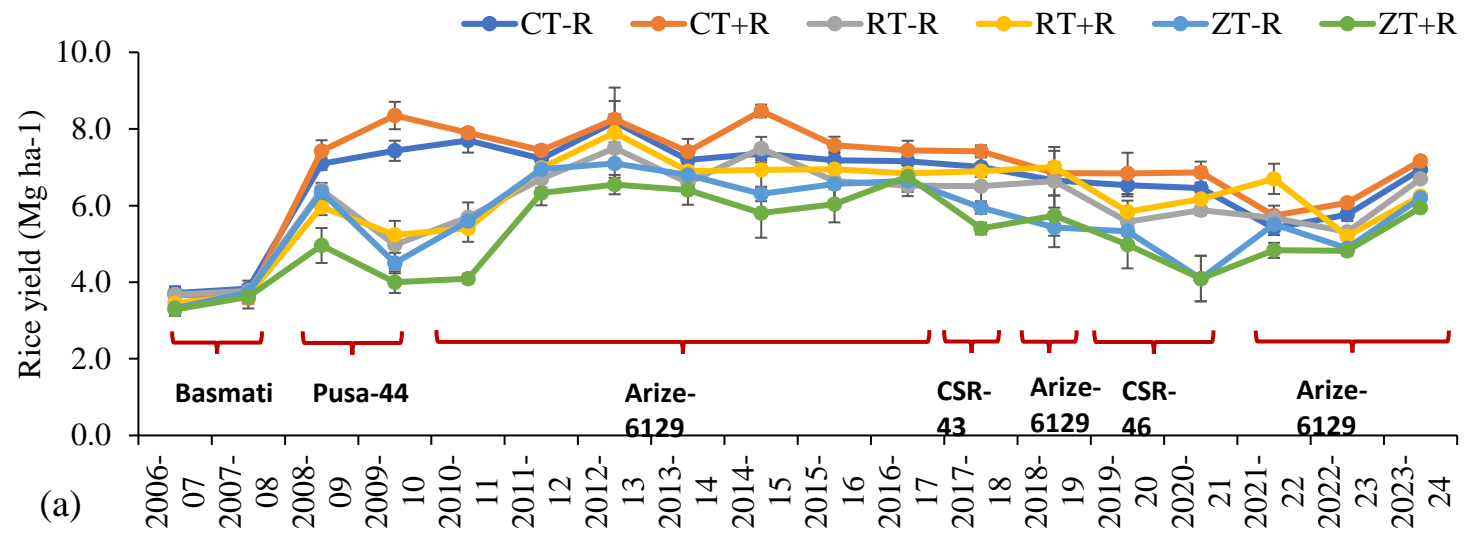
(Note: PTR- Puddled transplanted rice; RTDSR- Reduced tillage direct seeded rice ; ZTDSR- Zero tillage direct seeded rice; CTW- Conventional tilled wheat; RTW- Reduced tilled wheat; ZTW- Zero tilled wheat; RI- Residue incorporation; RR- Residue retention)

Long term trend analysis

The yield trends of rice and wheat over an 18-year period are presented in Fig 5. Different rice varieties, namely, salt-tolerant Basmati CSR-30 (2006 and 2007), Pusa-44 (2008 and 2009), hybrid rice Arize-6129 (2010–2016, 2018 and 2021–2023), salt-tolerant CSR-43 (2017), and salt-tolerant CSR-46 (2019 and 2020), were grown during the study period. Wheat varieties, namely PBW-343 (2006–07, 2007–08, and 2008–09), DBW-17 (2009–10, 2010–11, and 2011–12), HD-2967 (2012–13 to 2019–20) and DBW-222 (2020–21 to 2022–23) and KRL-210 (2023–24) were grown. Irrespective of the treatments, rice yield increased compared to the initial year (2006) up to 2008, with a notable spike from 2007 to 2008. In 2009, rice grain yield increased under conventional tillage but decreased under reduced and zero tillage conditions. In 2010 and 2011, rice grain yield decreased under conventional tillage while increasing under reduced and zero tillage. Rice grain yield showed fluctuations in subsequent years: it increased in 2012, decreased in 2013, increased again in 2014, and then decreased in 2015 across all treatments. However, the RT-R treatment displayed almost consistent rice grain yields from 2013 to 2018. A sharp decline in 2020 under ZT-R and ZT + R was recorded, which increased thereafter in 2021. Wheat grain yield increased until the 2011–12 season, with a decline recorded in 2008–09 and the highest peak observed in 2011–12. After this peak, grain yield declined again in 2012–13. From the 2015–16 to 2020–21 seasons, there were not many fluctuations in wheat grain yield. In comparison to 2020–2021, a slight

decrease in wheat grain yield was recorded in 2021–22. Wheat yield 2023–24 also noted a sharp decline due to varietal change. Variation in rice and wheat grain yield between the years was mainly because of the confounding effect of the yield potential of the different crop varieties grown, prevailing weather conditions, management practices undertaken under different treatments, and variations in the soil health in a particular year.

Fig 5. Trends in grain yield of (a) rice and (b) wheat during 18-years of the experimentation under tillage and residue management in rice-wheat system.



Rice-Wheat System Grain Yield and Sustainable Yield Index

Significant ($p < 0.0001$) changes in rice and wheat yields were observed due to crop establishment and CsT+RM practices (Table 1). The 14-year pooled rice yield was highest (6.73 Mg ha^{-1}) in Sc-1, where the crop was established as PTR, followed by Sc-3 (6.14 Mg ha^{-1}) in which RTDSR with residue incorporation was adopted. The lowest yield (5.28 Mg ha^{-1}) was attained in Sc-5, where rice was grown as ZTDSR with anchored rice residue. In wheat, yield improvement to the tune of 9.2 % in Sc-3 (RTW; 5.68 Mg ha^{-1}) and 6.5 % in Sc-5 (ZTW; 5.54 Mg ha^{-1}) was recorded with residue addition as compared to CTW (5.20 Mg ha^{-1}) (Table 1). Conventionally grown rice and wheat crops in annual rotation (Sc-1) had the highest RWS yield (11.93 Mg ha^{-1}) closely followed by Sc-3 (11.82 Mg ha^{-1}).

Table 1: Effect of tillage, crop establishment and residue management practices on grain yield, sustainable yield index and yield trend in rice-wheat system (2006–2020).

Scenarios/ treatments	Grain yield (Mg ha ⁻¹)						Sustainable yield index (SYI)			Cumulative yield gain		
	First year (2006-07)			14-years pooled mean			Rice	Wheat	RWS	Rice	Wheat	RWS
	Rice	Wheat*	RWS	Rice	Wheat	RWS						
Sc-1	3.72 ^a	4.61	8.32 ^a	6.73 ^a	5.20 ^c	11.93 ^a	0.65 ^a	0.64 ^e	0.73 ^a	+0.136	+0.007	+0.143
Sc-2	3.67 ^a	4.48	8.16 ^{ab}	6.05 ^b	5.43 ^b	11.48 ^b	0.58 ^b	0.67 ^b	0.70 ^b	+0.163	+0.040	+0.203
Sc-3	3.45 ^{ab}	4.38	7.83 ^{bc}	6.14 ^b	5.68 ^a	11.82 ^a	0.58 ^c	0.69 ^a	0.70 ^b	+0.207	+0.090	+0.297
Sc-4	3.32 ^b	4.38	7.70 ^c	5.76 ^c	5.43 ^b	11.18 ^b	0.55 ^d	0.65 ^d	0.67 ^c	+0.129	+0.083	+0.212
Sc-5	3.29 ^b	4.30	7.58 ^c	5.28 ^d	5.54 ^b	10.82 ^c	0.50 ^e	0.66 ^c	0.63 ^d	+0.169	+0.117	+0.285
p-Value	0.0122	0.2854	0.0130	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001			

Note: Means with the same letter in a column are not significantly different at 5 % level of significance using DMRT. *Treatments effect was found to be non-significant Where, Sc-1: Puddle transplanted rice - conventional tilled wheat (PTR/CTW) (farmers' practice); Sc-2: Reduce tilled direct seeded rice - reduce tilled wheat (RTDSR/RTW); Sc-3: Reduce tilled direct seeded rice - reduce tilled wheat + 1/3rd residue incorporation in both crops (RTDSR+RI/RTW+RI); Sc-4: Zero tilled direct seeded rice - zero tilled wheat (ZTW) (ZTDSR/ZTW); and Sc-5: Zero tilled direct seeded rice - zero tilled wheat + 1/3rd crop residue anchored in both crops (ZTDSR+RR/ZTW+RR)

IIFSR

A field experiment has been continuing since 2015 to assess the impacts of location specific conservation agriculture (CA) based management practices and crop diversification on crop intensification, soil sustainability, energy budgeting and energy-economic relationship. The experiment comprises three different scenarios i.e. business as usual (rice-wheat (PTR-CTW); sugarcane-ratoon-wheat (CT-CT-CT); improved production, income and soil nutrition through intensification (rice-wheat- green gram (CT-CT-CT); maize-mustard- green gram (CT-CT-CT); sustainable intensification to address the issues of labour, water, energy and soil health degradation (rice-wheat (DSR-ZTW); sugarcane+ green gram-ratoon+ green gram -wheat (RT-ZT-ZTW); rice-wheat-green gram (DSR-ZTW-ZT); maize-mustard- green gram (ZT-ZT-ZT).

Table 2: crop yield of different crops as influenced by tillage, crop residue and diversification

Cropping systems	Yield data of different crops (t ha ⁻¹)	
	Kharif	Rabi
R-W (CP)	5.51	5.66
R-W (CA)	4.67	6.43
R-W-GG (CP)	6.49	5.94
R-W-GG (CA)	5.38	6.90
M-M-GG (CP)	8.79	2.76
M-M-GG (CA)	9.86	3.09
S-R-W (CP)	136.8	5.91
S+GG-R-W (CA)	121.4	6.53
SE (m)±	2.209	0.247
C.D. (P=0.05)	6.766	0.756
C.V.	10.90	8.869

The data related crop yield is presented in table 2. It showed that the direct seeded rice recorded 15.2 and 17.1% less yield in R-W (CA) and R-W-GG (CA) over the conventional practices.



Plate 5. Experimental field view

Zero tilled wheat crop

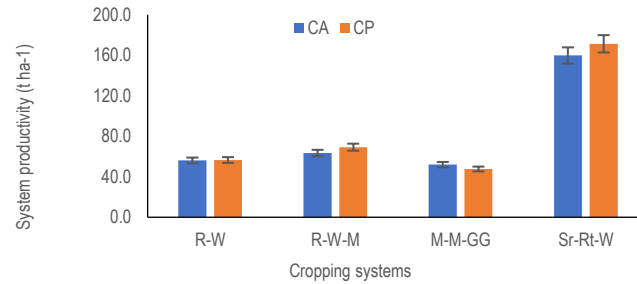
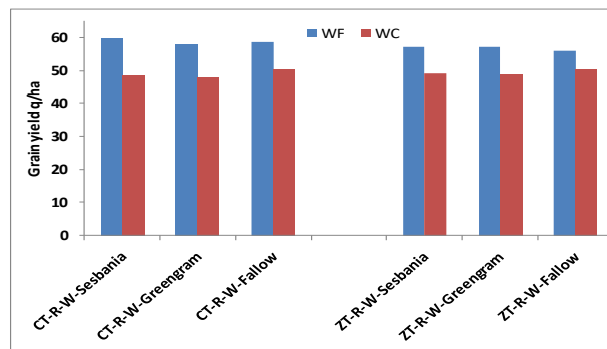


Fig 6. Experimental field view under CA based management practices

Conservation agriculture (CA) based management practices are considered as one of the important components of climate smart farming (CSF) and precision farming. NDVI values using green seeker and crop nitrogen status using SPAD were recorded at the 15 days' interval among all the cropping systems.

IIWBR

In rice-wheat system, wheat grain yield was similar under ZT (53.18 q/ha) compared to CT system (54.05 q/ha). The effect of manuring on wheat was not distinctly visible and long-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 puddled transplanting was 47.41 q/ha and in CA was 41.11 q/ha. It means that rice is less suitable under CA system than CT system.



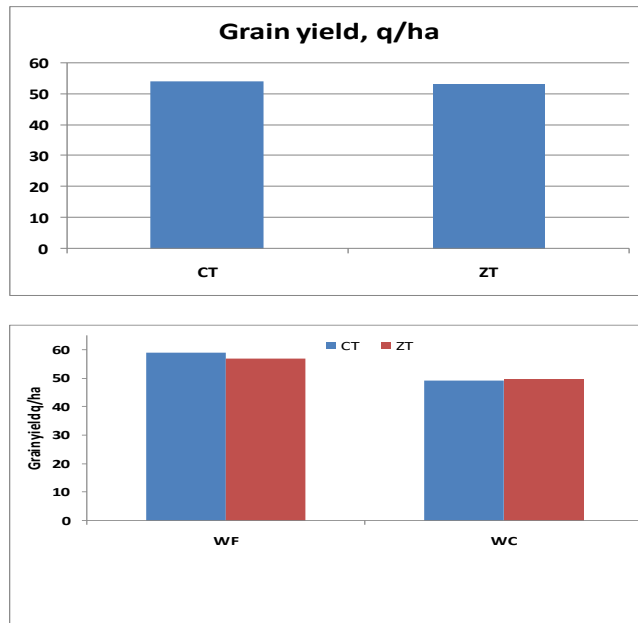


Fig 7. Effect of tillage and manuring on wheat yield in rice-wheat system

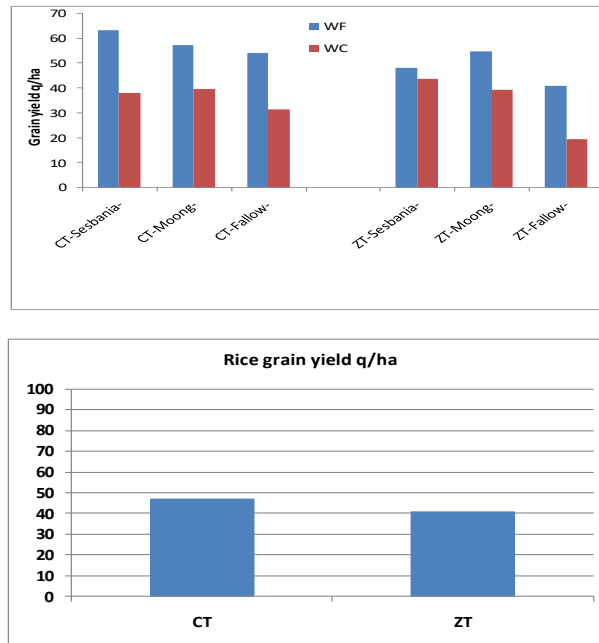


Fig 8. Effect of tillage and manuring on rice yield in rice-wheat system



Plate 6. Rice transplanting under ZT and puddle conditions

2. Rice- Fallow cropping system

RCER

During *kharif* season, a large area remains fallow in Gaya (>25000 ha) due to inadequate rainfall and its poor distribution. To address these issues, 18 farmers were selected for demonstration of pigeon pea (arhar) IPA-203 during *Kharif* 2023. Selected farmers were provided need-based training and awareness of pigeonpea cultivation. This intervention was adopted by farming community in their upland fields & raised field bunds. Performance of arhar under rainfed condition was good and farmers were encouraged to cultivate this high-value crops. Similarly, short-duration pulse/oilseed crops were demonstrated during *rabi* season to farming community (350 no.) for greening rice-fallow area covering >255 acres through integrated crop management (ICM &) CA-based management practices (Table 3). In ICM, need-based standard agronomic management practices like seed priming (soaking seed in water overnight) before sowing, seed treatment with suitable *rhizobium*, nutrient management through foliar application of 2% urea, management of pests/diseases through suitable agro-chemicals practised. The details of critical inputs provided to the participating farmers for demonstration in rice-fallow areas are as indicated below:

Table 3: Crop input demonstrations and greening rice-fallow area at Gaya project site during 2023-25

S.N.	Crop	Variety	Quantity (kg)	Farmers (no.)	Area (acre)
2023-24 & 2024-25: Rabi season					
1.	Arhar (CT)	IPA 203	300	50	40
2.	Lentil (ZT)	IPL 220	800	75	50
3.	Chickpea (ZT)	GNG 2299	1600	60	50
4.	Mustard (ZT)	DRMR-150-35	100	50	50
5.	Mustard (FLD*)	DRMR-150-35	30	15	15
Kharif-2024					
1.	Rice	Swarna Shreya	50	75	50
Total			2880	350	255



Plate 7. Winter crops under residual soil moistures at project site Guleriyachak, Gaya, Bihar

Demonstrations results revealed that seed/grain yields of rice (Swarna Shreya: 3.5-4.0 t/ha), arhar (IPA 203), lentil (IPA 220), chickpea (GNG 2299), mustard (DRMR 150-35) was 1.75 t/ha, 1.15 t/ha, 1.50 t/ha and 1.1-1.14 t/ha, respectively on residual soil moistures & improved agronomic management practices at farmers field of Guleriyachak, Simuara, Tekari block, Gaya district of Bihar (Table 4 and Plate 7).

Table 4: Winter crop yields under demonstrated plots of rice fallows project site Gaya, Bihar

Crops	Varieties	Sowing	Harvesting	Duration	Crop yield (t/ha)	REY (t/ha)
Kharif						
Rice	Swarna Shreya	25-30 June	25-30 Oct.	120-125	3.5-4.00	3.75
Arhar	IPA 203	22-29 July	15-26 April	270-275	1.75	5.61
Rabi						
Lentil	IPL 220	8-17 Nov.	7-17 March	115-120	1.15	3.38
Chickpea	GNG 2299	14-24 Nov.	15-26 March	120-125	1.50	3.74
Mustard	DRMR 150-35	6-18 Nov.	28 Jan-16 Feb	115-120	1.10	2.85
Mustard*	DRMR 150-35	4-10 Nov.	27 Feb-23 Mar.	115-120	1.14	2.95

Evaluation of crop establishment methods for improving productivity of rice-fallows system in eastern India: Long-term field study was initiated during rainy season of 2016 at ICAR Research Complex for Eastern Region, Patna, Bihar, India to find out the most suitable

rice-winter cropping rotations; and appropriate crop establishment methods & residue management practices in rice-fallow systems of eastern India (Plate 11). Treatment comprised of six levels of crop establishment methods-cum-residue management (CERM) practices: zero-till-direct seeded rice (ZTDSR), conventional-till-DSR (CTDSR), transplanted puddled rice (TPR), ZTDSR with rice residue retention (ZTDSRR+), CTDSR with rice residue retention (CTDSRR+), TPR with rice residue retention (TPRR+) and 6 post-rainy crops viz. chickpea (Pusa 3043), lentil (HUL 57), safflower (PBNS 12), mustard (Pro-agro 5111), linseed (T 397) and toria (TS 36) fitted in a split-plot design. After 9th year of experimentation, rice yields were higher in general under TPR production system. Rice productivity was 57.9 & 37.6% were higher with TPR (5.27 t/ha) compared to ZTDSR (3.34 t/ha) and CTDSR (3.83 t/ha). Irrespective of tillage & cropping systems, effect of residue management on crop yield was more pronounced in all treatments (Table 5). During 9th year of winter cropping, infestation of dry-root rot in chickpea was more severe in ZTDSR followed by CTDSR under residue retained plots. But more interestingly that yield of all the post-rainy crops had higher in ZTDSR/CTDSR production system compared to TPR. TPR production system adversely impacted performance of all post-rainy pulses/oilseed crops over time.

Table 5: Rice yield as influenced by different crop-establishment-cum-residues management (CERM) practices and succeeding winter crops under long-term CA-based rice-fallows system of eastern India (Mean data of Kharif 2024: After 9th years of

CERM		Rice yield (t/ha)						Mean
		Chickpea	Lentil	Safflower	Linseed	Mustard	Toria	
[ZTDSR-ZT] R-	CA	3.35	3.21	3.15	3.29	3.33	2.96	3.22
[ZTDSR-ZT] R+		3.42	3.48	3.37	3.58	3.59	3.34	3.46
[CTDSR-ZT] R-	pCA	3.80	3.52	3.51	3.71	3.82	3.80	3.69
[CTDSR-ZT] R+		4.12	3.83	3.70	3.90	4.15	4.11	3.97
[TPR-ZT] R-	FP	5.28	5.39	4.99	5.13	4.99	5.09	5.14
[TPR-ZT] R+		5.49	5.56	5.28	5.24	5.36	5.48	5.40

experimentation)

CA: conservation agriculture, pCA: partial conservation agriculture; FP: farmers practices



Plate 8. Performance of rice under different CERM and proceeding winter crops at ICAR RCER Patna

Jharkhand: Experimental Site 1: Chene, Namkum, Ranchi

Evaluation of CA practices in rice-fallows: CA-based practices was evaluated during 2024-25 at the farmer's field at 2-locations viz. Chene, Ranchi, Jharkhand & Kandora, Jashpur, Chhattisgarh. CA-based management practices comprised of zero-till transplanted rice (ZTTR), zero-till-direct seeded rice (ZT- DSR), conventional till-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 on residual soil moisture and fertility status.

Evaluation of CA-based management practices on productivity of rice: CA practices was evaluated during 2024-25 in farmer's field at Chene, Ranchi, Jharkhand. CA-practices comprised of ZTTR, ZTDSR, CTDSR, FPTR & rice fallow were evaluated on winter crops i.e., mustard (Pusa-26) and linseed (BAU 06-03) after harvesting of rice. Rice grain yield was significantly higher (4.65 t/ha) under ZTDSR system compared to other CA & farmer's management practices (Table 6). Farmer's practice registered grain yield of 4.25 t/ha.

Table 6: Yields of kharif & rabi season crops at Jharkhand and Chhattisgarh experimental 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	4.39 ^{bc}	-	-	4.55 ^b	-	-	-
ZTDSR	4.65 ^a	6.35 ^a	3.56 ^a	5.28 ^a	2.51 ^a	6.67 ^a	3.57 ^a
CTDSR	4.40 ^{bc}	5.51 ^{bc}	3.30 ^{ab}	4.51 ^b	2.17 ^{bc}	6.04 ^b	3.10 ^{bc}
ZTTR	4.59 ^{ab}	5.84 ^b	3.42 ^{ab}	5.16 ^a	2.38 ^{ab}	6.51 ^a	3.39 ^{ab}
FPTR	4.25 ^c	5.29 ^c	3.02 ^b	4.71 ^b	2.02 ^c	5.41 ^c	2.89 ^c

Values in column having different superscripts significantly different from each other (DMRT, P<0.05).

Evaluation of CA practices on productivity of winter crops

Winter crops of mustard & linseed were grown in rice-fallow under different CA practices. Significantly highest mustard seed yield was recorded (6.35 q/ha) under ZTDSR followed by ZTTR (5.84 q/ha). CA-practices of ZTDSR were recorded highest grain yield over ZTTR & FPTR (Table 6). Grain yield of linseed varied from 3.02 to 3.56 q/ha among different CA-based management practices. The CA-based practices (ZTDSR) registered the highest grain yield (3.56 q/ha) followed by ZTTR. Rice equivalent yield (REY) was obtained under winter crops ranged between 0.98 to 1.90 t/ha. Among the different treatments, REY was found higher under CA and noted higher in ZTDSR treatment (Fig 9).

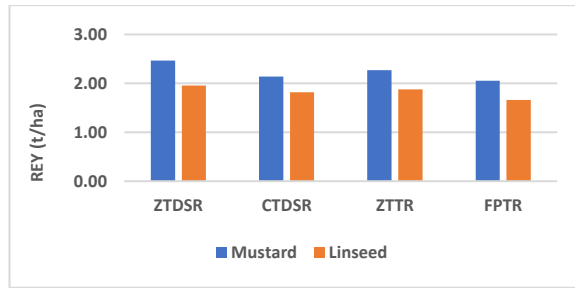


Fig 9. Rice equivalent yields of different crops and cropping systems at Jharkhand

System REY of cropping sequences were also evaluated under different CA-based management practices. It was observed that REY of rice-mustard cropping sequences (7.12 t/ha) under ZTDSR was significantly better over other cropping system of rice-linseed and rice-fallow system alone. Higher REY of these sequences were observed under CA practices (ZTDSR & ZTTR) as depicted in Fig 10.

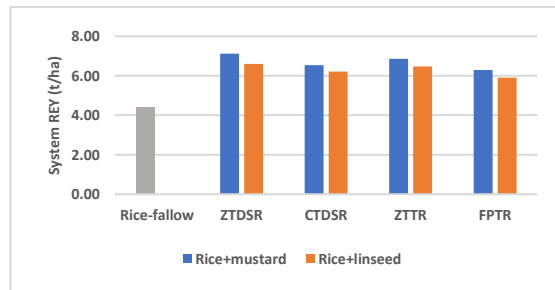


Fig 10. Rice equivalent yields of different crops and cropping systems at Jharkhand

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

Evaluation of CA practices on productivity of rice: The maximum rice grain yield (5.28 t/ha) was recorded under ZTDSR and followed by ZTTR (5.16 t/ha) production system. CTDSR production system was recorded the lowest grain yield (4.51 t/ha) during the study.

Evaluation of CA practices on productivity of winter crops: Different winter crops like lentil, mustard and linseed were grown in different CA-based management practices. Seed yield of lentil was recorded significantly highest (2.51 q/ha) in ZTDSR compared to other CA & farmer’s practices. Similarly, highest linseed yield (3.57 q/ha) was recorded in ZTDSR followed by ZTTR and it was found better than other management practices., In case of mustard, significantly maximum grain yield (6.67 q/ha) was recorded under ZTDSR followed by ZTTR (6.51 q/ha). REY of mustard was recorded in ZTDSR (2.59 t/ha). Higher REY of these sequences were noted in plots having CA (ZTDSR & ZTTR) as depicted in Fig 11.

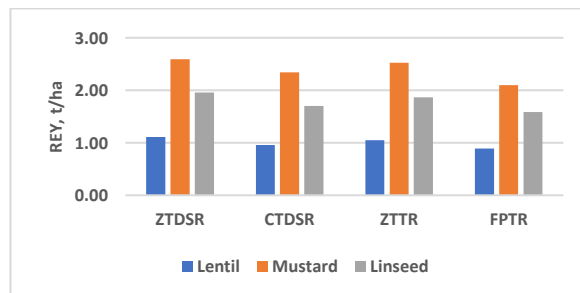


Fig 11. Rice equivalent yields of different crops and cropping systems at Chhattisgarh

System REY of rice-mustard system was recorded in ZTDSR (7.87 t/ha), which was higher over rice-lentil and rice-linseed cropping sequences. Higher REY of all sequences was noted in the plots having CA-based management practices as depicted in Fig 12.

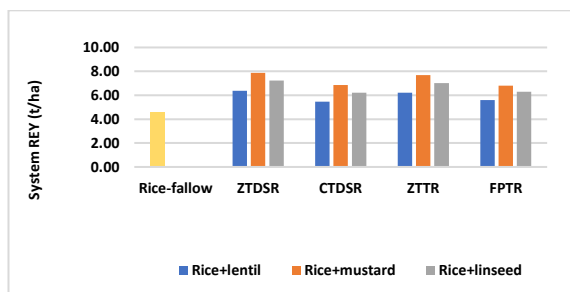


Fig 12. Rice equivalent yields of different crops and cropping systems at Chhattisgarh

Maize-Wheat cropping system (MWS)

IARI

After a long-term CA experiment for 13 years, the strategic tillage (ST) based system was adopted/ introduced in the 14th year. This showed that new ST-based system and CA-based system were comparable on maize, wheat and system yield but significantly higher than CT. ST gave 14.7% while long-term CA gave 13.7% higher system yield than CT. The CA based permanent flat bed with residue resulted in higher maize grain yield (6.12 t/ha), while higher wheat grain yield (5.64 t/ha) was obtained in STFBR and PNBR systems. (Fig 13 & 14).

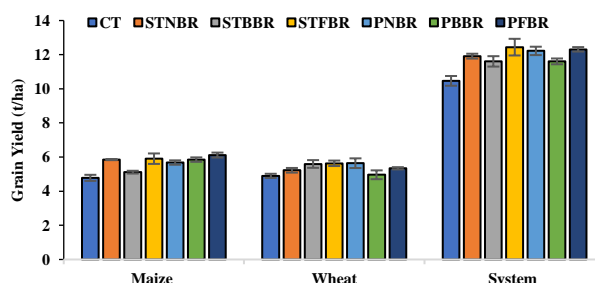


Fig 13. Effect of CA on maize yield, wheat yield, and system productivity under maize-wheat cropping system

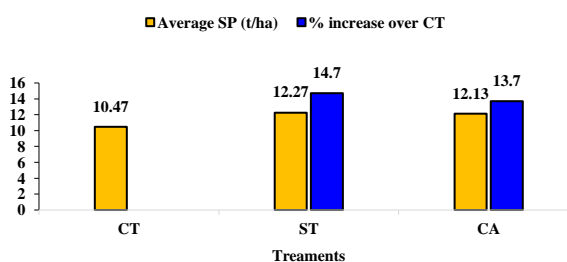


Fig 14. Effect of CA and ST on average system productivity (SP) under maize–wheat (MzW) system

IWBR

In maize-wheat system two tillage (CT and ZT+R), two manuring treatments (no, sesbania) and two weed control options (weedy check and weed free) were evaluated. The experiments were started in 2020 with maize crop. The green manure crop *Sesbania* was sown during the first week of May. 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 15). Whereas, in presence of weeds the yield advantage was observed under CA system.

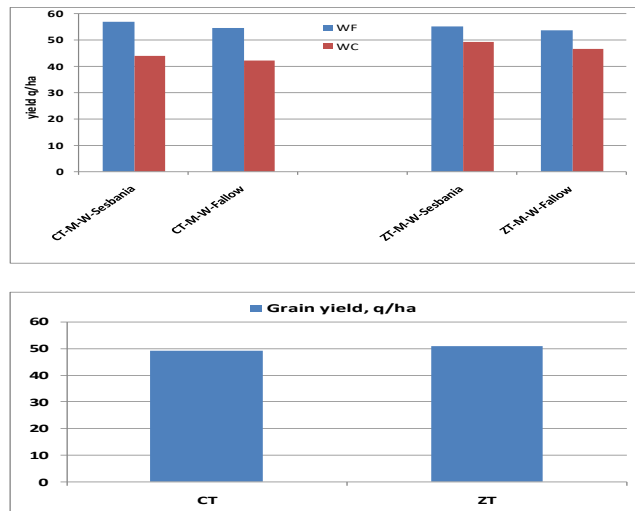
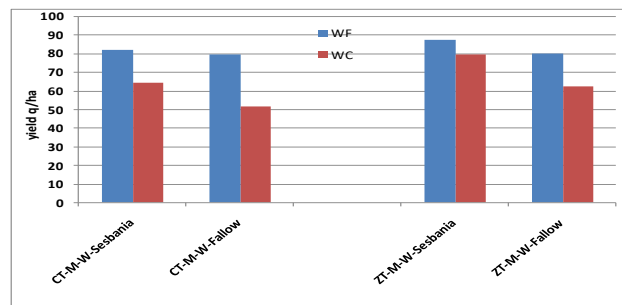


Fig 15. Effect of tillage and manuring on wheat yield in maize-wheat system

The maize yield was higher in CA system both in the presence and absence of weeds (Fig 16). 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.



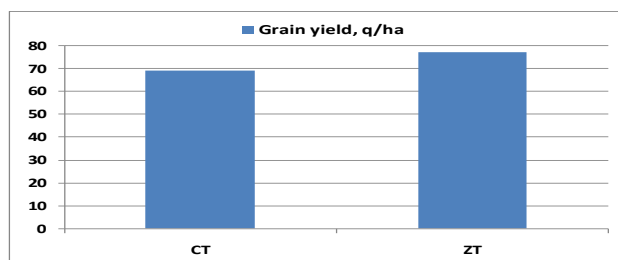


Fig 16. Effect of tillage and manuring on maize yield in maize-wheat system

4. Maize-Wheat-Green gram cropping system

IIWBR

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 9164 was sown using a seed rate of 25 kg/ha at a row spacing of 60 cm. For weed control tembotrione at 110 g a.i./ha + atrazine 1000 g/ha were applied at 20 DAS. Among tillage and residue management options, maximum yield was obtained in CA treatment (90.21 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 69.53 q/ha. Among nutrient management treatments, unfertilized plots recorded significantly lowest yield (64.06 q/ha).

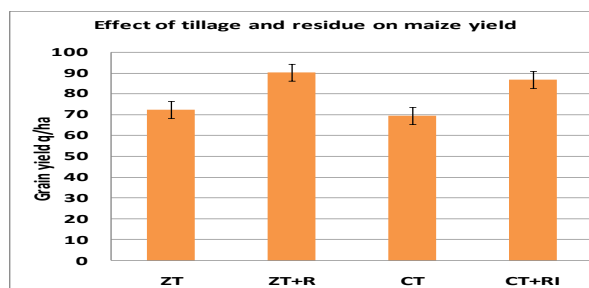


Fig 17. Effect of tillage and residue on maize yield

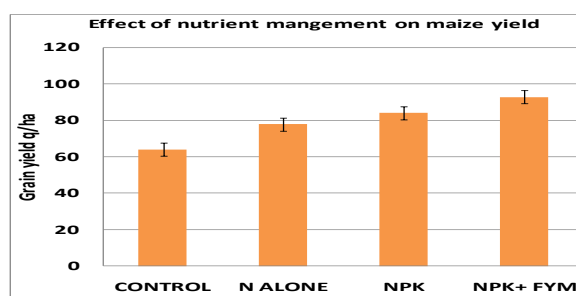


Fig 18. Effect of nutrient management on maize yield



Plate 9. Lesser adverse effect of heavy rainfall in CA maize

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 (2023-24) was sown on November 24, 2023 at row-to-row spacing of 20.0 cm using a seed rate of 125 kg/ha considering the 1000 grain weight as 38 g. The sowing was done using Smart Seeder. The full residue load of maize (180 q/ha) after removing the cobs was either removed, or retained or incorporated. The incorporation was done using rotary tiller. The irrigations were given as per the recommended practices. For control of weeds pinoxaden 50 g/ha fb metsulfuron 4 g/ha were applied at 35 fb 40 DAS. The recommended dose of N: P₂O₅:K₂O consisted of 150:60:40 kg/ha. Full P and K were applied as basal before pre seeding irrigation. Whereas N was applied in two equal splits (half dose each just before first and second irrigation).

The perusal of data in Table-7 revealed that the effect of tillage and residue management, nutrient management and their interactions were significant for grain yield. Among four nutrient management options minimum yield was recorded in unfertilized control plots having a mean yield of 15.51 q/ha. The poor yield in this treatment was due to lesser yield attributes mainly the effective tillers. The wheat grain yield was maximum (62.29 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, CA wheat had highest 1000 grains weight.

Table 7: Effect of tillage, residue and nutrient management in wheat under Maize-wheat system during 2023-24

Tillage and residue management	Plant height, cm	Earhead length, cm	Tillers/m ²	Yield q/ha	1000 grain weight, g	Protein (%)
ZT	83.0	8.2	404.4	39.00	39.11	10.3
ZT+R*	90.4	8.9	418.3	44.01	42.02	10.0
CT	84.6	7.7	402.9	42.26	39.31	9.7
CT+RI*	89.1	8.9	420.2	44.56	40.35	9.3
CD at 5%	2.94	0.62	NS	3.52	0.52	0.43
Nutrient management						
Control	61.3	5.9	363.8	15.51	37.67	8.4
N Alone	84.0	8.4	391.0	34.95	40.65	11.4
Rec. NPK	98.4	9.6	434.8	57.09	41.20	9.6
Rec. NPK+ FYM 10t/ha	103.5	9.9	456.3	62.29	41.26	9.8

CD at 5%	4.09	0.55	28.46	2.56	1.08	0.40
FactorB at same level of A	NS	1.16	NS	5.44	NS	NS
FactorA at same level of B	NS	1.14	NS	5.64	NS	NS

*R=Residue Retention and RI= Residue incorporation



Plate 10. Long term maize-wheat experiment's treatments

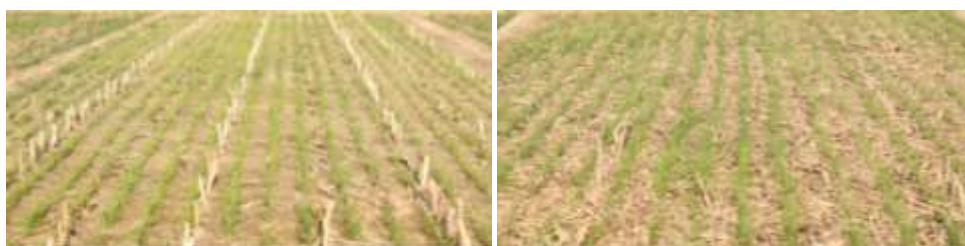


Plate 14. CA-Wheat (Wheat in full maize residue)

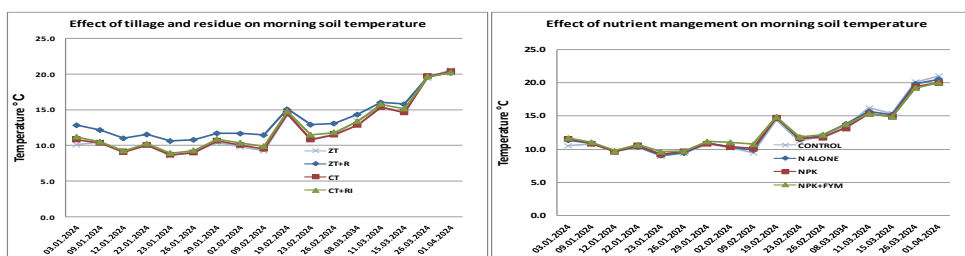


Fig 19. Effect of tillage, residue and nutrient management on morning soil temperature in long term maize-wheat-greengram

Observations were also taken on soil temperature in the morning and noon on different dates (Fig 19 and 20). 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.

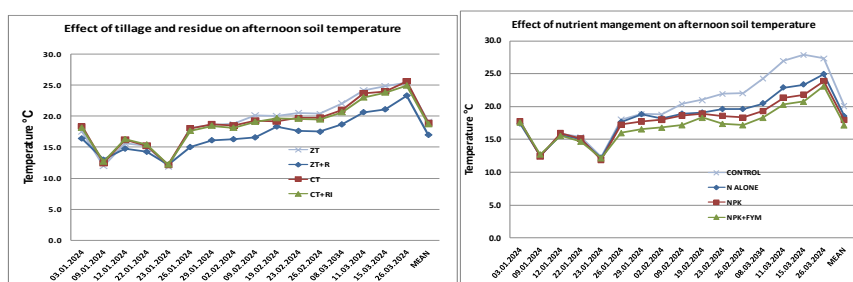


Fig 20. Effect of tillage, residue management and nutrient management on afternoon soil temperature during different crop seasons in long term maize-wheat-greengram experiment

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. 22).

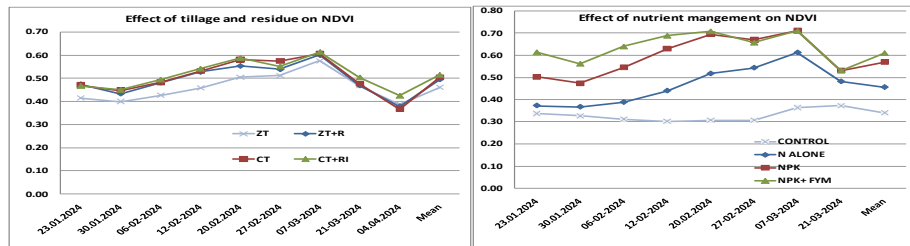


Fig 21. Effect of tillage, residue and nutrient management on NDVI in long term maize-wheat-greengram experiment

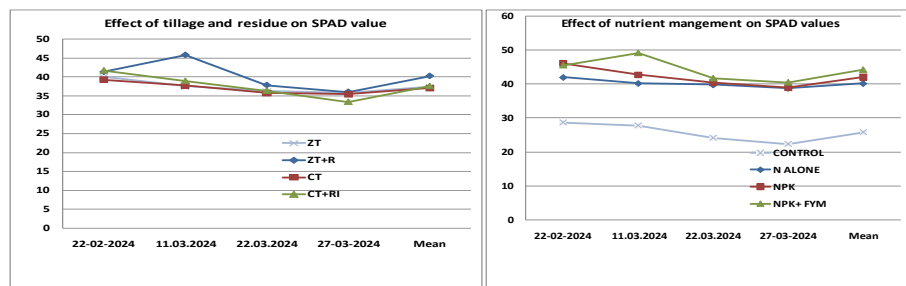


Fig 22. Effect of tillage, residue and nutrient management on SPAD values in long term maize-wheat-greengram experiment

5. Cotton-Wheat cropping system (CW)

IARI

A long-term CA experiment for 14 years revealed that in CA-based cotton-wheat system, all the CA-based ZT permanent broad, narrow, and flat beds with residue resulted in significantly higher yields of cotton, wheat, and system productivity than conventional tillage (CT) system (Fig 23). The PBBR100N resulted in 52% higher seed cotton yield, 18.6% higher wheat yield and 39.5% higher system yield than CT. PBBR100N fetched 71%, 27% and 54% higher net returns from cotton, wheat and system than CT (Fig 24 & 25). However, PBBR75N was comparable with PBBR100N on yield of these crops, indicating a saving of 25%N. In all the stages, the treatment PBBR100N resulted in higher earthworm population and biomass. There was 33.5% increase in the available N status in CT and 60-75% increase in residue retention treatments. Similarly, 44% and 36% increase was seen in P and K status respectively by CT and 72-91% increase in P and 86-96% increase in K respectively in residue retention treatments. The CA-based cotton - wheat systems could be the promising crop diversification option for rice-wheat system and an important adaptation and mitigation strategy to climate change.

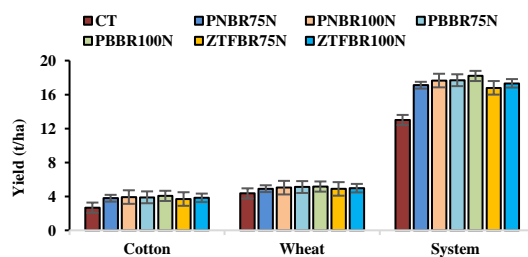


Fig 23. Cotton yield, wheat yield, and system productivity under CA-based cotton-wheat system

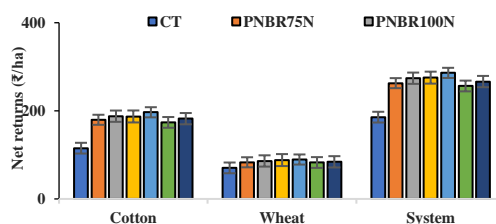


Fig 24. Effect of CA on Net returns cotton, wheat, and system productivity under cotton-wheat cropping system



Fig 25. Conservation agriculture-based cotton-wheat cropping system

6. Pigeon pea-Wheat System (PWS)

IARI

After 14-year of CA experiment, under component trial, organic farming module was introduced as a production scenario in pigeon pea-wheat system. It showed that the CA system led to 24.3-30.5% and 30.1-36.8% higher yield of pigeonpea than CT and OF-PBB respectively (Fig 26). Similarly, it had 14.1-19.4% and 21.3-26.3% higher wheat yield than CT and OF-PBB, respectively. Similarly, the pigeonpea-wheat system yield was 20.1-24.7% higher under CA than CT. Under the CA, the net returns accrued from pigeonpea was 40-46% higher, from wheat 26.5-35.4% higher, and from the PW system 32-40.7% higher than CT (Fig 27). The CA-PFB had 7.5, 28.7 and 29.8 times higher C accumulation rate, and 6.2, 8.7, and 12.9 times higher carbon sequestration rate than CT. The carbon mineralization was higher under OF treatments at both 35°C and 15°C, which led to higher temperature sensitivity of carbon. The GHGI was also higher under OF treatments (OF-CT; 0.45kg CO₂ eq./kg grain) that led to higher GHGs emission for producing 1kg grain. 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. CA based practices

gave 24-31%, 21-26% and 20-25% higher yield of pigeon pea, wheat and system, resp. Similarly, they showed 40-46%, 27-35% and 32-41% increase in net returns over CT.

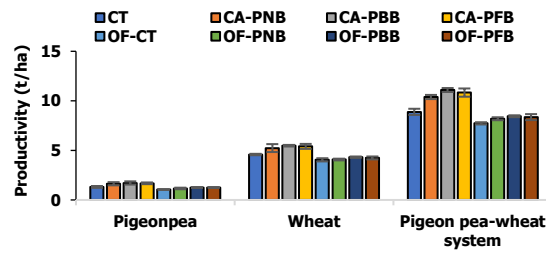


Fig 26. Effect of CA on productivity and profitability of pigeon pea-wheat system

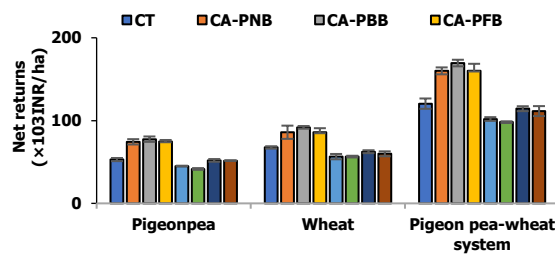


Fig 27. Effect of CA on Net returns pigeon pea, wheat, and system productivity under pigeon pea -wheat cropping system

Tillage and crop residue effects on productivity and profitability of CA-based pigeon pea-wheat cropping system

An experiment comprising of four tillage and crop residue treatments namely, zero-tillage with 25% crop residue (ZT+25R), zero-tillage with 50% crop residue (ZT+50R), zero-tillage with 75% crop residue (ZT+75R) and conventional tillage (CT) were evaluated in randomized completely block design with five replications. Results of the study revealed that zero-tillage pigeon pea with 50% or 75% wheat residue (ZTP+50WR or ZTP+75WR) followed by zero-tillage wheat with 50% or 75% pigeon pea residue (ZTW+50PR or ZTW+75PR) resulted in significantly higher yield of pigeon pea (Fig 28), wheat (Fig 29) and system (Fig 30) in terms of pigeonpea equivalent yield as compared to conventional tillage pigeonpea-conventional tillage wheat (CTP-CTW) system. Again, ZTP with 75% WR fb ZTW with 75% PR resulted in ~21% higher system productivity (3.51 t/ha) (pigeonpea equivalent yield) than CT treatment and remained at par with ZTP +50% WR fb ZTW+50% PR.

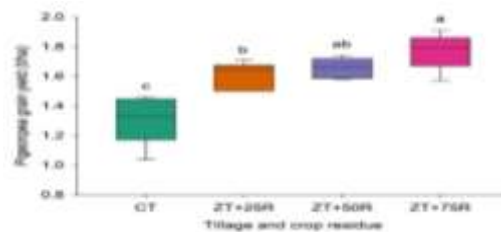


Fig 28. Effect of tillage and crop residue on pigeonpea grain yield under pigeonpea -wheat cropping system

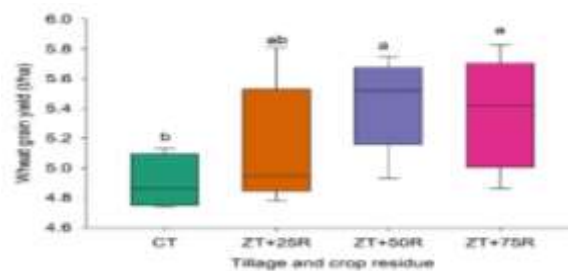


Fig 29. Effect of tillage and crop residue on wheat grain yield under pigeonpea-wheat cropping system

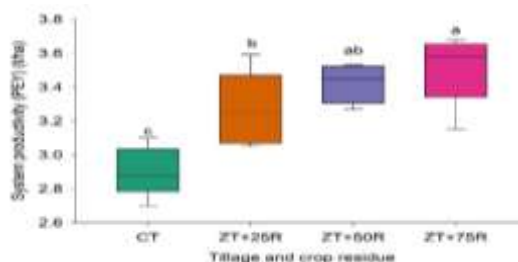


Fig 30. Effect of tillage and crop residue system productivity (pigeonpea equivalent yield) under pigeonpea-wheat cropping system

We also performed the combined analysis to compare the performance of pigeonpea-wheat and maize-mustard system for system productivity (in terms of maize equivalent yield) across the tillage and crop residue treatments. A result revealed that maize-mustard cropping system resulted in ~20% higher system productivity (MEY) over pigeonpea-wheat cropping 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 40).

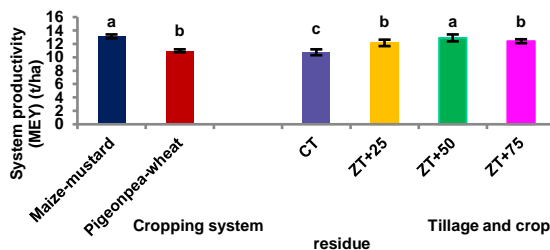


Fig 40. Combined effect of cropping systems and tillage and crop residues on system productivity

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

IARI

In maize-mustard system, inclusion of legume mungbean under a CA-based treatment, i.e., ZT maize with summer mungbean (SMB) residue (MBR)- ZT mustard (ZTW) with maize residue (RR)- ZT summer mungbean (ZTSMB) with mustard residue (WR) gave higher system productivity (SP) and net returns than CT system. In MzMs system, this TZT+R uniformly increased maize, mustard and system yield by 20, 27 and 65% resp over CT system (Fig 41). This led to a saving of almost 25% N (~57.5 kg N/ha) and 50% S in maize-mustard system.

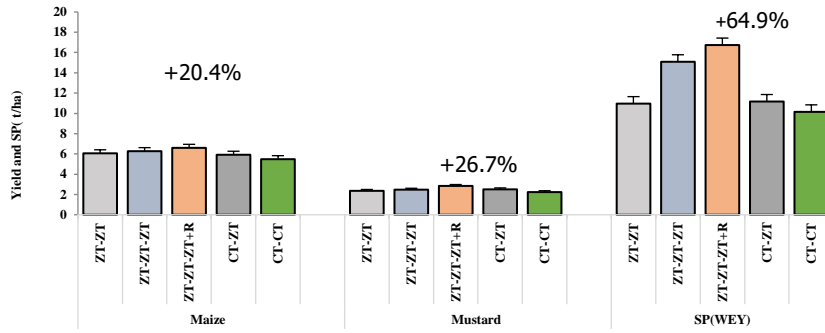


Fig 41. Maize yield, mustard yield, and system productivity under conservation agriculture-based maize-mustard system

Tillage and crop residue effects on productivity and profitability of CA-based maize-mustard cropping system

An experiment comprising of four tillage and crop residue treatments namely, zero-tillage with 25% crop residue (ZT+25R), zero-tillage with 50% crop residue (ZT+50R), zero-tillage with 75% crop residue (ZT+75R) and conventional tillage (CT) were evaluated in randomized completely block design with five replications. Results of the study revealed that Zero-tillage maize with 50% mustard residue resulted in significantly higher yield of maize than other treatment and it was remained similar with 75% residue treatment (Fig 42), Whereas, mustard yield was significantly higher under zero-tillage mustard with 50% or 25% residue of maize over other treatments (Fig 43). Again, ZT maize + 50% mustard residue-ZT mustard+50% maize residue resulted in 20% higher system productivity over CT maize-CT mustard (Fig 44).

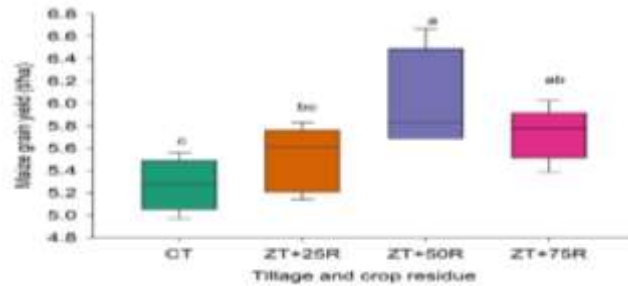


Fig 42. Effect of tillage and crop residue on maize grain yield under maize-mustard cropping system

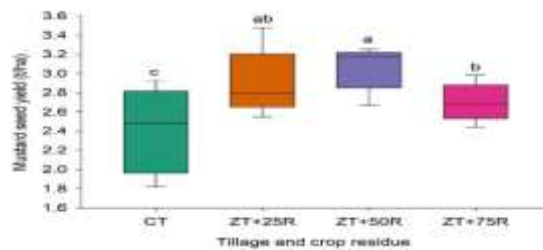


Fig 43. Effect of tillage and crop residue on mustard seed yield under maize-mustard cropping system

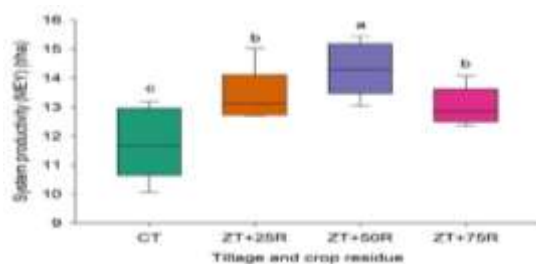


Fig 44. Effect of tillage and crop residue on system productivity (maize equivalent yield) under maize-mustard cropping system

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

RCER

The field experiment was conducted during *kharif* 2024-25 at ICAR RCER, FSRCHPR, Ranchi. Different cropping systems *viz.* rice-lentil, rice-mustard, and rice-linseed were evaluated under different rice establishment methods of ZTDSR, ZTTR and CTDSR. Crop yields were expressed in terms of rice equivalent yield (REY: t/ha). ZTTR rice-lentil system showed highest rice yield of 5.17 t/ha, while performance of winter crops of linseed in ZTDSR rice-linseed had highest REY of 4.76 t/ha. System REY was significantly the highest of 9.61 t/ha in ZTDSR rice-linseed system compared to other treatments (Fig. 45).

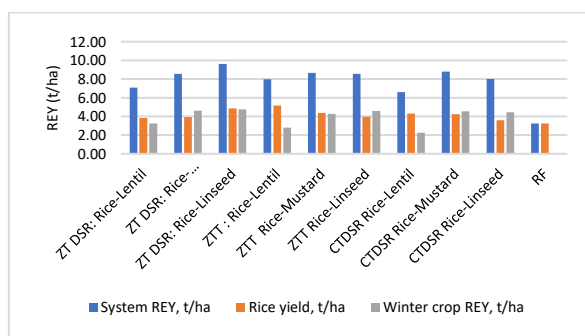


Fig 45. REY of cropping systems under CA practices at ICAR- RCER, FSRCHPR, Ranchi

Irrespective of cropping systems, system REY was highest in CA practice (ZTDSR and ZTTR). Rice grain yield was highest of 4.51 t/ha under CA-based management practice of ZTTR and least in rice-fallow (3.26 t/ha). Performance of winter crop was better in ZTDSR practice compared to ZTTR and CTDSR. Highest winter crop REY was 4.2 t/ha under ZTDSR-based management practice.

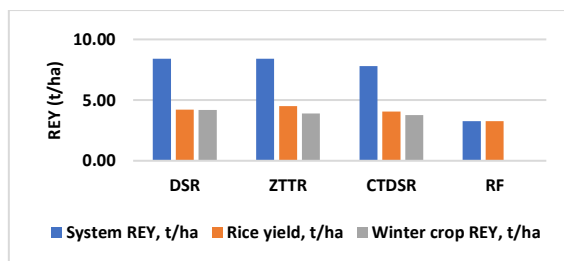


Fig 46. Influence of CA practices on REY of crops & cropping systems at FSRCHPR, Ranchi

After harvest of kharif crops, winter crops were grown in different CA & conventional practices viz., ZT- DSR, ZTTR & CTDSR. It was observed that winter crops of lentil and linseed performed better in ZTDSR & ZTTR and followed trend as, ZTDSR>ZTTR>CTDSR. Highest lentil REY was 3.23 t/ha in ZTDSR. Similarly, highest linseed REY was 4.76 t/ha in ZTDSR. In mustard, highest REY was 4.61 t/ha in ZT-DSR, which was followed by CTDSR & ZTTR. In all winter crops, ZTDSR was better for crop yields.

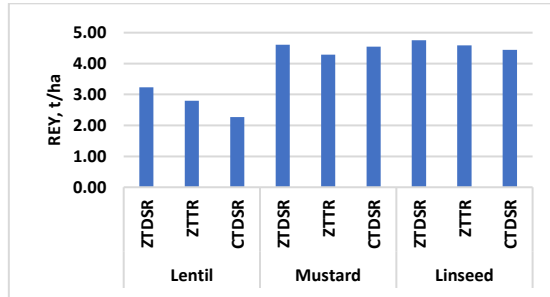


Fig 47. Rice equivalent yields of winter crops under CA practices at ICAR-RCER, FSRCHPR, Ranchi





9. Sugarcane Cropping System

NIASM

Long-term effects of tillage, residue, and nutrient management in a laser levelled drip irrigated sugarcane system

In 2024–25, a fourth ratoon crop field trial was conducted using a split-split design to study the long-term impacts of tillage, residue, and nutrient management in laser levelled plots under a drip-irrigated sugarcane (Cv. Co-86032) system. The plant crop included three tillage and nutrient management treatments i.e. M1: Laser land levelling (LLL) + conventional tillage (CT) + 10% of the recommended dose of fertiliser (RDF) as basal and 90% through fertigation, M2: LLL + minimum tillage (MT) + 25% RDF as basal and 75% through fertigation, and M3: LLL+ reduced tillage (RT) + 15% RDF as basal, 20% RDF at 60 days after planting and 65% through fertigation in main plots, and (ii) two soil surface trash retention practices i.e. mulching (S1) and non-mulching (S2) in subplots. The subplots were further divided into sub-sub plots to accommodate three nutrient levels, i.e., N1: 10% RDF as basal using SORF (stubble shaving, off-barring, root pruning, and band placement of fertilisers) drill and rest through fertigation, N2: 25% RDF as basal with SORF and rest 75% through fertigation, and N3: 15% RDF as basal using SORF, 20% RDF at 60 days, and rest 65% through fertigation in subsequent ratoon crops. The results showed that the highest increase in ratoon yield (36.6%) was observed in the M3+S1+N3 treatment

combination, i.e., reduced tillage (RT) with SORF, involving 15% RDF as basal, 20% at 60 days after planting, and 65% through fertigation in a trash retained treatment. Additionally, mulching led to a 5.4–15.1% increase in ratoon cane yield compared to residue burning treatments.

Assessing the impact of deficit irrigation, plant growth regulators, and surface trash retention under conservation tillage in a sugarcane system

In 2024–25, a field trial was repeated to establish a second ratoon crop (Co-86032) to assess the effects of deficit irrigation (DI), exogenous PGRs, and surface trash retention under conservation tillage practices as previously employed in the plant crop. The experiment was replicated thrice in a split-split plot design. The main plot treatments included three levels of deficit irrigation (50% ET, 75% ET, and 100% ET), applied via a drip system. Subplot treatments involved the exogenous application of four PGRs—1800 ppm thiourea (TU), 10 ml L⁻¹ irradiated chitosan (IC), 4 ml L⁻¹ nano urea (NU), and 25 µM salicylic acid (SA), along with a control (no PGRs). The sub-sub plots consisted of two soil surface trash retention practices: S1 (mulching) and S2 (no mulching/burning). As observed in plant crop (157.1 t ha⁻¹), the highest second ratoon crop cane yield (147.8 t ha⁻¹) was recorded under 75% ET irrigation combined with irradiated chitosan (10 ml L⁻¹) and surface mulching under conservation tillage. PGRs application improved ratoon cane yields by 3.9–13.4%, 11.6–31.1%, and 15.9–33.9% under full irrigation (100% ET), 75% ET, and 50% ET, respectively. Similarly, mulching (S1) enhanced ratoon cane yields by 7.4–19.0, 17.3–35.1, and 35.9–40.6% under 100% ET, 75% ET, and 50% ET, respectively, compared to the non-mulching control (S2). When referring to the plant crop, the integrated application of 75% ET, IC (10 ml L⁻¹), and soil surface mulching reduced the yield gap between plant and ratoon crops by up to 5.9%, while also saving 25% of irrigation water relative to traditional farmers' practice.



Plate 18. Plant crop (10 ml irradiated chitosan) 2nd ratoon (10 ml irradiated chitosan)

Effect of tillage and surface trash retention on diversified vegetables intercropping in a drip irrigated sugarcane system

In September 2024, a new field experiment was initiated to examine the interactive effects of tillage, intercropping, and soil surface crop residue management practices in the sugarcane (cv. Co-86032) cropping system. The experiment included 16 treatment combinations arranged in a split-split plot design. The main plots comprised two tillage systems—reduced tillage (RT) and conventional tillage (CT); the sub-plots included three intercrops—potato (cv. Kufri Pukhraj), onion (cv. Bhima Shakti), and beetroot (cv. Lalima), along with a control; and the sub-sub plots involved two surface trash retention practices—mulching (M) and non-mulching (NM). The average yields of onion, beetroot, and potato were 24.4, 10.6, and 8.0 tons/ha, respectively, while the sugarcane plant crop is yet to be harvested. Preliminary results indicated that under reduced tillage (RT) practices, the intercrop yields of beetroot, potato, and onion improved by 35.1%, 30.3%, and 14%, respectively, compared to conventional tillage (CT) in plant sugarcane. Measurements of real-time plant-water-soil parameters are currently in progress.



Plate 19. Sugarcane+ potato Sugarcane+ beetroot Sugarcane+ onion

B. Weed Management Practices in Conservation Agriculture

Rice Wheat Cropping System

IARI

Weed management in CA based cropping systems

Weed and pest dynamics under CA-based cropping systems. Higher infestation of weeds, *Cyperusesculentus*, *Euphorbia microphylla* and *Cyperusrotundus* were observed in CA than CT in rice-wheat system. In cotton-wheat, maize-wheat and pigeon pea-wheat systems, CT showed highest population of *Cyperusesculentus*, while the lowest infestation was in permanent flatbed with residue (PFB+R). The pyrazosufuron-ethyl *fb*cyhalofop-butyl *fb* bispyribac-Na treatment resulted in higher weed control efficiency (87%). In rice-wheat system, stem borer infestation in rice was highest in PTR-CTW (9.08), but in case of wheat, it was under the ZTDSR+WR-RR+ZTW (3.30). In cotton-wheat and maize-wheat systems, higher number of dead hearts was observed in CT. Similarly, in maize-mustard system, highest aphid infestation was found in CT (27.87). The fall army worm infestation was higher in ZTMz-ZTW (10.03) in maize-wheat and in ZTMz-ZTMs (8.90) under maize-mustard cropping systems.

IISS

Weed Fresh Biomass (g/m²) in wheat crop

The table presents the mean values of weed fresh biomass at three different growth stages 30 days after sowing (30 DAS), 60 DAS, and 90 DAS under different treatments involving Factor A (Tillage and Crop Residue Management) and Factor B (Nutrient Management). At 30 and 60 days after sowing there were no significant variation observed among various tillage treatments. However, it was observed significant at 90 days after sowing in wheat crop. The maximum weed biomass recorded at 60 DAS thereafter it decreased with the progression of crop stage towards maturity. At all the growth stages lowest value associated with conventional tillage treatment. At 90 DAS no tillage treatments recorded with maximum values of fresh weed biomass followed by reduced tillage treatments. Different nutrient doses were recorded with non-significant variation in fresh weed biomass.

Table 8: Weed Fresh Biomass (g/m²) in wheat crop

Treatment	Weed fresh biomass		
	30DAS	60DAS	90DAS
Factor A			
NT + 30cm CR	4.71	20.97	13.80
NT + 60cm CR	4.43	25.90	13.45

RT + 30cm CR	5.30	22.63	12.96
RT + 60 cm CR	4.26	22.42	13.01
CT	3.13	14.94	8.74
C.D.	NS	NS	2.85
SE(m)	0.48	3.01	0.98
Factor B			
RDN	4.42	20.98	12.11
75% RDN	4.45	22.01	13.79
STCR	4.23	21.12	11.28
C.D	NS	NS	NS
SE(m)	0.37	2.33	0.76
C.D(A*B)	NS	NS	NS
SE (m) (A*B)	0.84	5.22	1.69

NT + 30cm CR -No tillage + 30 cm crop residue, NT + 60cm CR -No tillage+60cm crop residues RT + 30cm CR- Reduced tillage+30 cm crop residues, RT + 60 cm CR -Reduced tillage+ 60cm crop residues, CT- conventional tillage. RDN - Recommended dose of nutrients, 75% RDN - 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Dry Weed Biomass (g/m²) in wheat crop

At 30 and 60days after sowing no variation was observed in weed dry biomass, however, at 90 days after sowing there was significant variation observed. The lowest dry weight was associated with conventional tillage, which showed an efficient weed biomass control over No tillage and Reduced tillage treatments.

Dry biomass of weeds varied with non-significant variation among at 30 and 60 days after sowing, however, it differed significantly at 90 days after sowing. The maximum weight was associated with 75% RDN followed by RDN, STCR contained lowest dry weight of weeds. This might be due to solid stem or heavy foliage weed species with low moisture content in biomass.

Table 9: Dry Weed Biomass (g/m²) in wheat crop

Treatment	Weed dry biomass		
	30DAS	60DAS	90DAS
Factor A			
NT + 30cm CR	0.88	4.00	2.12
NT + 60cm CR	0.83	4.97	1.91
RT + 30cm CR	1.00	4.26	2.16
RT + 60 cm CR	0.80	3.65	1.83
CT	0.59	2.37	1.12

C.D.	NS	NS	0.68
SE(m)	0.09	0.74	0.23
Factor B			
RDN	0.83	3.73	1.78
75% RDN	0.84	3.84	2.19
STCR	0.79	3.99	1.52
C.D	NS	NS	0.53
SE(m)	0.07	0.57	0.18
C.D(A*B)	NS	NS	NS
SE (m) (A*B)	0.16	1.28	0.40

Weed Density (Number of weeds /m²) in wheat crop

Total number of weeds per m² were recorded similar at 30 days after sowing and 90DAS among all the tillage treatments, however, at 60 DAS there was significant variation observed in weed density, lowest number of weeds were associated with conventional tillage. Maximum number of weeds at 60DAS were associated under reduced tillage with 30 cm crop residue height. Various nutrient doses had no significant variation among them in weed density.

Table 10: Weed Density (Number of weeds /m²) in wheat crop

Treatment	Weed density		
	30DAS	60DAS	90DAS
Factor A			
NT + 30cm CR	3.44	9.33	6.33
NT + 60cm CR	4.00	7.22	7.66
RT + 30cm CR	4.11	10.33	6.00
RT + 60 cm CR	3.22	7.77	6.00
CT	2.22	6.44	7.00
C.D.	N/A	2.26	N/A
SE(m)	0.693	0.77	0.86
Factor B			
RDN	3.60	7.26	7.70
75% RDN	3.06	8.93	5.90
STCR	3.53	8.46	6.30
C.D	NS	NS	NS

SE(m)	0.53	0.60	0.67
C.D(A*B)	NS	NS	NS
SE (m) (A*B)	1.02	1.35	1.50

NT + 30cm CR -No tillage + 30 cm crop residue, NT + 60cm CR -No tillage+60cm crop residues RT + 30cm CR-Reduced tillage+30 cm crop residues, RT + 60 cm CR -Reduced tillage+ 60cm crop residues, CT- conventional tillage. RDN - Recommended dose of nutrients, 75% RDN - 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Effect of various cropping systems on weed biomass

Weed weight

Among all cropping system weed dry matter observed at 90DAS with non-significant variation. However minimum weed fresh weight value was recorded i.e. 117.333±30.552 maize-chickpea +CT and maximum is 177±16.523 maize-chickpea +NT. Dry weight of weeds also followed similar trend.

Table 11: Effect of conservation agriculture and different type of cropping system on weed biomass

Weed Biomass at 90 days after sowing (g /m2)		
Treatments	Fresh weight	Dry weight
Maize-Chickpea + CT	117.333±30.552	40.333±7.623
Maize-Wheat + CT	160.333±29.812	68.667±9.244
Soybean-Wheat+ CT	136.333±13.094	49.667±11.348
Maize-Chickpea + NT	177±16.523	74.667±8.413
Maize-Wheat +NT	144.667±8.95	56±10.693
Soybean-Wheat +NT	142±8.083	64±6.083.
C.D.	NS	NS
SE(m)	20.086	9.374

Table 12: Weed dry biomass (q/ha) during Kharif (Maize crop)

Treatment	Weed biomass (q/ha)
	Maize
Factor A	
NT + 30cm CR	10.11
NT + 60cm CR	11.51
RT + 30cm CR	7.78
RT + 60 cm CR	6.10
CT	3.79

C.D.	0.036
Factor B	
RDN	9.23
75% RDN	4.99
STCR	9.35
C.D	0.016

NT + 30cm CR -No tillage + 30 cm crop residue, NT + 60cm CR -No tillage+60cm crop residues RT + 30cm CR- Reduced tillage+30 cm crop residues, RT + 60 cm CR -Reduced tillage+ 60cm crop residues, CT- conventional tillage. RDN - Recommended dose of nutrients, 75% RDN - 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Table 13: Major Weed species in

Major Weed species	Description
<i>Convolvulus arvenses</i>	English name – Field bind weed Hindi name- Hirankhuri Family- Convolvulaceae
<i>Launaea aspleniifolia</i>	English name – Launanea Hindi name – Jungali gobhi Family- Asteraceae
<i>Euphorbia hirta</i>	English name- <i>Asthma herb</i> , Common Spurge Hindi name- Dudhi Family- Euphorbiaceae
<i>Anagallis arvensis</i>	English name- scarlet pimpernel Hindi Name – Krishnaneel Family- Primulaceae
<i>Cyperus rotundus</i>	English name- Nut grass Hindi name- Motha Family- Cyperaceae
<i>Parthenium hysterophorus</i>	English name- Congress grass, Carrot grass Hindi name- Gajar ghass

	Family- Asteraceae
<i>Chenopodium album</i>	English name- Lambsquarter Hindi Name – Bathua Family- Chenopodiaceae
<i>Vicia sativa</i>	English name- Vetch Hindi Name – Ankri Family- Fabaceae
<i>Melilotus indica</i>	English name- yellow clover Hindi Name – Peeli Sanji Family- Fabaceae
<i>Lathyrus aphaca</i>	English name- yellow vetchling Hindi Name – Matri Family-Fabaceae
<i>Cichorium intybus</i>	English name- Chicory Hindi Name – Kasni Family-Asteraceae
<i>Avena fatua</i>	English name- Wild oat Hindi Name – Jangali jayee Family- Poaceae
<i>Cynodon dactylon</i>	English name – Bermuda grass Hindi name- Doob ghass Family- Poaceae
<i>Dactyloctenium aegypticum</i>	English name – Crowfoot grass Hindi name- Makra grass Family- Poaceae
<i>Dicanthium annulatum</i>	English name – Marvel grass Hindi name- Jingva Family: Poaceae
<i>Desmostachy bipinnata</i>	English name – Sacrificial grass. Halfa grass Hindi name- Daab Family: Poaceae
<i>Commelina benghalensis</i>	English name – Day flower Hindi name- Kankaua

	Family: Commelinaceae
<i>Echinochloa sp.</i>	English name – Barnyard grass Hindi name- Sawa Family: Poaceae

DWR

Wheat 2023-24

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

At 60 DAS, the wheat field was comprised of weeds, i.e. *Medicago denticulata* (84.05%), whereas the rest of the weeds, like *Avena ludoviciana* (3.93%), *Convolvulus arvensis* (3.46%), *Digitaria sanguinalis* (3.38%), *Chenopodium album* (1.89%), *Cynodon dactylon* (1.65%) were minor weeds present (Fig 48 a & b). The relative weed biomass followed the trend of relative density and recorded the highest with *Medicago denticulata* (88.86%) and the rest were minor weeds in wheat.

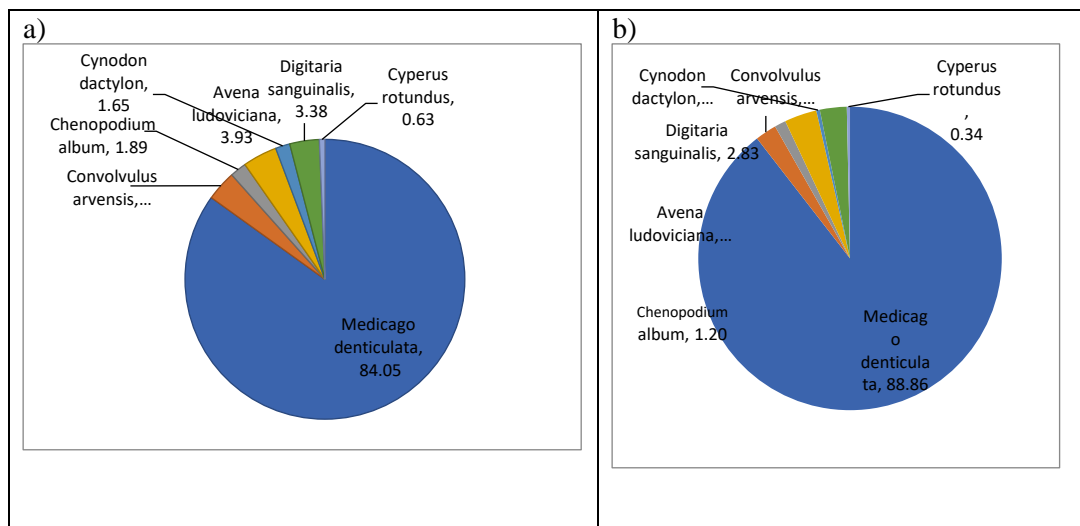


Fig 48. Relative weed density (a) and biomass (b) at 60 DAS in wheat under rice-wheat-greengram system

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 as higher in the conventional system (CT-CT-CT) with 64.7 no./m² and 50.9 g/m², respectively. The lowest total weed density and biomass were measured in ZTR-ZTR-ZTR with 50.3 no./m² and 45.6 g/m², respectively (Table 1 & 2). In general, ZTR systems have more grassy weeds and CT systems have more broadleaf weeds.

Among weed management practices, the weedy check recorded the highest total weed density and biomass, with 212.1 no./m² and 178.3 g/m², respectively, while the lowest was observed in integrated weed management (IWM, clodinafop-propargyl +metsulfuron-methyl at 60+4 g/ha fb hand weeding at 45 DAS), followed by herbicide rotation (clodinafop + metsulfuron at 60+4 g/ha) (Table 15). Additionally, the highest weed control efficiency was recorded with ZTR-ZTR-ZTR (72.51%) compared to the CT-CT-CT system. Similarly, the weed control index followed the trend of the weed control efficiency and reached its highest with ZTR-ZTR-ZTR (74.45%) over the CT-CT-CT system. Weed management practices significantly influenced the weed control efficiency and weed control index, achieving the highest in IWM at 97.25% and 98.82%, respectively, followed by herbicide rotation and the recommended herbicide over weedy check.

Table 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		Sedges	
	<i>Medicago denticulata</i>	<i>Convolvulus arvensis</i>	<i>Chenopodium album</i>	<i>Avena ludoviciana</i>	<i>Cynodon dactylon</i>	<i>Digitaria sanguinalis</i>	<i>Cyperus rotundus</i>
	Weed density (no./m²)						
Crop establishment methods (C)							
CT-CT-CT	5.77(56.3)	1.39(2.2)	1.17(1.3)	1.26(2.0)	0.9(0.4)	1.2(1.2)	1.22(1.2)
ZTR-ZTR-ZTR	4.88(43.2)	1.94(4.0)	0.98(0.8)	1.85(2.2)	1.45(2.2)	1.83(3.8)	0.71(0)
SEm±	0.20	0.04	0.13	0.43	0.04	0.05	0.05
CD (p=0.05)	NS	0.30	NS	NS	0.26	0.38	0.37
Weed management practices (W)							
W1	13.33(178.3)	2.79(7.3)	2.03(4.0)	4.09(8.3)	1.85(3.5)	2.64(7.2)	1.23(1.3)
W2	3.18(9.8)	1.63(2.7)	0.85(0.3)	0.71(0)	1.14(1.0)	1.42(1.7)	1.03(0.7)
W3	2.14(4.2)	1.09(1.0)	0.71(0)	0.71(0)	0.71(0)	0.88(0.3)	0.71(0)
W4	2.65(6.7)	1.16(1.3)	0.71(0)	0.71(0)	1(0.7)	1.11(0.8)	0.88(0.3)
SEm±	0.18	0.27	0.16	0.57	0.17	0.14	0.06
CD (p=0.05)	0.58	0.85	0.50	1.78	0.54	0.45	0.20
C X W	NS	NS	NS	NS	NS	0.71	0.39
	Weed biomass (g/m²)						
Crop establishment methods (C)							
CT-CT-CT	4.7(46.27)	1.1(1.09)	1(0.82)	1.1(1.18)	0.8(0.10)	1.0(0.6)	0.9(0.5)
ZTR-ZTR-ZTR	4.2(37.02)	1.5(2.29)	0.9(0.33)	1.2(1.87)	1(0.50)	1.5(2.4)	0.7(0)
SEm±	0.18	0.09	0.05	0.01	0.01	0.04	0.02
CD (p=0.05)	NS	NS	NS	0.06	0.10	0.29	0.17
Weed management practices (W)							
W1	12.6(158.45)	2.1(4.03)	1.6(2.13)	2.5(6.1)	1.1(0.7)	2.2(5.1)	0.9(0.6)
W2	2.2(4.5)	1.3(1.82)	0.8(0.17)	0.7(0)	0.9(0.3)	1.1(0.7)	0.8(0.3)
W3	1.4(1.48)	0.9(0.42)	0.7(0)	0.7(0)	0.7(0)	0.8(0.1)	0.7(0)
W4	1.6(2.16)	0.9(0.5)	0.7(0)	0.7(0)	0.8(0.2)	0.9(0.3)	0.7(0.1)
SEm±	0.16	0.20	0.10	0.06	0.05	0.09	0.03
CD (p=0.05)	0.52	0.65	0.31	0.18	0.17	0.28	0.10
C X W	NS	NS	NS	0.27	NS	0.46	0.19

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 (clodinafop + metsulfuron at 60+4 g/ha)

Table 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 sedges	Total weeds	WCE (%)
Weed density (no./m²)					
Crop establishment methods (C)					
CT-CT-CT	1.67(3.6)	5.96(59.8)	1.22(1.2)	6.25(64.7)	69.51
ZTR-ZTR-ZTR	2.66(9.4)	5.35(48.1)	0.71(0)	6.05(58.3)	72.51

SEm±	0.04	0.16	0.05	0.18	-
CD (p=0.05)	0.30	NS	0.37	NS	-
Weed management practices (W)					
W1	4.45(20.5)	13.75(189.6)	1.23(1.3)	14.55(212.1)	0.00
W2	1.87(3.3)	3.64(12.8)	1.03(0.7)	4.20(17.2)	91.91
W3	0.88(0.3)	2.35(5.2)	0.71(0)	2.50(5.8)	97.25
W4	1.44(1.8)	2.89(8)	0.88(0.3)	3.34(10.8)	94.89
SEm±	0.18	0.22	0.06	0.22	-
CD (p=0.05)	0.58	0.69	0.20	0.70	-
C X W	NS	NS	0.39	NS	-
Weed biomass (g/m²)					WCI (%)
Crop establishment methods (C)					
CT-CT-CT	1.3(1.9)	4.8(48.2)	1.0(0.5)	5.0(50.6)	71.61
ZTR-ZTR-ZTR	2.0(5.5)	4.5(39.6)	0.7(0)	4.9(45.6)	74.45
SEm±	0.03	0.15	0.02	0.15	-
CD (p=0.05)	0.20	NS	0.17	NS	-
Weed management practices (W)					
W1	3.6(12.9)	12.8(164.6)	1.0(0.6)	13.4(178.3)	0.00
W2	1.3(1.3)	2.6(6.5)	0.9(0.3)	2.9(8.1)	95.43
W3	0.8(0.1)	1.5(1.9)	0.7(0)	1.6(2.1)	98.82
W4	1(0.6)	1.8(2.7)	0.8(0.1)	2(3.8)	97.87
SEm±	0.06	0.22	0.03	0.19	-
CD (p=0.05)	0.19	0.70	0.10	0.60	-
C X W	0.31	NS	0.19	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 biomass and test weight were comparatively more in ZTR-ZTR-ZTR but was statistically similar to CT-CT-CT (Table 16). Among weed management practices, plant height, spikes per meter running length, spike length, 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 17). The interaction between crop establishment methods and weed management practices was non-significant except for plant height and plant biomass.

Table 16: Effect of crop establishment methods and weed management practices on growth and yield parameters of wheat under rice-wheat-greengram cropping system

Treatm ent	Plant populat ion 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	26.58	96.97	92.39	16.60	847.9	3.2	59.82	37.93
ZTR-ZTR-ZTR	26.22	100.73	101.08	17.20	930.7	3.5	63.13	38.49

SEm±	0.18	0.38	1.40	0.11	4.24	0.05	0.78	0.20
CD (p=0.05)	NS	2.51	9.20	NS	27.7	NS	NS	NS
Weed management practices (W)								
W1	25.18	88.49	54.88	14.96	472.5	2.6	41.81	36.69
W2	26.08	100.74	106.28	17.33	1007.0	3.5	64.97	38.36
W3	27.42	104.01	115.00	17.80	1052.1	3.7	71.39	39.07
W4	26.92	102.18	110.78	17.51	1025.6	3.6	67.72	38.72
SEm±	0.31	0.56	1.96	0.13	6.61	0.11	1.13	0.25
CD (p=0.05)	0.97	1.75	6.11	0.43	20.5	0.34	3.54	0.80
C X W	NS	3.13	NS	NS	36.0	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 (3917.9 kg/ha) which was comparatively higher over the CT-CT-CT system (3584.0 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 17). Among weed management practices, weedy check has the lowest grain, straw and biological yields (1917.7, 3256.3 and 5174.0 kg/ha, respectively). The highest crop yields were obtained under IWM (4551.3, 5935.0 and 10486.3 kg/ha, respectively), followed by herbicide rotation and recommended herbicides (Table 17). 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 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	3584.0	5058.3	8642.3	40.8
ZTR-ZTR-ZTR	3917.9	5403.3	9321.2	41.6
SEm±	20.82	133.59	118.82	0.64
CD (p=0.05)	136.45	NS	NS	NS
Weed management practices (W)				
W1	1917.7	3256.3	5174.0	37.0
W2	4176.8	5790.3	9967.2	41.9
W3	4551.3	5935.0	10486.3	43.5
W4	4358.0	5941.5	10299.5	42.3
SEm±	17.00	136.18	137.99	0.59
CD (p=0.05)	52.98	424.26	429.92	1.86
C X W	116.25	NS	NS	NS

Chickpea 2023-24

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

At 60 DAS, the relative density of weeds in chickpea fields comprised of *Medicago denticulata* (84.72%), *Convolvulus arvensis* (3.91%), *Digitaria sanguinalis* (3.33%) whereas the rest of the weeds like, *Chenopodium album*, *Cyperus rotundus*, *Avena ludoviciana*, *Cynodon dactylon*, were minor weeds present (Fig 49 a & b). The relative weed biomass followed the trend of relative density and recorded the highest with *Medicago denticulata* (89.79%), *Convolvulus arvensis* (3.14%) and the rest were minor weeds.

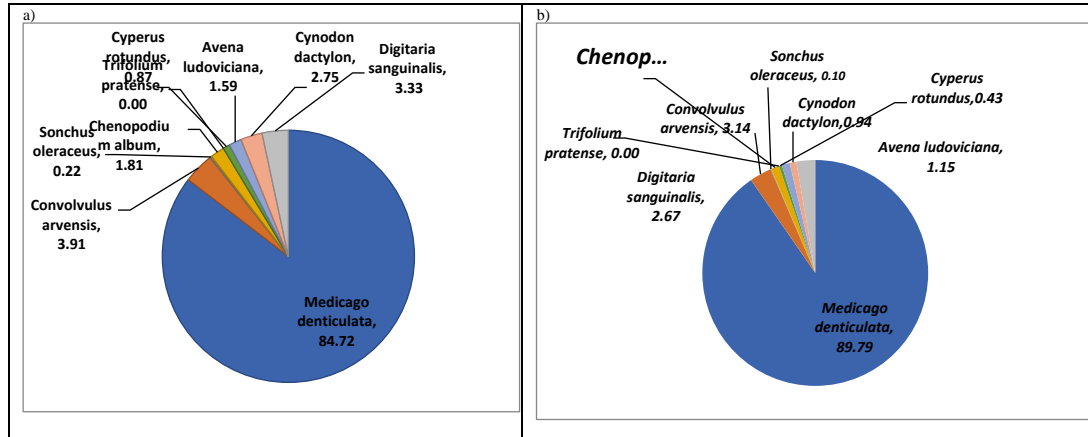


Fig 49. Relative density (a) and biomass (b) of weeds at 60 DAS in chickpea under rice-chickpea-greengram system

Weed density and biomass at 60 DAS in chickpea under rice-chickpea-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 83.3 no./m² and 64.8 g/m², respectively. The lowest total weed density and biomass were measured in ZTR-ZTR-ZTR with 77.7 no./m² and 60.7 g/m², respectively (Table 18 & 19). The weed density and biomass of *Chenopodium album*, and *Cyperus rotundus* were significantly higher in CT-CT-CT and lowest in ZTR-ZTR-ZTR, whereas the rest of the weed species were more with CT-CT-CT. 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 230.2 no./m² and 209.3 g/m², respectively and the lowest in IWM (pendimethalin 678 g/ha fb HW at 30 DAS) followed by herbicide rotation (pendimethalin+imazethapyr 1000 g/ha (PE) fb topamezone 25.2 g/ha) (Table 19). Likewise, WCE was better with the ZTR-ZTR-ZTR (66.26%) over CT-CT-CT system. Likewise, WCI followed the trend of WCE and recorded the highest with the ZTR-ZTR-ZTR (70.99%) over the CT-CT-CT system. Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 89.07 and 96.49%, respectively followed by herbicide rotation and recommended herbicide over weedy check.

Table 18: Effect of crop establishment methods and weed management practices on density and biomass of different weed species on chickpea at 60 DAS under rice-chickpea-greengram system

Treatment	Broad leaf weeds					Sedges	Grassy weeds		
	<i>Medicago denticulata</i>	<i>Convolvulus arvensis</i>	<i>Sonchus oleraceus</i>	<i>Chenopodium album</i>	<i>Trifolium pratense</i>	<i>Cyperus rotundus</i>	<i>Avena ludoviciana</i>	<i>Cynodon dactylon</i>	<i>Digitaria sanguinalis</i>
Weed density (no./m²)									
<i>Crop establishment methods (C)</i>									
CT-CT-CT	7.41(71.5)	2.09(5.0)	0.71(0)	1.19(1.4)	0.78(0.2)	1.41(1.9)	0.93(0.5)	1.2(1.5)	1.27(1.3)
ZTR-ZTR-ZTR	6.34(56.8)	2.22(5.7)	0.82(0.3)	1.02(0.8)	1.4(2.5)	0.71(0)	2.18(2.2)	1.74(3.5)	1.91(4.2)
SEm±	0.03	0.02	0.04	0.06	0.17	0.11	0.29	0.14	0.05
CD (P=0.05)	0.25	NS	NS	NS	NS	NS	NS	NS	0.33
<i>Weed management practices (W)</i>									
W1	13.96(195.0)	3.03(9.0)	0.94(0.5)	2.14(4.2)	0.71(0)	1.4(2.0)	3.47(3.7)	2.48(6.3)	2.71(7.7)
W2	5.12(26.5)	2.18(5.7)	0.71(0)	0.85(0.3)	1.14(1.0)	1.28(1.5)	1.18(1.3)	1.7(3.0)	1.45(1.7)
W3	4.21(17.7)	1.55(2.7)	0.71(0)	0.71(0)	1.65(4.0)	0.71(0)	0.71(0)	0.71(0)	0.94(0.5)
W4	4.2(17.5)	1.89(4)	0.71(0)	0.71(0)	0.85(0.3)	0.85(0.3)	0.85(0.3)	1.0(0.7)	1.26(1.2)
SEm±	0.24	0.24	0.06	0.09	0.27	0.08	0.52	0.26	0.13
CD (P=0.05)	0.74	0.76	NS	0.30	NS	0.25	1.63	0.81	0.42
C X W	NS	NS	NS	NS	NS	0.58	2.75	NS	0.66
Weed biomass (g/m²)									
<i>Crop establishment methods (C)</i>									
CT-CT-CT	6(57.81)	1.8(3.60)	0.7(0)	1.1(0.92)	0.7(0)	1.1(0.80)	0.9(0.50)	0.9(0.40)	1(0.70)
ZTR-ZTR-ZTR	5.3(49.52)	2.1(4.48)	0.8(0.1)	0.9(0.52)	0.9(0.40)	0.7(0)	1.1(1.02)	1.1(1.0)	1.5(2.70)
SEm±	0.01	0.24	0.03	0.04	0.02	0.06	0.04	0.03	0.03
CD (P=0.05)	0.06	NS	NS	NS	NS	NS	NS	0.25	0.24
<i>Weed management practices (W)</i>									
W1	13.7(187.96)	2.7(6.57)	0.8(0.2)	1.7(2.4)	0.7(0)	1.1(0.90)	1.6(2.40)	1.5(2.00)	2.3(5.60)

W2	3.8(14.24)	2(4.55)	0.7(0)	0.9(0.47)	0.9(0.3)	1.0(0.60)	0.9(0.43)	1(0.60)	1.1(0.70)
W3	2.3(4.92)	1.3(1.67)	0.7(0)	0.7(0)	0.9(0.5)	0.7(0)	0.7(0)	0.7(0)	0.8(0.2)
W4	2.8(7.55)	1.8(3.37)	0.7(0)	0.7(0)	0.7(0.1)	0.8(0.10)	0.8(0.20)	0.8(0.20)	1(0.40)
SEm±	0.18	0.31	0.05	0.12	0.10	0.04	0.13	0.11	0.08
CD (p=0.05)	0.57	NS	NS	0.38	NS	0.14	0.40	0.37	0.26
C X W	NS	NS	NS	NS	NS	0.32	NS	NS	0.42

W1: control (weedy check); W2: recommended herbicide (pendimethalin+imazethapyr 1.0 kg/ha *fb* topramezone 25.2 g/ha); W3: integrated weed management [pendimethalin 678 g/ha *fb* hand weeding (30 DAS)]; W4: herbicide rotation (pendimethalin+imazethapyr 1000 g/ha (PE) *fb* topramezone 25.2 g/ha)

Table 19: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 60 DAS in chickpea under rice-chickpea-green gram cropping system

Treatment	Total grasses	Total broadleaf weeds	Total sedges	Total weeds	WCE (%)
Weed density (no./m²)					
<i>Crop establishment methods (C)</i>					
CT-CT-CT	1.73(3.3)	7.81(77.9)	1.41(1.9)	8.1(83.3)	82.34
ZTR-ZTR-ZTR	3.08(11.6)	6.84(63.3)	0.71(0)	7.75(77.7)	66.26
SEm±	0.05	0.07	0.11	0.14	-
CD (P=0.05)	0.36	0.49	NS	NS	-
<i>Weed management practices (W)</i>					
W1	4.25(19.5)	14.42(208.2)	1.4(2.0)	15.17(230.2)	0.00
W2	2.58(6.7)	5.67(32.5)	1.28(1.5)	6.46(41.7)	81.90
W3	1.05(0.8)	4.54(20.3)	0.71(0)	5.03(25.2)	89.07
W4	1.74(2.8)	4.66(21.5)	0.85(0.3)	5.03(25)	89.14
SEm±	0.21	0.23	0.08	0.26	-
CD (P=0.05)	0.66	0.74	0.25	0.81	-
C X W	0.98	NS	0.58	NS	-
Weed biomass (g/m²)					WCI (%)
<i>Crop establishment methods (C)</i>					
CT-CT-CT	1.3(1.6)	6.4(62.3)	1.1(0.8)	6.5(64.8)	69.07
ZTR-ZTR-ZTR	2.1(5.8)	5.9(54.5)	0.7(0)	6.2(60.7)	70.99
SEm±	0.02	0.12	0.06	0.07	-
CD (P=0.05)	0.13	NS	NS	NS	-
<i>Weed management practices (W)</i>					
W1	3.3(11.3)	14(196.9)	1.1(0.9)	14.5(209.3)	0.00
W2	1.6(2.1)	4.4(19.3)	1(0.6)	4.7(22.1)	89.43
W3	0.9(0.3)	2.7(6.6)	0.7(0)	2.8(7.4)	96.49
W4	1.2(1.1)	3.4(10.9)	0.8(0.1)	3.5(12.2)	94.20
SEm±	0.14	0.20	0.04	0.20	-
CD (P=0.05)	0.45	0.62	0.14	0.64	-
C X W	0.64	NS	0.32	NS	-

Crop growth and yield parameters in chickpea under rice-chickpea-green gram system

Between the crop establishment methods, the populations of chickpea plants at 15 DAS were comparable, where rest of growth and yield parameters was higher with the ZTR-ZTR-ZTR system. Contrarily, plant biomass and pods/plant were significantly higher with the ZTR-ZTR-ZTR system. But, plant height, branches/plant, seeds/pod and seed index were statistically comparable between the crop establishment methods (Table 20). Among weed management practices, plant population, plant height and plant biomass were comparable, whereas branches/plant, pods/plant, seeds/pod and seed index were significantly highest with IWM, followed by herbicide rotation and recommended herbicides. The lowest growth and yield parameters were recorded with the weedy check (Table 20). The interaction between crop establishment methods and weed management practices was non-significant except plant height and plant biomass.

Table 20: Effect of crop establishment methods and weed management practices on growth and yield parameters of chickpea under rice-chickpea-greengram cropping system

Treatment	Plant population at 15 DAS	Plant height (cm) at harvest	Plant biomass per (g) m ² at harvest	Branches/plant at harvest	Pods/plant	Seeds/pod	Seed index (g)
<i>Crop establishment methods (C)</i>							
CT-CT-CT	9.79	59.12	178.71	5.22	54.4	1.61	19.17
ZTR-ZTR-ZTR	8.92	54.32	135.16	4.89	56.7	1.67	19.61
SEm±	0.22	0.77	3.34	0.19	0.17	0.05	0.11
CD (p=0.05)	NS	5.07	21.90	NS	1.15	NS	NS
<i>Weed management practices (W)</i>							
W1	8.08	54.68	115.33	2.83	18.2	1.31	18.06
W2	9.42	55.35	153.55	5.61	65.6	1.70	19.53
W3	10.50	59.13	189.53	5.94	72.2	1.80	20.16
W4	9.42	57.73	169.33	5.83	66.3	1.75	19.82
SEm±	0.30	0.71	4.59	0.22	0.66	0.04	0.22
CD (p=0.05)	0.94	2.22	14.30	0.70	2.08	0.15	0.71
C X W	NS	4.66	26.05	NS	NS	NS	NS

Seed and haulm yield of chickpea under rice-chickpea-greengram system

Between the crop establishment methods, the chickpea yields (seed, and haulm yield) and harvest index were statistically similar. This might be due to the ZTR system has accumulated more yield attributing characters, but the overall plant population was lower in the ZTR system (Table 21). Among weed management practices, weedy check has the lowest seed, haulm and biological yields (153.7, 448.7 and 602.3 kg/ha, respectively). The highest crop yields were obtained under IWM (1884.7, 4118.0 and 6002.7 kg/ha, respectively) followed by herbicide rotation and recommended herbicides (Table 21). The harvest index was recorded at its highest with herbicide rotation followed by IWM and recommended herbicides. The interaction between crop establishment methods and weed management practices was found to be significant in yields and harvest index data.

Table 21: Effect of crop establishment methods and weed management practices on yields of chickpea under rice-chickpea-greengram cropping system

Treatment	Seed yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
<i>Crop establishment methods (C)</i>				
CT-CT-CT	1435.3	3205.5	4640.8	29.0
ZTR-ZTR-ZTR	1349.7	3044.1	4393.8	30.1
SEm±	7.54	36.57	32.12	0.11
CD (p=0.05)	49.41	NS	210.42	0.73
<i>Weed management practices (W)</i>				
W1	153.7	448.7	602.3	25.0
W2	1721.0	3872.2	5593.2	30.8
W3	1884.7	4118.0	6002.7	31.4
W4	1810.7	4060.3	5871.0	30.8
SEm±	12.83	26.09	22.93	0.70

CD (p=0.05)	39.97	81.28	71.45	2.20
C X W	68.21	186.85	164.19	3.17

Greengram-2024

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

At 45 DAS, the relative weed density in greengram under the study area was *Echinochloa colona* (25%), *Cyperus rotundus* (23%), *Dinebra retroflexa* (22%), *Digitaria sanguinalis* (16%), *Convolvulus arvensis* (6%) and other weeds like *Eleusine indica*, *Alternanthera sessilis*, *Physalis minima*, *Dichanthium annulatum* etc. Likewise, relative weed biomass recorded the highest for *Echinochloa colona* (27%), *Dinebra retroflexa* (23%), *Digitaria sanguinalis* (17%), *Cyperus rotundus* (10%), *Convolvulus arvensis* (8%), and other weeds (Fig 50 a and b).

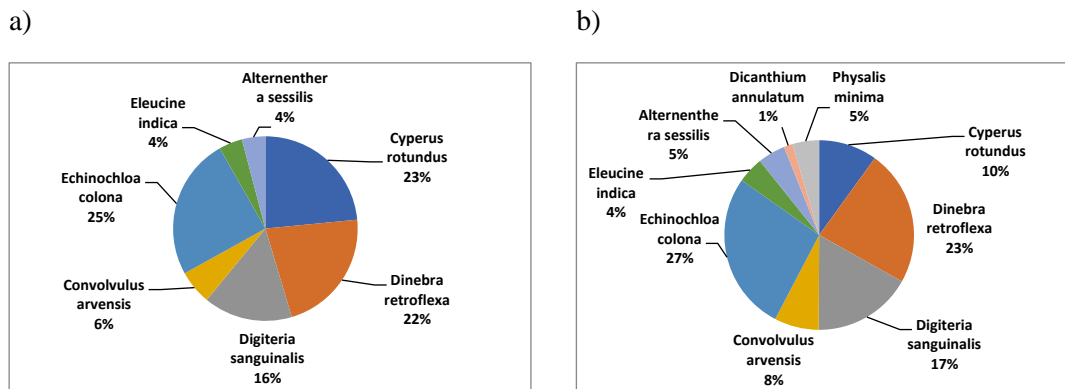


Fig 50. Relative weed density (a) and biomass (b) in greengram with rice-wheat-greengram system

Weed density and biomass at 45 DAS in greengram under rice-wheat-greengram system

At 45 DAS, under crop establishment methods, the total weed density and biomass were recorded higher in the ZTR-ZTR-ZTR with 43.50 no./m² and 23.25 g/m², respectively. The lowest total weed density and biomass were measured in the CT-CT-CT with 37.50 no./m² and 19.76 g/m², respectively (Table 22 & 23). In general, ZTR systems have more of grassy weeds and CT systems have more of broadleaf weeds (BLWs) and sedges. Likewise, WCE was better with CT-CT-CT (63.29%) over ZTR-ZTR-ZTR system. WCI followed the trend of WCE and recorded the highest with CT-CT-CT (67.19%) over the ZTR-ZTR-ZTR system (Fig 51).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 102.17 no./m² and 60.24 g/m², respectively and the lowest in IWM (pendimethalin 678 g/ha fb HW) followed by herbicide rotation (pendimethalin 678 g/ha fb quizalofop 60 g/ha) and recommended herbicide. Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 88.50 and 93.75%, respectively followed by herbicide rotation and recommended herbicide over weedy check.

Table 22: Effect of crop establishment methods and weed management practices on weed density and biomass of weeds at 45 DAS in greengram under rice-wheat-greengram cropping system

Treatment	Grassy weeds					Broadleaved weeds			Sedge
	<i>Dinebra retroflexa</i>	<i>Digitaria sanguinalis</i>	<i>Echinochla colona</i>	<i>Eleusine indica</i>	<i>Dichanthium annulatum</i>	<i>Physalis minima</i>	<i>Convolvulus arvensis</i>	<i>Alternanthera sessilis</i>	<i>Cyperus rotundus</i>
Weed density (no./m²)									
Crop establishment methods (C)									
CT-CT-CT	2.27(6.75)	2.31(5.58)	2.55(8.58)	1.21(1.42)	0.71(0)	1.12(1.25)	1.87(3.92)	1.04(0.83)	2.54(9.17)
ZT+R-ZT+R-ZT+R	2.83(9.25)	2.98(10.25)	2.66(8.17)	1.87(3.17)	1.09(0.92)	1.02(0.75)	1.57(2.42)	1.55(2.5)	2.3(6.08)
SEm±	0.08	0.28	0.19	0.19	0.11	0.11	0.36	0.09	0.06
CD (P=0.05)	0.56	NS	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)									
W1	4.63(21.33)	3.85(15.17)	4.94(24.17)	1.99(4.00)	1.23(1.33)	1.94(3.5)	2.32(5.83)	1.97(4.00)	4.76(22.83)
W2	2.60(6.05)	2.95(8.67)	2.06(4.17)	1.46(2.00)	0.85(0.33)	0.94(0.5)	1.47(2.00)	1.32(1.50)	2.13(4.17)
W3	1.17(1.17)	1.76(3.33)	1.66(2.50)	1.28(1.33)	0.71(0)	0.71(0)	1.39(1.67)	0.71(0)	1.37(1.67)
W4	1.79(3.00)	2.02(4.50)	1.77(2.67)	1.43(1.83)	0.79(0.17)	0.71(0)	1.72(3.17)	1.19(1.17)	1.43(1.83)
SEm±	0.25	0.34	0.21	0.22	0.06	0.13	0.33	0.21	0.23
CD (p=0.05)	0.79	1.06	0.67	NS	0.18	0.41	NS	0.68	0.71
C x W	NS	NS	NS	NS	0.46	NS	NS	NS	NS
Weed biomass (g/m²)									
Crop establishment methods (C)									
CT-CT-CT	1.78(4.03)	1.72(2.94)	1.97(5.29)	1.03(0.82)	0.71(0)	1.06(0.98)	1.63(2.82)	0.94(0.54)	1.43(2.33)
ZT+R-ZT+R-ZT+R	2.11(5.34)	2.23(5.79)	2(4.81)	1.38(1.57)	0.97(0.57)	0.96(0.57)	1.42(1.82)	1.27(1.46)	1.3(1.43)
SEm±	0.09	0.15	0.1	0.13	0.07	0.09	0.29	0.07	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)									
W1	3.77(13.96)	3.19(10.21)	4.08(16.32)	1.69(2.7)	1.11(0.91)	1.75(2.74)	2.09(4.58)	1.71(2.83)	2.51(6.01)
W2	1.99(3.61)	2.29(5.00)	1.64(2.39)	1.22(1.17)	0.8(0.18)	0.89(0.35)	1.31(1.43)	1.09(0.8)	1.18(0.91)
W3	0.89(0.34)	1.15(0.96)	1.09(0.72)	0.93(0.39)	0.71(0)	0.71(0)	1.20(1.07)	0.71(0)	0.87(0.28)
W4	1.13(0.82)	1.27(1.29)	1.12(0.76)	0.99(0.53)	0.74(0.06)	0.71(0)	1.50(2.2)	0.92(0.39)	0.89(0.33)
SEm±	0.16	0.17	0.14	0.15	0.04	0.11	0.27	0.15	0.07
CD (p=0.05)	0.5	0.54	0.44	0.49	0.12	0.34	NS	0.48	0.23
C x W	NS	NS	NS	NS	NS	NS	NS	NS	0.38

W1: control (weedy check); W2: recommended herbicide (RH, pendimethalin 678 g/ha fb imazethapyr 100 g/ha); W3: integrated weed management (IWM, pendimethalin 678 g/ha fb hand weeding); W4: herbicide rotation (HR, pendimethalin 678 g/ha fb quizalofop 50 g/ha)

Table 23: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 45 DAS in greengram under rice-wheat-greengram cropping system

Treatment	Total grasses	Total broadleaf weeds	Total sedges	Total weeds
Weed density (no./m²)				
<i>Crop establishment methods (C)</i>				
CT-CT-CT	4.26(22.33)	2.22(6.00)	2.54(9.17)	5.45(37.50)
ZT+R-ZT+R-ZT+R	5.27(31.75)	2.29(5.67)	2.3(6.08)	6.18(43.50)
SEm±	0.25	0.27	0.06	0.13
CD (p=0.05)	NS	NS	NS	NS
<i>Weed management practices (W)</i>				
W1	8.12(66.00)	3.66(13.33)	4.76(22.83)	10.12(102.17)
W2	4.68(21.67)	1.99(4.00)	2.13(4.17)	5.48(29.83)
W3	2.81(8.33)	1.39(1.67)	1.37(1.67)	3.38(11.67)
W4	3.45(12.17)	1.98(4.33)	1.43(1.83)	4.28(18.33)
SEm±	0.31	0.33	0.23	0.27
CD (p=0.05)	0.97	1.04	0.71	0.86
C x W	NS	NS	NS	NS
Weed biomass (no./m²)				
<i>Crop establishment methods (C)</i>				
CT-CT-CT	3.11(13.08)	1.91(4.35)	1.43(2.33)	3.83(19.76)
ZT+R-ZT+R-ZT+R	3.78(18.08)	1.93(3.85)	1.3(1.43)	4.37(23.35)
SEm±	0.15	0.21	0.03	0.09
CD (p=0.05)	NS	NS	NS	NS
<i>Weed management practices (W)</i>				
W1	6.65(44.09)	3.21(10.14)	2.51(6.01)	7.78(60.24)
W2	3.56(12.35)	1.67(2.58)	1.18(0.91)	4.02(15.84)
W3	1.63(2.42)	1.2(1.07)	0.87(0.28)	2.03(3.76)
W4	1.94(3.46)	1.61(2.59)	0.89(0.33)	2.58(6.38)
SEm±	0.19	0.26	0.07	0.19
CD (p=0.05)	0.60	0.82	0.23	0.59
C x W	NS	NS	0.38	NS

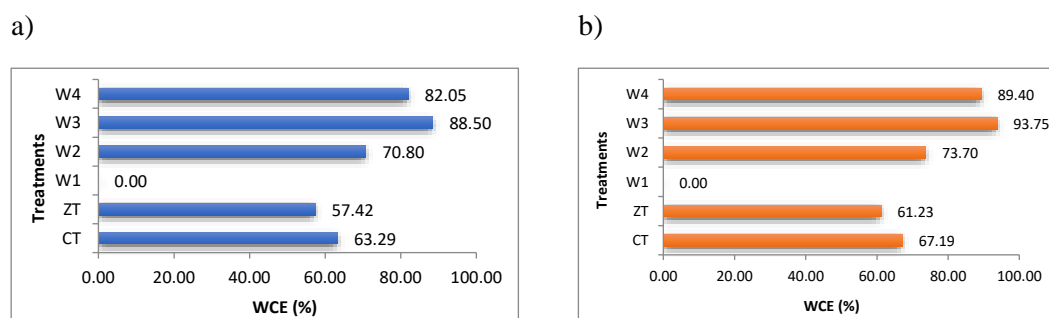


Fig 51. Weed control efficiency (a) and weed control index (b) in greengram under rice-wheat-greengram system

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

Between the crop establishment methods, plant height, plant biomass, branches/plant, pods/plant, pod length, seeds/pod, test weight was higher with the CT-CT-CT system but comparable to the ZTR-ZTR-ZTR system (Table 24).

Among weed management practices, all the growth parameters viz. plant height, plant biomass and branches/plant were recorded highest with IWM and followed by herbicide rotation and recommended herbicides. The lowest growth parameters were recorded with weedy check plots. Like growth parameters, yield parameters were recorded highest with IWM followed by herbicide rotation and recommended herbicide. The lowest yield parameters were recorded with weedy check (Table 24). The interaction between crop establishment methods and weed management practices was found to be non-significant for plant biomass, seeds/pod and test weight. Whereas, it was found significant for plant height, branches/plant, pods/plant and pod length.

Table 24: Effect of crop establishment methods and weed management practices on growth parameters and yield attributes of greengram under rice-wheat-greengram cropping system

Treatment	Growth parameters			Yield parameters			
	Plant height (cm)	Plant biomass (g/plant)	Branches / plant	No of pods/plant	Pod length	Seeds/pod	Test weight (1000 seeds)
<i>Crop establishment method (C)</i>							
CT-CT-CT	52.75	11.08	4.31	33.75	8.72	9.21	34.95
ZT+R-ZT+R-ZT+R	50.27	9.66	3.49	31.25	8.44	8.83	33.91
SEm±	0.85	0.26	0.26	0.81	0.26	0.28	1.37
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
<i>Weed management practices (W)</i>							
W1	40.36	8.80	2.56	18.33	6.71	7.50	32.81
W2	50.69	10.05	3.38	32.67	8.04	8.75	33.76
W3	57.99	11.57	4.96	40.00	10.22	10.17	35.89
W4	57.01	11.07	4.71	39.00	9.37	9.67	35.28
SEm±	0.73	0.44	0.17	0.70	0.17	0.43	1.29
CD (p=0.05)	2.27	1.35	0.53	2.20	0.52	1.36	NS
C x W	4.92	NS	1.26	4.71	1.26	NS	NS

Seed and haulm yield of green gram

Between the crop establishment methods, the green gram yields (seed, haulm and biological yield) and harvest index were statistically similar and recorded a higher value with the CT-CT-CT system. The highest seed yield (916.71 kg/ha), haulm yield (2099.47 kg/ha) and biological yield (3016.19 kg/ha) were recorded with the CT-CT-CT system, but the harvest index was higher (30.48%) in the ZTR-ZTR-ZTR system. This might be due to the fact that the CT system has developed better growth parameters and accumulated more yield attributing characters resulting in higher seed yield under the CT system (Table 25). Among weed management practices, weedy check has the lowest seed, haulm and biological yields (467.36, 1197.48 and 1664.84 kg/ha, respectively). The highest seed, haulm and biological yields were obtained under IWM (1118.23, 2348.94 and 3467.18 kg/ha, respectively) followed by herbicide rotation and recommended herbicides (Table 25). The harvest index

was recorded at its highest with IWM followed by herbicide rotation and recommended herbicides. The interaction between crop establishment methods and weed management practices was found to be non-significant.

Table 25: Effect of crop establishment methods and weed management practices on yield of greengram under rice-wheat-greengram cropping system

Treatment	Seed yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)	HI (%)
<i>Crop establishment method (C)</i>				
CT-CT-CT	916.71	2099.47	3016.19	29.92
ZT+R-ZT+R-ZT+R	842.48	1900.28	2742.77	30.48
SEm±	34.35	47.09	66.65	1.00
CD (p=0.05)	NS	NS	NS	NS
<i>Weed management practices (W)</i>				
W1	467.36	1197.48	1664.84	27.95
W2	879.44	2059.14	2938.58	29.93
W3	1118.23	2348.94	3467.18	32.34
W4	1053.36	2393.94	3447.30	30.57
SEm±	34.75	66.79	88.06	0.75
CD (p=0.05)	108.26	208.08	274.37	2.35
C x W	NS	NS	NS	NS

Relative weed density and biomass (%) in greengram under rice-chickpea-greengram system

At 45 DAS, the relative weed density in greengram under the study area was *Cyperus rotundus* (28%), *Echinochloa colona* (28%), *Dinebra retroflexa* (19%), *Digitaria sanguinalis* (12%), *Eleusine indica* (5%), and other weeds like, *Convolvulus arvensis*, *Alternanthera sessilis*, *Physalis minima*, *Dichanthium annulatum* etc. Likewise, relative weed biomass recorded the highest for *Echinochloa colona* (32%), *Dinebra retroflexa* (22%), *Digitaria sanguinalis* (14%), *Cyperus rotundus* (13%), *Eleusine indica* (6%) and other weeds (Fig 52a and b).

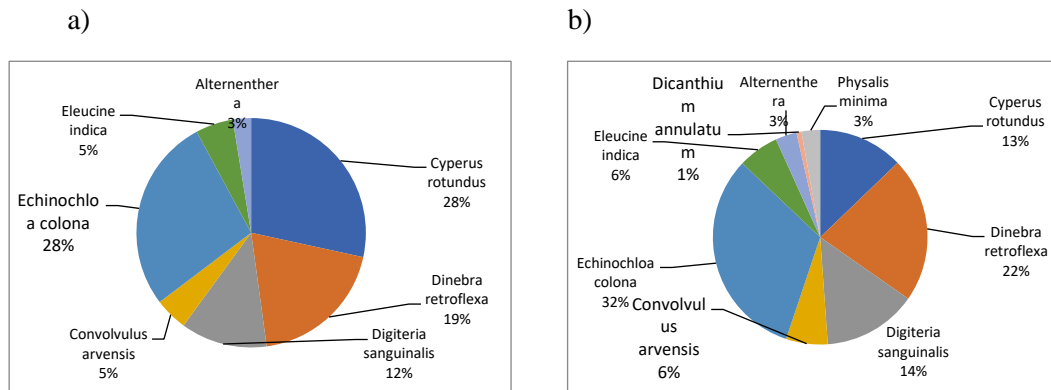


Fig 52. Relative weed density (a) and biomass (b) in greengram with rice-chickpea-greengram system

Weed density and biomass at 45 DAS in greengram under rice-chickpea-greengram system

At 45 DAS, under crop establishment methods, the total weed density and biomass were recorded as comparable between both the establishment methods; however, the total weed density (43.7 no./m²) and total weed biomass (22.0 g/m²) were higher in the CT system (Table 26 & 27). The weed density and biomass of *Echinochloa colona* was more in CT system, whereas rest of the grassy weeds were more with ZTR system. All the broadleaf weeds and

sedges except *Physalis minima* were more in the CT system than the ZT system. In general, CT systems have more of broadleaf weeds (BLWs) and sedges over ZTR, while grassy weeds were more in ZTR. Likewise, WCE was better with ZTR-ZTR-ZTR (65.51%) over CT-CT-CT system. WCI followed the trend of WCE and recorded the highest WCI with ZTR-ZTR-ZTR (66.76%) over CT-CT-CT system (Fig 53).

Among weed management practices, weedy check was recorded the highest total weed density and biomass with 106.70 no./m² and 60.32 g/m², respectively and the lowest in IWM (pendimethalin 678 g/ha *fb* HW) followed by herbicide rotation (pendimethalin 678 g/ha *fb* quizalofop 50 g/ha). Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 89.87 and 93.84%, respectively followed by herbicide rotation and recommended herbicide over weedy check (Fig 53).

Table 26: Effect of crop establishment methods and weed management practices on weed density and biomass of weeds at 45 DAS in greengram under rice-chickpea-greengram cropping system

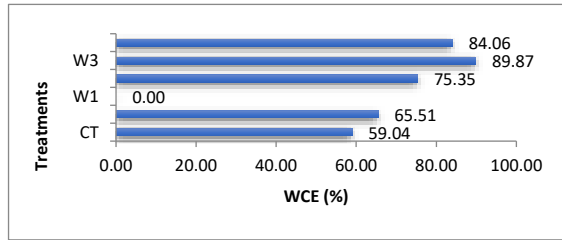
Treatment	Grassy weeds					Broadleaved weeds			Sedge
	<i>Dinebra retroflexa</i>	<i>Digitaria sanguinalis</i>	<i>Echinochloa colon a</i>	<i>Eleusine indica</i>	<i>Dichanthium ann ulatum</i>	<i>Physalis minima</i>	<i>Convolvulus arvensis</i>	<i>Alternanthera sessilis</i>	<i>Cyperus rotundus</i>
Weed density (no./m²)									
<i>Crop establishment methods (C)</i>									
CT-CT-CT	2.73(8.1)	2.15(5.0)	3.02(11.3)	1.42(2.0)	0.71(0)	1.06(0.9)	2.02(4.1)	1.06(0.8)	2.84(11.5)
ZT+R-ZT+R-ZT+R	2.60(8.1)	2.25(5.8)	2.60(8.3)	1.64(2.8)	1.13(1.2)	0.98(0.7)	1.66(2.5)	1.13(1.0)	2.03(6.5)
SEm±	0.14	0.34	0.14	0.07	0.22	0.19	0.1	0.13	0.09
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.64
<i>Weed management practices (W)</i>									
W1	4.54(20.2)	3.57(12.7)	5.35(28.5)	2.41(5.5)	0.94(0.7)	1.51(2.2)	2.20(4.8)	1.77(2.7)	5.35(29.5)
W2	2.56(6.3)	2.24(4.8)	2.21(4.5)	1.62(2.7)	1.05(0.8)	0.94(0.5)	2.06(3.8)	0.85(0.3)	1.60(2.5)
W3	1.80(2.8)	1.38(1.7)	1.68(2.7)	0.97(0.5)	0.71(0)	0.94(0.5)	1.47(1.8)	0.79(0.2)	1.00(0.7)
W4	1.75(3)	1.60(2.3)	1.99(3.5)	1.11(0.8)	0.98(0.8)	0.71(0)	1.62(2.7)	0.97(0.5)	1.79(3.3)
SEm±	0.21	0.18	0.2	0.21	0.13	0.16	0.26	0.1	0.38
CD (p=0.05)	0.65	0.57	0.62	0.67	NS	0.52	NS	0.32	1.2
C x W	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed biomass (g/m²)									
<i>Crop establishment methods (C)</i>									
CT-CT-CT	1.95(4.36)	1.62(2.81)	2.24(6.73)	1.16(1.16)	0.71(0)	1(0.71)	1.74(2.89)	0.96(0.56)	1.53(2.82)
ZT+R-ZT+R-ZT+R	1.98(4.75)	1.75(3.43)	1.99(5.06)	1.35(1.67)	0.97(0.59)	0.93(0.5)	1.47(1.84)	0.99(0.6)	1.24(1.61)
SEm±	0.06	0.2	0.1	0.07	0.14	0.15	0.07	0.08	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Weed management practices (W)</i>									
W1	3.69(13.2)	2.96(8.55)	4.42(19.26)	2.02(3.71)	0.89(0.45)	1.38(1.70)	1.98(3.79)	1.55(1.93)	2.80(7.73)
W2	1.96(3.49)	1.77(2.81)	1.74(2.59)	1.34(1.57)	0.92(0.44)	0.89(0.37)	1.79(2.74)	0.80(0.18)	0.99(0.54)
W3	1.10(0.73)	0.96(0.47)	1.09(0.75)	0.80(0.14)	0.71(0)	0.88(0.35)	1.25(1.14)	0.74(0.05)	0.76(0.09)
W4	1.11(0.8)	1.06(0.66)	1.22(0.99)	0.85(0.24)	0.84(0.29)	0.71(0)	1.42(1.8)	0.81(0.17)	0.98(0.5)
SEm±	0.11	0.14	0.12	0.14	0.08	0.14	0.21	0.06	0.16
CD (p=0.05)	0.36	0.43	0.37	0.43	NS	0.43	NS	0.19	0.51
C x W	NS	NS	NS	NS	NS	NS	NS	NS	NS

W1: control (weedy check); W2: recommended herbicide (RH, pendimethalin 678 g/ha fb imazethapyr 100 g/ha); W3: integrated weed management (IWM, pendimethalin 678 g/ha fb hand weeding); W4: herbicide rotation (HR, pendimethalin 678 g/ha fb quizalofop 50 g/ha)

Table 27: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 45 DAS in green gram under rice-chickpea-green gram cropping system

Treatment	Total grasses	Total broadleaf weeds	Total sedges	Total weeds
Weed density (no./m²)				
<i>Crop establishment methods (C)</i>				
CT-CT-CT	4.72(26.3)	2.35(5.8)	2.84(11.5)	6.01(43.7)
ZT+R-ZT+R-ZT+R	4.65(26.1)	2.06(4.2)	2.03(6.5)	5.46(36.8)
SEm±	0.11	0.26	0.09	0.12
CD (p=0.05)	NS	NS	0.64	NS
<i>Weed management practices (W)</i>				
W1	8.24(67.5)	3.12(9.7)	5.35(29.5)	10.33(106.7)
W2	4.40(19.2)	2.24(4.7)	1.60(2.5)	5.14(26.3)
W3	2.80(7.7)	1.73(2.5)	1.00(0.7)	3.32(10.8)
W4	3.29(10.5)	1.74(3.2)	1.79(3.3)	4.15(17)
SEm±	0.15	0.23	0.38	0.22
CD (p=0.05)	0.46	0.71	1.2	0.71
C x W	0.85	NS	NS	NS
Weed biomass (g/m²)				
<i>Crop establishment methods (C)</i>				
CT-CT-CT	3.35(15.07)	2.00(4.16)	1.53(2.82)	4.10(22.05)
ZT+R-ZT+R-ZT+R	3.42(15.51)	1.77(2.94)	1.24(1.61)	3.96(20.05)
SEm±	0.08	0.19	0.07	0.13
CD (p=0.05)	NS	NS	NS	NS
<i>Weed management practices (W)</i>				
W1	6.76(45.17)	2.75(7.42)	2.80(7.73)	7.79(60.32)
W2	3.34(10.9)	1.92(3.28)	0.99(0.54)	3.87(14.72)
W3	1.59(2.09)	1.42(1.54)	0.76(0.09)	2.04(3.71)
W4	1.86(2.98)	1.46(1.97)	0.98(0.5)	2.42(5.45)
SEm±	0.08	0.18	0.16	0.12
CD (p=0.05)	0.24	0.57	0.51	0.38
C x W	0.52	NS	NS	0.8

(a)



(b)

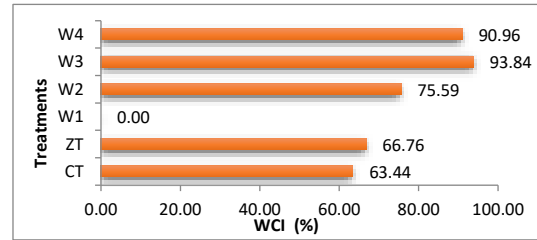


Fig 53. Weed control efficiency (a) and weed control index (b) of greengram under rice-chickpea-greengram system

Crop growth and yield parameters in greengram under rice-chickpea-greengram system

Between the crop establishment methods, all growth and yield parameters like plant height, plant biomass, branches/plant, pods/plant, pod length, seeds/pod and test weight were higher with the CT-CT-CT system but comparable to the ZTR-ZTR-ZTR system (Table 28).

Among weed management practices, all the growth parameters, viz. plant height, plant biomass and branches/plant were recorded highest with IWM and followed by herbicide rotation and recommended herbicides. The lowest growth parameters were recorded with weedy check plots. Like growth parameters, yield parameters were recorded highest with IWM followed by herbicide rotation and recommended herbicide. The lowest yield parameters were recorded with weedy check. The interaction between crop establishment methods and weed management practices was found to be non-significant for plant biomass, seeds/pod and test weight. However, it was found significant for plant height, branches/plant, pods/plant and pod length.

Table 28: Effect of crop establishment methods and weed management practices on growth parameters and yield attributes of green gram under rice-chickpea-green gram cropping system

Treatment	Growth parameters			Yield attributes			
	Plant height (cm)	Plant biomass (g/plant)	Branches/plant	No of pods/plant	Pod length	Seeds /pod	Test weight (g)
<i>Crop establishment methods (C)</i>							
CT-CT-CT	54.95	11.84	4.64	38.33	9.96	11.04	37.55
ZT+R- ZT+R- ZT+R	52.67	10.69	3.87	35.04	9.68	10.92	36.52
SEm±	0.86	0.26	0.27	0.78	0.25	0.41	1.38
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
<i>Weed management practices (W)</i>							
W1	42.66	9.70	2.91	22.17	7.95	9.28	35.40
W2	52.99	10.95	3.74	36.83	9.28	10.75	36.36
W3	60.29	12.46	5.32	44.42	11.46	12.22	38.49
W4	59.31	11.96	5.07	43.33	10.61	11.67	37.89
SEm±	0.73	0.44	0.19	0.68	0.16	0.65	1.29
CD (p=0.05)	2.27	1.36	0.54	2.14	0.51	2.04	NS
C x W	4.93	NS	1.28	4.58	1.28	NS	NS

Seed and haulm yield of greengram

Between the crop establishment methods, the greengram yields (seed, haulm and biological yield) were statistically similar and recorded a higher value with the ZTR-ZTR-ZTR system. The highest seed yield (986.92 kg/ha), haulm yield (2204.56 kg/ha) and biological yield (3191.49 kg/ha) were recorded with the ZTR-ZTR-ZTR system. This might be due to the fact that the ZTR system has developed better growth parameters and accumulated more yield attributing characters, resulting in higher seed yield under the ZT system (Table 29). Among weed management practices, weedy check has the lowest seed, haulm and biological yields (480.98, 1192.79 and 1673.78 kg/ha, respectively). The highest crop yields were obtained under IWM (1299.25, 2818.16 and 4117.41 kg/ha, respectively) followed by herbicide rotation and recommended herbicides. The harvest index was recorded at its highest with IWM followed by herbicide rotation and recommended herbicides. The interaction between crop establishment methods and weed management practices was found to be non-significant for crop yields and harvest index.

Table 29: Effect of crop establishment methods and weed management practices on yield of greengram under rice-chickpea-greengram cropping system

Treatment	Seed yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)	HI (%)
Crop establishment method (C)				
CT-CT-CT	965.29	2195.32	3160.61	30.23
ZT+R-ZT+R-ZT+R	986.92	2204.56	3191.49	30.56
SEm±	12.98	42.13	48	0.42
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	480.98	1192.79	1673.78	28.68
W2	911.28	2106.73	3018.02	30.17
W3	1299.25	2818.16	4117.41	31.59
W4	1212.91	2682.08	3894.99	31.14
SEm±	41.55	97.6	128.04	0.68
CD (p=0.05)	129.47	304.07	398.9	2.14
C x W	NS	NS	NS	NS

Maize-2024

Relative density and biomass of weeds in maize under maize-wheat-greengram system

The maize field was severely infested with a wide range of weeds. At 60 DAS, the relative density of weeds indicated that *Dinebra retroflexa* (46.14%), *Echinochloa colona* (24.42%), *Cyperus rotundus* (17.93%) and *Alternanthera sessilis* (5.47%) were the major weeds. With the progress of time, the weed-like *Digitaria sanguinalis*, *Cynodon dactylon*, *Alternanthera sessilis*, *Phyllanthus urinaria* and *Convolvulus arvensis* became other weeds. Likewise, relative weed biomass followed a similar trend, *Dinebraret roflexa* (48.07%), *Echinochloa colona* (25.92%), *Cyprus rotundus*, (14.38%), *Alternanthera sessilis* (6.45%), *Phyllanthus urinaria* (2.60%), *Digitaria sanguinalis* (2.20%) and *Cynodon dactylon* (0.92%) as the dominant weeds, apart from these other weeds were minor at 60 DAS (Fig 57 a & b).

a)

b)

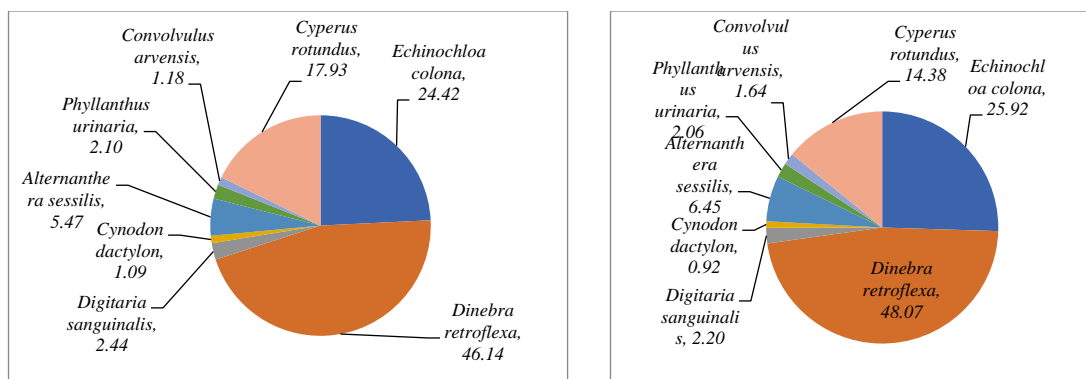


Fig 57. Relative weed density and biomass at 60 DAS in maize under maize-wheat/chickpea-greengram cropping system

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

At 60 DAS, under crop establishment methods, the total weed density and biomass were recorded as higher in CT-CT-CT (75.75 no./m² and 178.17 g/m², respectively). The weed density and biomass of *Echinochloa colona*, *Alternanthera sessilis*, *Phyllanthus urinaria*, *Convolvulus arvensis*, *Cyperus rotundus* were higher in the CT system, whereas rest of the weeds were more with the ZTR system. Likewise, WCE was 3.42% more with ZTR-ZTR-ZTR system, whereas WCI was 4.05% better in ZTR-ZTR-ZTR over the CT-CT-CT (Fig 58). Among weed management practices, weedy check recorded the highest total weed density and biomass with 178.17 no./m² and 120.49 g/m², respectively and the lowest density and biomass in herbicide rotation (Atrazine + topramezone at 500+25.2 g/ha) followed by in IWM and recommended herbicide (Table 30 & 31). The WCE and WCI were highest with herbicide rotation (96.07% and 98.09%, respectively) followed by IWM and recommended herbicide over weedy check (Fig 58).

Table 30: Effect of crop establishment methods and weed management practices on density and biomass of different weed species on maize at 60 DAS under maize-wheat-greengram system

Treatment	<i>Echinochloa colona</i>	<i>Dinebra retroflexa</i>	<i>Digitaria sanguinalis</i>	<i>Cynodon dactylon</i>	<i>Alternanthera sessilis</i>	<i>Phyllanthus urinaria</i>	<i>Convolvulus arvensis</i>	<i>Cyperus rotundus</i>
Weed density (no./m²)								
Crop establishment methods (C)								
CT-CT-CT	4.07(19.50)	4.58(28.95)	1.19(1.20)	0.96(0.60)	2.24(5.40)	1.45(1.80)	1.44(1.65)	3.78(17.70)
ZTR-ZTR-ZTR	3.39(14.48)	4.67(29.78)	1.36(1.73)	1.32(1.43)	2.1(4.80)	1.29(1.35)	1.4(1.50)	3.6(15.53)
SEm±	0.13	0.24	0.15	0.11	0.05	0.01	0.09	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	0.08	NS	NS
Weed management practices (W)								
W1	6.62(43.50)	9.01(82.20)	2.19(4.35)	1.58(1.95)	3.17(9.75)	2.11(3.75)	1.68(2.10)	5.68(31.95)
W2	3.48(11.85)	4.91(23.70)	1.40(1.35)	1.18(1.20)	2.9(8.10)	1.39(1.50)	1.51(1.80)	4.77(22.20)
W3	1.63(10.05)	1.35(10.20)	0.71(0.15)	1.09(0)	1.22(1.50)	1.05(0.45)	0.88(0.30)	0.71(12.30)

W4	3.20(2.55)	3.24(1.35)	0.79(0)	0.71(0.9)	1.39(1.05)	0.94(0.60)	1.59(2.10)	3.60(0)
SEm±	0.21	0.31	0.10	0.19	0.22	0.18	0.18	0.07
CD (P=0.05)	0.68	0.99	0.33	NS	0.70	0.57	0.56	0.23
C x W	NS	NS	NS	NS	NS	NS	NS	NS
Weed biomass (g/m²)								
<i>Crop establishment methods (C)</i>								
CT-CT-CT	3.01(11.78)	3.45(18.00)	1(0.66)	0.86(0.35)	1.89(3.84)	1.12(0.94)	1.27(1.27)	2.44(7.42)
ZTR-ZTR-ZTR	2.50(8.51)	3.47(18.21)	1.09(0.93)	0.96(0.49)	1.76(3.26)	1.04(0.74)	1.23(1.13)	2.26(5.97)
SEm±	0.05	0.20	0.09	0.06	0.01	0.01	0.08	0.04
CD (P=0.05)	0.35	NS	NS	NS	0.04	NS	NS	NS
<i>Weed management practices (W)</i>								
W1	5.62(31.23)	7.58(57.92)	1.74(2.65)	1.24(1.11)	2.84(7.78)	1.72(2.48)	1.57(1.97)	4.21(17.32)
W2	2.35(5.10)	3.32(10.60)	0.99(0.49)	0.9(0.37)	2.33(4.96)	1.01(0.57)	1.3(1.32)	2.68(6.70)
W3	1.94(3.39)	1.96(3.42)	0.73(0.04)	0.71(0)	1.12(0.86)	0.79(0.14)	0.82(0.19)	1.8(2.74)
W4	1.12(0.86)	0.98(0.49)	0.71(0)	0.81(0.19)	1.02(0.6)	0.81(0.16)	1.29(1.31)	0.71(0)
SEm±	0.11	0.24	0.07	0.08	0.16	0.08	0.12	0.04
CD (P=0.05)	0.36	0.77	0.23	0.27	0.50	0.25	0.40	0.14
C x W	NS	NS	NS	NS	NS	NS	NS	0.29

W1: control (weedy check); W2: recommended herbicide (atrazine 1000 g/ha *fb* topramezone 25.2g/ha); W3: integrated weed management (atrazine + pendimethalin 500+500 g/ha *fb* hand weeding); W4: herbicide rotation (atrazine+topramezone at 500+25.2 g/ha)

Table 31: Effect of crop establishment methods and weed management practices on group wise weed density and biomass, and total weeds in maize at 60 DAS under maize-wheat-greengram system

Treatment	Total grassy weeds	Total broadleaved weeds	Sedges	Total weeds
Weed density (no./m²)				
<i>Crop establishment methods (C)</i>				
CT-CT-CT	10.81(50.50)	3.69(7.42)	3.78(17.83)	18.28(75.75)
ZTR-ZTR-ZTR	10.74(47.75)	3.40(6.33)	3.60(15.58)	17.73(69.67)
SEm±	0.57	0.04	0.08	0.66
CD (P=0.05)	NS	0.27	NS	NS
<i>Weed management practices (W)</i>				
W1	19.4(132.33)	5.29(13.83)	5.68(32.00)	30.38(178.17)
W2	10.97(38.50)	4.29(9.67)	4.77(22.33)	20.03(70.50)
W3	4.78(20.50)	2.27(2.17)	0.71(12.50)	7.75(35.17)
W4	7.94(5.17)	2.33(1.83)	3.6(0)	13.86(7.00)
SEm±	0.37	0.33	0.07	0.39
CD (P=0.05)	1.15	1.04	0.23	1.23
C x W	NS	NS	NS	NS

Weed biomass (g/m ²)				
<i>Crop establishment methods (C)</i>				
CT-CT-CT	8.32(30.79)	3.02(4.78)	2.44(7.42)	13.78(42.98)
ZTR-ZTR-ZTR	8.02(28.13)	2.80(4.00)	2.26(5.97)	13.08(38.1)
SEm±	0.35	0.02	0.04	0.36
CD (P=0.05)	NS	0.13	NS	NS
<i>Weed management practices (W)</i>				
W1	16.18(92.9)	4.56(10.26)	4.21(17.32)	24.94(120.49)
W2	7.55(16.56)	3.33(5.53)	2.68(6.70)	13.57(28.79)
W3	5.34(6.85)	1.91(0.99)	1.80(2.74)	9.05(10.58)
W4	3.62(1.54)	1.83(0.76)	0.71(0)	6.15(2.30)
SEm±	0.27	0.20	0.04	0.23
CD (P=0.05)	0.86	0.65	0.14	0.72
C x W	NS	NS	NS	NS

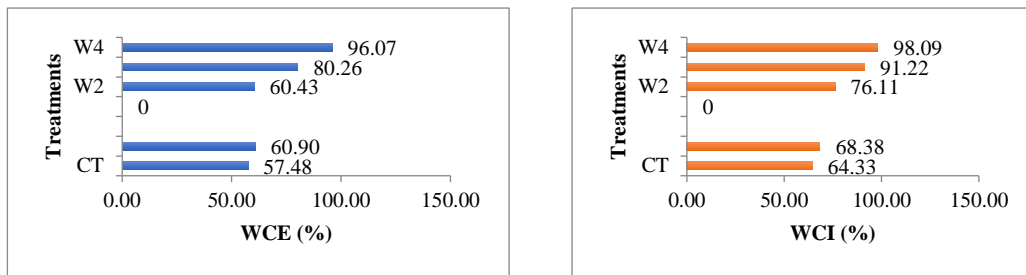


Fig 58. Weed control index (%) and weed control efficiency (%) as influenced by crop establishment methods and weed management practices in maize under maize-wheat-greengram system

Crop growth and yield parameters in maize under maize-wheat-greengram system

Between the crop establishment methods, all the growth and yield parameters were comparable between the systems except taller plant recorded in ZTR-ZTR-ZTR (Table 32). Among weed management practices, all the growth and yield parameters (plant height and plant biomass) and yield attributes (cobs/plant, row/cob, grains/row, cob length, cob weight and seed index) were highest with herbicide rotation followed by IWM and recommended herbicides. The lowest growth parameters were recorded with weedy check plots. The interaction between crop establishment methods and weed management practices was found to be non-significant for all the growth and yield parameters recorded during the experimentation.

Table 32: Effect of crop establishment methods and weed management practices on growth and yield parameters of maize under maize-wheat-greengram system

Treatment	Growth parameters		Yield attributes					
	Plant height (cm)	Plant biomass (g/plant)	Cob/plant	Row/cob	Grains/row	Cob length(cm)	Cob weight (g)	Seed index (g)
<i>Crop establishment methods (C)</i>								

CT-CT-CT	214.67	270.24	1.00	12.65	30.76	16.93	122.13	29.18
ZTR-ZTR-ZTR	223.97	285.90	1.00	13.30	32.82	17.24	135.13	30.15
SEm±	0.45	2.29		0.48	1.52	0.30	4.78	0.78
CD (P=0.05)	2.97	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)								
W1	196.64	207.71	1.00	10.36	21.77	14.76	89.55	27.42
W2	221.28	251.15	1.00	13.30	33.19	17.50	129.33	28.96
W3	228.55	304.88	1.00	13.84	35.57	17.92	142.04	30.72
W4	231.72	349.67	1.00	14.40	36.64	18.17	153.58	31.56
SEm±	2.51	2.17		0.60	1.07	0.53	9.43	0.94
CD (P=0.05)	7.79	6.71		1.87	3.34	1.66	29.38	2.94
C X W	NS	NS	NS	NS	NS	NS	NS	NS

Grain and stover yield of maize under maize-wheat-green gram system

Between the crop establishment methods, the grain, stover and biological yield were statistically comparable. However, the values of these parameters were more in the ZTR-ZTR-ZTR system (Table 33). Among weed management practices, weedy check has the lowest grain, straw, biological yield and harvest index (2293, 4425 and 6717 kg/ha, and 33.82%, respectively). The highest crop yields were obtained under herbicide rotation (7358, 7957 and 15314 kg/ha, and 48.06%, respectively) followed by IWM and recommended herbicides (Table 33). The interaction between crop establishment methods and weed management practices was found to be non-significant.

Table 33: Effect of crop establishment methods and weed management practices on yield in maize under maize-wheat-green gram system

Treatment	Grain yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)
Crop establishment methods (C)				
CT-CT-CT	5689	7577	13266	41.37
ZTR-ZTR-ZTR	5985	7916	13901	42.39
SEm±	118.57	524.79	413.64	1.72
CD (P=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	2293	4425	6717	33.82

W2	6529	9978	16507	39.87
W3	7170	8627	15796	45.77
W4	7358	7957	15314	48.06
SEm±	238.00	566.67	459.92	2.19
CD (P=0.05)	741.48	1765.43	1432.87	6.82
C X W	NS	NS	NS	NS

Relative density and biomass of weeds in maize under maize-chickpea-greengram system

The maize field was severely infested with a wide range of weeds. At 60 DAS, the relative density of weeds indicated that *Dinebra retroflexa* (44.90%), *Echinochloa colona* (21.88%), *Cyperus rotundus* (19.87%) and *Alternanthera sessilis* (5.35%) were the major weeds. With the progress of time, the weed-like *Phyllanthus urinaria*, *Cynodon dactylon*, *Digitaria sanguinalis* and *Convolvulus arvensis* became other weeds. Likewise, relative weed biomass followed a similar trend, *Dinebra retroflexa* (47.32%), *Echinochloa colona* (23.58%), *Cyperus rotundus* (15.99%) and *Alternanthera sessilis* (6.21%) as the dominant weeds, apart from these other weeds were minor at 60 DAS (Fig 59 a & b).

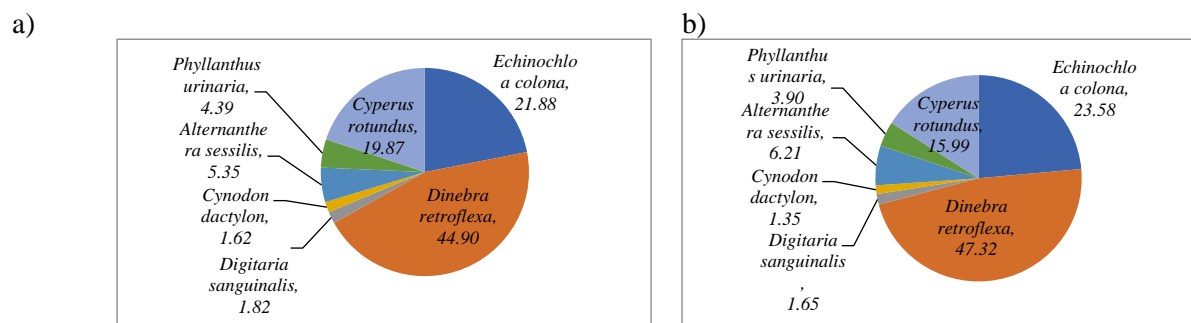


Fig 59. Relative weed density and biomass at 60 DAS in maize under maize-wheat-greengram cropping system

Weed density and biomass at 60 DAS in maize under maize-chickpea-greengram system

At 60 DAS, under crop establishment methods, the total weed density and biomass were recorded as higher in CT-CT-CT (65.75 no./m² and 35.53 g/m², respectively) but both were statistically comparable (Table 34 & 35). The weed density and biomass of *Echinochloa colona* was higher in the CT system, whereas rest of the grassy weeds were more with the ZTR system. The broadleaved weeds like *Alternanthera sessilis*, *Phyllanthus urinaria* and *Convolvulus arvensis* and sedges were more with CT system. Likewise, WCE was 0.17% more with ZTR-ZTR-ZTR system, whereas WCI was 1.16% better in ZTR-ZTR-ZTR over the CT-CT-CT (Fig 60). Among weed management practices, weedy check recorded the highest total weed density and biomass with 157.00 no./m² and 103.33 g/m², respectively and the lowest density and biomass of total weeds in herbicide rotation (atrazine+topramezone at 500+25.2 g/ha) followed by IWM and recommended herbicides. The WCE and WCI were highest with herbicide rotation (94.48% and 97.61%, respectively) followed by IWM and recommended herbicide over weedy check.

Table 34: Effect of crop establishment methods and weed management practices on weed density and biomass in maize under maize-chickpea-greengram system

Treatment	<i>Echinochloa colona</i>	<i>Dinebra retroflexa</i>	<i>Digitaria sanguinalis</i>	<i>Cynodon dactylon</i>	<i>Alternanthera sessilis</i>	<i>Phyllanthus urinaria</i>	<i>Convolvulus arvensis</i>	<i>Cyperus rotundus</i>
Weed density (no./m²)								
Crop establishment methods (C)								
CT-CT-CT	3.66(15.15)	4.18(23.18)	1.17(1.13)	1.02(0.75)	2.02(4.2)	2.02(4.2)	1.51(1.95)	3.64(16.65)
ZTR-ZTR-ZTR	3.24(12.75)	4.47(27.3)	1.19(1.13)	1.3(1.43)	1.9(3.75)	1.84(3.75)	1.51(1.8)	3.46(14.48)
SEm±	0.13	0.22	0.05	0.14	0.03	0.34	0.15	0.12
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)								
W1	5.87(34.35)	8.37(70.5)	1.84(2.85)	1.82(2.55)	2.95(8.4)	2.56(6.9)	1.71(2.55)	5.59(31.2)
W2	3.45(11.55)	4.67(21.3)	1.39(1.5)	1.18(1.2)	2.27(4.8)	1.9(3.6)	1.7(2.25)	4.58(20.55)
W3	2.88(7.8)	2.88(7.8)	0.71(0)	0.71(0)	1.51(1.8)	1.74(2.55)	1.04(0.6)	3.31(10.5)
W4	1.62(2.1)	1.36(1.35)	0.79(0.15)	1.04(0.6)	1.18(0.9)	1.83(2.85)	1.61(2.1)	0.71(0)
SEm±	0.24	0.30	0.14	0.14	0.24	0.39	0.18	0.18
CD (P=0.05)	0.75	0.95	0.43	0.45	0.75	NS	0.56	0.57
C X W	NS	NS	NS	NS	NS	NS	NS	NS
Weed biomass(g/m²)								
Crop establishment methods (C)								
CT-CT-CT	2.65(8.81)	3.14(14.4)	0.96(0.53)	0.9(0.42)	1.69(2.86)	1.4(1.75)	1.29(1.36)	2.31(6.76)
ZTR-ZTR-ZTR	2.37(7.38)	3.28(16.27)	0.98(0.59)	0.97(0.51)	1.58(2.51)	1.27(1.49)	1.28(1.28)	2.17(5.56)
SEm±	0.08	0.18	0.04	0.04	0.03	0.15	0.12	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)								
W1	4.95(24.36)	6.98(48.9)	1.46(1.71)	1.37(1.39)	2.61(6.42)	2.04(4.03)	1.57(2.15)	4.1(16.52)
W2	2.3(4.9)	3.11(9.23)	0.98(0.51)	0.89(0.35)	1.8(2.86)	1.24(1.16)	1.42(1.56)	2.54(5.99)
W3	1.7(2.43)	1.78(2.71)	0.71(0)	0.71(0)	1.19(0.99)	1.04(0.64)	0.89(0.36)	1.62(2.13)
W4	1.08(0.7)	0.98(0.48)	0.73(0.03)	0.77(0.12)	0.94(0.49)	1.02(0.65)	1.29(1.21)	0.71(0)
SEm±	0.16	0.22	0.07	0.04	0.16	0.20	0.13	0.12
CD (P=0.05)	0.52	0.69	0.22	0.15	0.52	0.64	0.42	0.37

C X W	NS	NS	NS	NS	NS	NS	NS	NS
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W1: control (weedy check); W2: recommended herbicide (atrazine 1000 g/ha *fb* topramezone 25.2 g/ha); W3: integrated weed management (atrazine + pendimethalin 500+500 g/ha *fb* hand weeding); W4: herbicide rotation (atrazine+topramezone at 500+25.2 g/ha)

Table 35: Effect of crop establishment methods and weed management practices on group wise weed density and biomass, and total weeds in maize at 60 DAS under maize-chickpea-greengram system

Treatment	Grassy weeds	BLWs	Sedges	Total weeds
Weed density (no./m²)				
<i>Crop establishment methods (C)</i>				
CT-CT-CT	10.03(40.58)	4.04(8.5)	3.64(16.67)	17.71(65.75)
ZTR-ZTR-ZTR	10.19(43.08)	3.74(7.67)	3.46(14.58)	17.4(65.33)
SEm±	0.18	0.31	0.12	0.60
CD (P=0.05)	NS	NS	NS	NS
<i>Weed management practices (W)</i>				
W1	17.88(110.67)	5.51(15.17)	5.59(31.17)	28.98(157.00)
W2	10.69(36.17)	4.17(8.5)	4.58(20.67)	19.43(65.33)
W3	4.04(15.83)	2.27(4.67)	3.34(10.67)	5.63(31.17)
W4	2.27(4.67)	2.12(4.00)	0.71(0)	3.03(8.67)
SEm±	0.48	0.38	0.18	0.63
CD (P=0.05)	1.51	1.18	0.57	1.96
C X W	NS	NS	NS	NS
Weed biomass (g/m²)				
<i>Crop establishment methods (C)</i>				
CT-CT-CT	4.97(24.16)	2.26(4.61)	2.69(6.76)	6.00(35.53)
ZTR-ZTR-ZTR	5.02(24.75)	2.12(4.01)	2.46(5.56)	5.90(34.32)
SEm±	0.10	0.12	0.08	0.31
CD (P=0.05)	NS	NS	NS	NS
<i>Weed management practices (W)</i>				
W1	14.77(76.36)	4.64(10.45)	4.1(16.52)	23.51(103.33)
W2	7.28(14.99)	3.04(4.02)	2.54(5.99)	12.86(25)
W3	2.37(5.14)	1.46(1.63)	1.62(2.13)	3.07(8.91)
W4	1.36(1.34)	1.28(1.13)	0.71(0.00)	1.72(2.47)
SEm±	0.27	0.21	0.12	0.35
CD (P=0.05)	0.85	0.67	0.37	1.11
C X W	NS	NS	NS	NS

* BLW means Broad Leaved Weeds

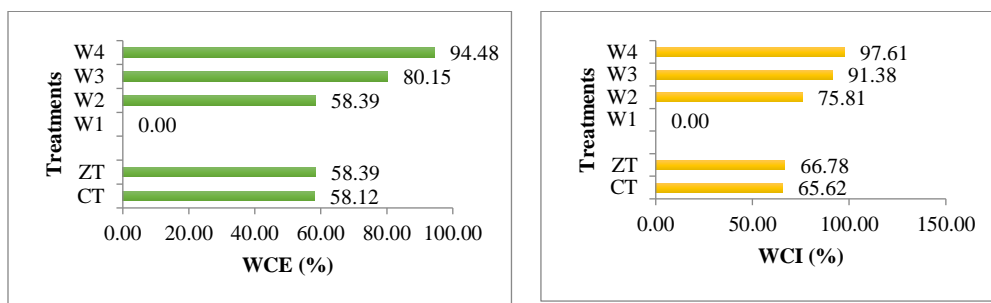


Fig 60. Weed control index (%) and weed control efficiency (%) as influenced by crop establishment methods and weed management practices in maize under maize-chickpea-greengram system

Crop growth and yield parameters in maize under maize-chickpea-greengram system

Between the crop establishment methods, all the growth and yield parameters were comparable between the systems except plant height (Table 36). Among weed management practices, all the growth and yield parameters (plant height and plant biomass) and yield attributes (cobs/plant, row/cob, grains/row, cob length, cob weight and seed index) were highest with herbicide rotation followed by IWM and recommended herbicides. The lowest growth parameters were recorded with weedy check plots. The interaction between crop establishment methods and weed management practices was found to be non-significant for all the growth and yield parameters.

Table 36: Effect of crop establishment methods and weed management practices on growth and yield parameters of maize under maize-chickpea-greengram system

Treatment	Growth parameters		Yield parameters					
	Plant height (cm)	Plant biomass (g/plant)	Cob/plant	Row/cob	Grains/row	Cob length(cm)	Cob weight (g)	Seed index (g)
<i>Crop establishment methods (C)</i>								
CT-CT-CT	217.34	277.52	1.00	13.74	32.00	17.20	122.31	29.62
ZTR-ZTR-ZTR	227.58	293.30	1.00	14.70	34.31	17.54	132.83	30.22
SEm±	0.55	2.60		0.23	1.47	0.21	5.25	2.49
CD (P=0.05)	3.45	NS	NS	NS	NS	NS	NS	NS
<i>Weed management practices (W)</i>								
W1	198.97	2013.25	1.00	12.61	30.03	15.67	106.40	28.22
W2	223.37	258.46	1.00	14.34	32.90	17.55	130.87	29.69
W3	233.85	3013.45	1.00	14.75	34.40	17.99	135.18	30.67
W4	234.60	359.27	1.00	15.19	35.29	18.28	137.83	31.11
SEm±	2.95	2.09		0.62	2.67	0.30	16.40	1.57
CD (P=0.05)	9.08	6.53	NS	NS	NS	0.95	NS	NS
C X W	NS	NS	NS	NS	NS	NS	NS	NS

Grain and straw yield of maize under maize-chickpea-greengram system

Between the crop establishment methods, the grain, stover, biological yield and harvest index were statistically comparable. However, the values of these parameters were more in the ZTR-ZTR-ZTR system (Table 37). Among weed management practices, weedy check has the lowest grain, stover, biological yield and harvest index (2546, 4707 and 7252 kg/ha, and 34.83%, respectively). The highest crop yields were obtained under herbicide rotation (7489, 7918 and 15407 kg/ha, and 48.63%, respectively) followed by IWM and recommended herbicides (Table 37). The interaction between crop establishment methods and weed management practices was found to be non-significant.

Table 37: Effect of crop establishment methods and weed management practices on yield in maize under maize-chickpea-greengram system

Treatment	Grain yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)
<i>Crop establishment methods (C)</i>				
CT-CT-CT	5967	7722	13689	42.23
ZTR-ZTR-ZTR	6226	8134	14359	42.54

SEm±	118.74	39.79	153.89	0.54
CD (P=0.05)	NS	260.70	NS	NS
Weed management practices (W)				
W1	2546	4707	7252	34.83
W2	7007	10401	17407	40.24
W3	7345	8686	16031	45.85
W4	7489	7918	15407	48.63
SEm±	213.54	326.85	482.83	0.71
CD (P=0.05)	665.27	1018.30	1504.24	2.22
C X W	NS	NS	NS	NS

CRRI

Evaluation of tillage practices on the performance of Herbicide tolerant rice (HTR) vis-a-vis popular cultivar

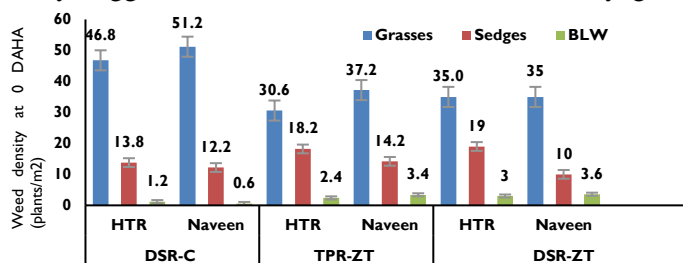
The most significant obstacle to the popularization of CA practices is the problem of weed management. In CA, weeds can cause significant losses in terms of yield and costs if timely management is not implemented. It is hypothesized that herbicide-tolerant rice (HTR) may help reduce weed management costs without affecting the yield. An experiment was conducted to evaluate the Herbicide tolerant rice, HTR-Naveen variety, under CA practices and compare its performance with popular cultivar “Naveen”. The main plot treatments comprised of three establishment methods under CA viz., (1) zero tillage direct seeded rice (ZT-DSR) (2) zero tillage mechanical transplanted (ZT-TPR), and (3) conventional tillage DSR (CT-DSR). The sub-plot consisted of rice variety “Naveen” and HTR i.e. “HTR-Naveen”. Imazethapyr was applied @ 100 g a.i. ha⁻¹ in HTR- Naveen variety, whereas in Naveen variety, fenoxaprop-p-ethyl+ehoxysulfuron was applied @ 100 g a.i. ha⁻¹+25 g a.i. ha⁻¹.

Weed flora

Weed infestation is the single most important factor that affect the outcome of CA practices. Different tillage practices recorded differences in appearance of weed. In DSR plots, the predominant grass weeds were *Echinochloa colona*, *Echinochloa crus-galli*, *Digitaria snaguinallis* and *Eleusine indica*. Among the sedges, *Cyperus difformis* and *Fimbristylis miliacea* were the most predominant weeds. DSR plots recorded broad leaf weeds viz., *Alternanathera philoxeroids*, *Alternanthera paronychioides*, *Digera arvensis* and *Aeschenomene indica*. In ZT-TPR, *Sphenochlea zeylanica*, *Paspalum distichum*, *Panicum repens* were the other grass weeds apart from the above-mentioned weeds. Among the broad leaf weed, *Ludwigia octovalvis* and *Ipomea aquatica* recorded their presence in addition to *Alternanathera philoxeroids*, *Alternanthera paronychioides*, *Digera arvensis* and *Aeschenomene indica*.

Weed density

Data on weed density suggests that weed flora was dominated by grassy weeds across the treatments.



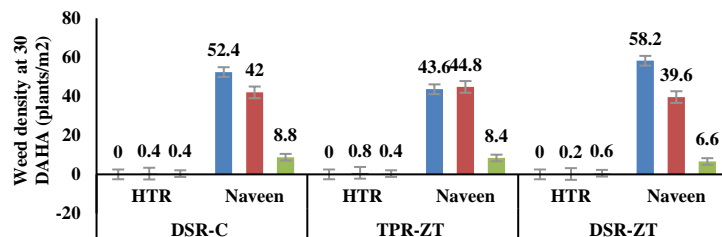


Fig 61. Weed density (plants m⁻²) at 0 days after herbicide application (DAHA) and 30 DAHA. Post emergence herbicide was applied 15 days after emergence (DAE) in DSR and 15 days after transplanting (DAT) in TPR.

The tillage practices in the main plot had a remarkable impact on the weed density. The grassy weed densities in conventional tillage were 44.5 and 40.0% higher than that of ZT-TPR and ZT-DSR, respectively. However, the sedge and broad leaf populations were higher ZT plots. This indicates that tillage operation helps in germination of weeds whereas it is suppressed in zero tillage. On application of herbicide, i.e. Imazethapyr in HTR-Naveen, and fenoxaprop-p-ethyl+ethoxysulfuron in Naveen varieties had significant effect on the weed population which was evident from the data collected at 30 days after herbicide application (DAHA).

Imazethapyr had a prolonged effect on weed suppression compared to herbicide mix of fenoxaprop-p-ethyl+ethoxysulfuron. Grassy weeds were completely controlled (100%) in HTR-Naveen with Imazethapyr application, whereas, the grassy weed density was 2%, 17% and 67% higher in C-DSR, ZT-DSR and ZT-TPR, respectively at 30 DAHA with fenoxaprop-p-ethyl+ethoxysulfuron plots indicating a very short-term effect. Similarly, application of Imazethapyr also suppresses >95% sedges and >65% of Broad-leaved weed.

Table 38: Percent weed suppression at 30 DAHA as influenced by tillage practices, varieties and herbicide application. Fenoxaprop-p-ethyl+ethoxysulfuron was applied in Naveen variety, whereas, imazethapyr was applied in HTR-Naveen to control weeds.

	% Weed suppression in HTR-Naveen with Imazethapyr application		
	DSR-CT	TPR-ZT	DSR-ZT
Grass	100	97.10	66.66
Sedge	100	95.60	83.33
Broad leaved weed	100	98.94	80.00

Yield and yield attributes

Crop data at harvest non-significant difference in plant height between the treatments. Though non-significant, Naveen HTR recorded higher plant height (126.8 cm) compared to Naveen (122.1 cm). The number of panicles per m² was affected by the tillage practices as well as the varieties. Non- puddled ZT-TPR recorded maximum number of panicles (363/ m²) whereas conventional DSR recorded the lowest number of panicles (337/ m²). among the varieties, Naveen HTR recorded significantly higher number of panicles (359/ m²) than Naveen (341/ m²). The

tillage practices had no significant impact on the number of grains per panicle, however, among the varieties, Naveen HTR recorded significantly higher number of grains per panicle (157) than Naveen (149). 100 grain weight was not affected either by tillage practices of variety.

Table 39: Plant height (cm), number of panicles/ m², number of grains/ panicles, 1000 grain weight (g) as influenced by tillage practices and weed management

Main plot (Tillage practice)	Plant height (cm)	Number of panicles/ m ²	No. of grains/ panicle	1000 Grain weight (g)
DSR-C	124.5	337	151	20.39
TPR-ZT	123.8	363	163	20.35
DSR-ZT	125.1	350	146	20.35
Sub plot (Varieties with different weed management practices)				
Naveen HTR	126.8	359	157	20.37
Naveen	122.1	341	149	20.35
CD (p≤0.5)				
Main-plot	NS	5.34	NS	NS
Sub-plot	NS	7.65	6.05	NS
Sub-plot at same level of main plot	NS	NS	NS	NS
Main-plot at same level of sub plot	NS	NS	NS	NS

In terms of grain yield, Naveen HTR recorded higher yield (5.16 t/ha) than Naveen (4.50), however the difference was statistically non-significant. Non puddled ZT-TPR recorded significantly higher yields and the DSR both conventional-DSR and ZT-DSR. The higher yield in ZT-TPR may be attributed to higher number of grains and higher number of panicles. About 13% high yield of HTR was recorded in ZT-TPR, whereas, grain yield of HTR was 15.6% higher in ZT-DSR compared to Naveen. Among the Tillage practices the grain yield followed the order: ZT-TPR > ZT-DSR > DSR-C.

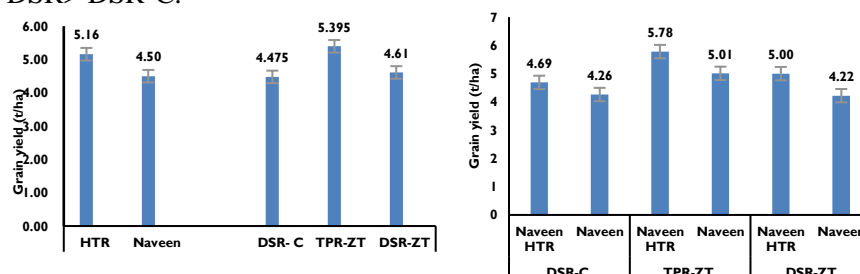


Fig 62. Grain yield of Naveen and Naveen-HTR under different tillage practices

Standardization of management practices for herbicide tolerance rice in double zero tillage rice

Weed control is the biggest hindrance in the cultivation of DSR as well as zero tillage. The problem is huge when DSR is combined with ZT. It is hypothesized that herbicide tolerant rice (HTR) can play a big role in addressing the issue. Therefore, we conducted an experiment to standardize the herbicide (Imazethapyr) application schedule and compare its performance with hand weeding and pendimethalin application. We also wanted to know whether application of pre-emergence herbicide (Pendimethalin) had an added effect on weed suppression and yield. Similar experiments conducted in previous years revealed that application of Imazethapyr at 15 and 21 DAE recorded weed suppression at par. Therefore, for this year we modified a treatment slightly to comprehend if the window of application of imazethapyr can be extended further. For this we conducted the experiment with 10 treatments viz., Pendimethalin @ 1000g a.i./ha (T1), Pendimethalin @ 1000g a.i./ha + Imazethapyr @ 100g a.i./ha at 15 DAE (T2), Pendimethalin @ 1000g a.i./ha + Imazethapyr @ 100g a.i./ha at 25 DAE (T3), Pendimethalin @ 1000g a.i./ha + Imazethapyr @ 100g a.i./ha at 35 DAE (T4), Imazethapyr @ 100g a.i./ha at 15 DAE (T5), Imazethapyr @ 100g a.i./ha at 25 DAE (T6), Imazethapyr @ 100g a.i./ha at 35 DAE (T7), Hand weeding at 15 and 30 DAE (T8), Weed free (T9), Weedy (T10). The experiment was conducted in RBD with three replications. The variety used for the experiment was Sahabhazi Dhan-HTR and its performance in zero tillage was compared with conventional tillage.

Effect of treatments on weed

There was significant difference in weed biomass due to scheduling of Imazethapyr on different DAE. Among the herbicide treated plots, sole application of Pendimethalin recorded the highest weed biomass and Imazethapyr application at 15 DAE recorded the lowest biomass. Application of Imazethapyr applied at 15 DAE and 25 DAE recorded weed biomass at par with or without Pendimethalin application. Imazethapyr application at 35 DAE recorded significantly higher weed biomass compared to its application at 15 and 25 DAE. It may be noted that hand weeding at 15 and 30 DAE recorded significantly lower weed biomass than all the herbicide treated plots.

WCE was significantly affected by herbicide scheduling. Imazethapyr applied at 15 & 25 DAE, and hand weeding at 15 & 30 DAE recorded significantly higher WCE compared to 35 DAE application of Imazethapyr and pre-emergence application of pendimethalin.

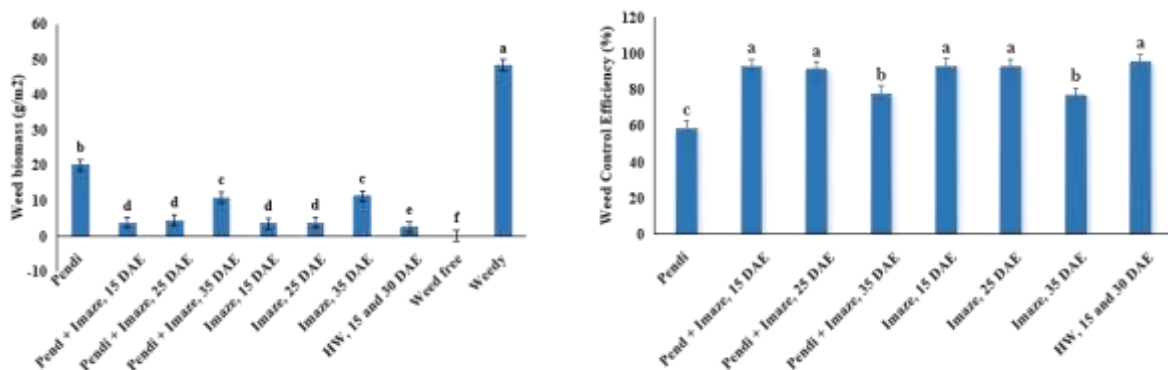


Fig 63. Weed dry weed weight (g m⁻²) at 30 DAHA as influenced by tillage practices, varieties and herbicide application. The CD value for weed biomass was 0.254 (based on square root transformation) and 8.40 for WCE (%).

Yield attributes and yield

The data on yield attributes and yield revealed that there was significant difference between the treatments due to scheduling of Imazethapyr on different DAE. Imazethapyr application at 15 & 25 DAE (T2, T3, T5 and T6) and hand weeding (T8) recorded plant height at harvest at par with the weed free check (T9). However, late application at 35 DAE (T4 and T7) recorded plant height similar to sole application of pendimethalin (T1) which was significantly lower than 15 and 25 DAE. Number of panicles per m² showed a similar trend among the treatments. Yield attributes viz., number of grains per panicle and 1000 grain weight did not differ significantly among the treatments. The grain yield was significantly affected by herbicide scheduling. The highest grain yield was recorded in weed free plot (T9) which was at par with T2, T3 and T5. Late application of Imazethapyr at 35 DAE (T4 and T7) recorded grain yield at par with pendimethalin application (T1) and was significantly lower than 15 DAE (T2 and T5) and 25 DAE (T3 and T6). The results suggest that 15 DAE to 25 DAE is optimum for Imazethapyr application when prior pre-emergence pendimethalin have already been applied. However, with sole Imazethapyr application, yield decline is evident at 25 DAE. The result signifies the importance of appropriate herbicide scheduling for reaping maximum benefit from HTR under zero tillage condition.

Table 40: Effect of herbicide application treatments on rice growth and yield at harvest

Treatment	Plant height (cm)	No.of panicles/ m ²	No. of grains per panicle	1000 grain weight (g)	Grain yield (t/ha)
T1	97.43	245.33	145.00	20.38	3.91
T2	106.57	321.33	157.33	20.39	4.91
T3	105.90	300.67	159.33	20.37	4.61
T4	100.87	264.67	146.67	20.32	3.69
T5	109.23	311.67	151.00	20.36	4.87
T6	108.57	303.00	140.00	20.33	4.43
T7	99.00	262.67	146.00	20.32	3.72
T8	107.73	290.33	154.33	20.31	4.21
T9	110.53	341.67	159.33	20.29	4.94
T10	88.00	167.00	134.00	20.62	1.20
C.D.	6.114	58.794	N/A	N/A	0.449

SE(m)	2.042	19.636	6.052	0.853	0.150
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Pendimethalin @ 1000g a.i./ha (T1), Pendimethalin @ 1000g a.i./ha + Imazethapyr @ 100g a.i./ha at 15 DAE (T2), Pendimethalin @ 1000g a.i./ha + Imazethapyr @ 100g a.i./ha at 25 DAE (T3), Pendimethalin @ 1000g a.i./ha + Imazethapyr @ 100g a.i./ha at 35 DAE (T4), Imazethapyr @ 100g a.i./ha at 15 DAE (T5), Imazethapyr @ 100g a.i./ha at 25 DAE (T6), Imazethapyr @ 100g a.i./ha at 35 DAE (T7), Hand weeding at 15 and 30 DAE (T8), Weed free (T9), Weedy (T10)

C. Water Management Practices in Conservation Agriculture

Rice Wheat Cropping System

CSSRI

Micro-irrigation methods

Rice crop during *kharif* 2024

Data presented in Fig 64 represents a comparison of different irrigation systems used in the rice crop during Kharif 2024. The results of micro-irrigation and surface irrigation systems are discussed below.

a) Surface irrigation in rice crop

DSR with reduced tillage under surface irrigation method (SIS-RTDSR) produced grain yield of 5.28 t ha⁻¹. Grain yield in DSR under surface irrigation method (SIS-RTDSR) was 22.97% lower than conventional PTR and 4.68-6.39 % higher compared to different micro sprinkler irrigation method.



Plate 20. Sprinkler irrigation in zero tillage direct seeded rice

b) Mini sprinkler irrigation system in rice crop

Results on irrigation system through mini sprinkler irrigation system showed that 4.94 and 4.71 t ha⁻¹ grain yield was obtained in DSR with reduce tillage (RTDSR) and RTDSR with 33% wheat residue incorporation (RTDSR+RI) during *kharif* 2024. During 2024, 27.89 and 31.27% lower yield of DSR was reported in RTDSR and RTDSR+RI, respectively under mini sprinkler irrigation system as compared to PTR (6.86 t ha⁻¹).



Plate 21. Drip irrigation in reduce tillage direct seeded rice

c) Drip irrigation system in rice crop

During *kharif* 2024, 5.34 t ha⁻¹ rice yield was reported under drip irrigation system with DSR in reduced tillage (DRIP-RTDSR) (Fig 64). Rice yield under DRIP-RTDSR was 22.06% lower than the conventional PTR (6.86 t ha⁻¹). Whereas, it was 1.17 % higher than the RTDSR under surface irrigation system (SIS-RTDSR; 5.28 t ha⁻¹).

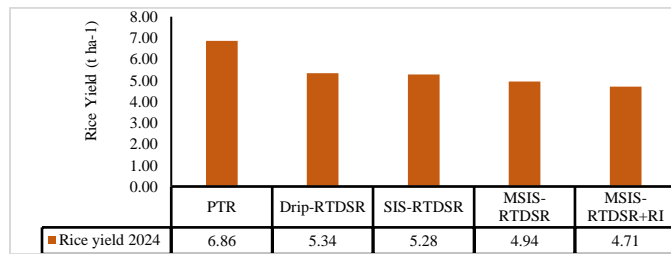


Fig 64. Effects of different micro-irrigation methods, tillage and crop residue management on rice grain yield during *kharif* 2024.

(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)

Wheat crop during *rabi* 2023-24

Figure 10 illustrates the outcomes of the wheat crop grown under zero tillage with rice residue mulch (ZTW+RM) using micro-irrigation methods (drip and mini sprinkler) during rabi season (2023–24). The findings are presented below:



Plate 22. Drip irrigation in Zero tillage wheat

a) Drip irrigation system in wheat

The grain yield of zero tilled wheat under drip irrigation (DRIP-ZTW+RM) was 5.05 t ha^{-1} , which was 16.09 % higher in comparison to CTW (4.35 t ha^{-1}) and 1.0 % higher in comparison to surface irrigation system in wheat with 100% rice residue mulch (SIS-ZTW+RM; 5.00 t ha^{-1}) (Figure 10).

b) Surface irrigation system in wheat

Surface irrigation system in wheat with 100% rice residue mulch (SIS-ZTW+RM) produced grain yield of 5.00 t ha^{-1} (Figure 10). Grain yield in SIS-ZTW+RM was 14.94% higher to that of CTW (4.35 t ha^{-1}), whereas lowest among the different micro irrigation applied (16.09-18.25%). 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.



Plate 23. Sprinkler irrigation in Zero tillage wheat

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 5.14 t ha⁻¹ (T9) to 5.08 t ha⁻¹ (T10) which was 18.25 % and 16.81 % higher in comparison to conventional tilled wheat (CTW; 4.35 t ha⁻¹) (Fig 65). Thus, the mini-sprinkler method may be feasible for wheat production. 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; 5.00 t ha⁻¹), which was about 2.79 and 1.60 % higher, respectively.

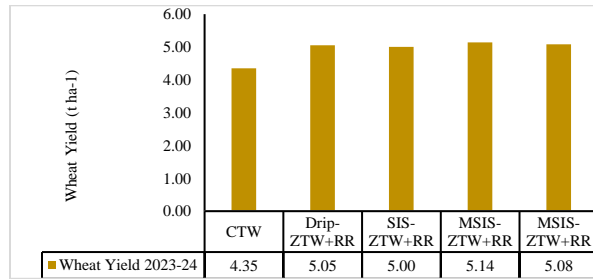


Fig 65. Effects of different micro-irrigation methods, tillage and crop residue management on wheat grain yield during rabi 2023-2024.

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

Rice-Wheat Cropping System during 2023-24

a) DRIP-RTDSR/ZTW+RM

Drip irrigation system with DSR in reduced tillage/ zero tilled wheat under drip irrigation (DRIP-RTDSR/ZTW+RM) produced grain yield of 10.39 t ha⁻¹ which was 7.25% lower than PTR/CTW (11.21 t ha⁻¹) (Fig 66).

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 10.28 t ha⁻¹ (Fig 66). Grain yield in SIS-RTDSR/SIS-ZTW+RM was 8.25% lower than PTR/CTW.

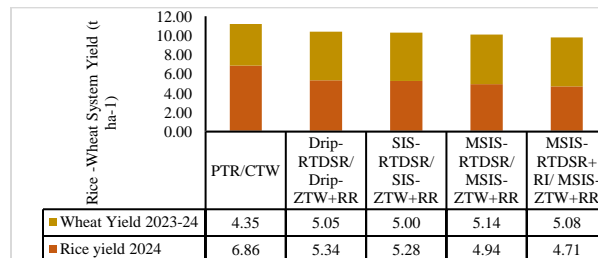


Fig 66. Effects of micro-irrigation methods, tillage and crop residue management on rice-wheat cropping system grain yield during 2023-24.

(**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).

c) MSIS-RTDSR+RI/ZTW+RM

Results on irrigation system through mini sprinkler irrigation system showed that 10.09 and 9.79 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 (Figure 11). During 2023-24, a decrease of 9.98 and 12.60% was reported in MSIS-RTDSR/MSIS-ZTW+RM and MSIS-RTDSR+RI/MSIS-ZTW+RM in comparison to PTR/CTW (11.21 t ha⁻¹).

D. Effect of Machinery in Conservation Agriculture

CIAE

Developed CA Machines such as slit-till drill, mulcher-cum-seeder and conservation seeder were tested for direct sowing of moong, maize and wheat crop at institute field for comparative performance with happy seeder. Table 41 represents the general specifications of machines that were used.

Table 41: General specifications of the machines

Specification	Happy seeder	Mulcher cum seeder	Slit-till-drill	Conservation Seeder
No. of rows	10	09	10	06
Effective width, mm	2250	2025	2500	1750
Row to row distance, mm	225	225	250	250
HP required range, hp	60	50-55	45	45
Operational speed, Km/h	3.5	3.0	2.5	2.5
Fuel consumption, l/h	4.5	4.0	3.5	3.5
Field capacity, ha/h	0.86	0.61	0.62	0.56
Seed rate (Wheat), kg/ha	100	100	100	100
Depth of sowing, mm	35-50	40-50	40-50	40-50
Operational cost, Rs./h	988.00	899.43	717.16	1017.15
Machine cost Rs.	144000/-	130000/-	135000/-	150000/-

Validation of location specific CA machinery for wheat crop

Wheat crop (HI-1544) was sown in the experimental field on 24th October, 2024 with different machines (plate 24). The seed rate applied was 120 kg. ha⁻¹ and depth of sowing was 50 mm (plate 25). Basal dose of fertilizer at the rate of di-ammonium phosphate (130 kg. ha⁻¹) and

muriate of potash (67 kg ha⁻¹) was applied during sowing. As per recommendation remaining of nitrogen was applied by two dressing of urea, each at the rate of 208 kg. ha⁻¹. Five irrigations were applied during different growth stage of the wheat crop.



Slit-till drill

Mulcher-cum-seeder

Conservation seeder

Turbo happy seeder

Plate 24. Field experiment with four machines

The observation of crop parameters (germination, spike length, 1000 test weight, number of effective tillers, plant height, harvest index, grain, straw and biomass yield,) were recorded for all the equipment as given in Table 42. Seed germination counts were taken at 15 days after sowing. The number of tillers per plant were counted 45 days after sowing. Plant counts and number of tillers were taken by marking one m² of sown area at five random places. The heights of ten randomly selected plants in a plot were measured with a meter scale (range: 0-1000 mm) at the maturity of crop. Samples for grain and biomass yields were collected from five randomly selected field locations in each treatment with the help of one square meter wooden frame. The plants were cut and thresh separately. Various production found with different CA machineries are illustrated in plate 25.



Plate 25. Wheat crop plots

Table 42: Crop parameters and crop yield for wheat crop.

Machine	No. of plants/ m ²	Spike length, mm	No. of grain/ spike	Grain yield, kg/ha	Straw yield, kg/ha	1000 test wt. gm	Harvest index, %	Straw grain ratio
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Slit till drill (Avg.)	129.85	108.26	47.19	4515.94	6484.33	39.11	46.83	1.43
Mulcher cum seeder (Avg.)	118.42	101.37	46.18	4256.06	6731.72	35.71	45.22	1.58
Conservation seeder (Avg.)	121.37	102.19	46.32	4471.18	6504.57	38.23	45.87	1.45
Turbo happy seeder (Avg.)	115.68	100.09	44.38	4187.21	6749.29	36.95	44.07	1.61

The wheat crop was harvested with combine harvester.

Validation of location specific CA machinery for Moong crop

Moong crop (Variety PDM- 139) was sown on 21/04/2024 in D₅ plot of institute research farm after harvesting of wheat crop. The seed rate applied was 25 kg ha⁻¹ and depth of sowing was 50 mm (Plate 26). Basal dose of fertilizer at the rate of di-ammonium phosphate (130 kg ha⁻¹) and muriate of potash (67 kg ha⁻¹) was applied during sowing. As per recommendation remaining of nitrogen was applied by two dressing of urea, each at the rate of 10 kg ha⁻¹. The observation of crop parameters (germination, number of effective tillers, plant height, 1000 test weight, number of effective tillers, plant height, harvest index, grain, straw and biomass yield) were recorded for all the equipment as given in Table 43. Seed germination counts were taken at 15 days after sowing. The numbers of branches per plant were counted 45 days after sowing. Plant counts numbers of branch were taken by marking one plant of sown area at five random places. The heights of ten randomly selected plants in a plot were measured with a meter scale (range: 0-500 mm) at the maturity of crop. Various operations performed on assigned experimental field are presented in Plate 26. Samples for grain and biomass yields were collected from five randomly selected field locations in each treatment with the help of one m² wooden square frame. The plants were cut and thresh separately.



Plate 26. Green gram plot

Table 43: Crop parameters and crop yield for Moong crop

Machine	No. of plants/m ²	Plant height, mm	Pod length, mm	No. of pod/m ²	Grain yield/m ² (gm)	Straw yield/m ² (gm)	Harvest index, %	Straw grain ratio
Slit till drill (Avg.)	33.25	464.16	75.41	210.17	719.11	1754.19	40.99	2.44

Mulcher cum seeder (Avg.)	34.9	462.5	79.38	206.25	678.23	1697.56	39.95	2.50
Conservation seeder (Avg.)	30.18	455.83	76.25	198.05	667.63	1710.56	39.02	2.56
Turbo happy seeder (Avg.)	30.5	461.5	74.66	191.83	649.26	1685.67	38.51	2.60

The observation of crop parameters (germination, pod length, plant height, 1000 test weight, plant height, harvest index, grain, straw and biomass yield) were recorded for all the equipment as given in Table 44. Seed germination counts were taken at 15 days after sowing. The numbers of branches per plant were counted 45 days after sowing. Plant counts numbers of branch were taken by marking one plant of sown area at five random places. The heights of ten randomly selected plants in a plot were measured with a meter scale (range: 0-500 mm) at the maturity of crop. Samples for grain and biomass yields were collected from five randomly selected field locations in each treatment with the help of one m² wooden square frame. The plants were cut and thresh separately.

Validation of location specific CA machinery for maize crop

Maize crop (Variety Nath Samrat- 1144) was sown on 05/07/2024 in D₅ plot of institute research farm after harvesting of moong crop. The seed rate applied was 65 kg ha⁻¹ and depth of sowing was 50 mm. Basal dose of fertilizer at the rate of di-ammonium phosphate (130 kg ha⁻¹) and muriate of potash (67 kg ha⁻¹) was applied during sowing. As per recommendation remaining of nitrogen was applied by two dressing of urea, each at the rate of 10 kg ha⁻¹. Five irrigations were applied during different growth stage of the maize crop.

Table 44: Crop parameters and crop yield for Maize crop

Machine	Plant heights, cm	Average number of cobs /m²	Cob weight, g	Grain yield, kg/ha	Straw Yield, kg/ha
Slit till drill (Avg.)	212.75	13.63	275.12	2352.74	11410
Mulcher cum seeder (Avg.)	211.54	12.58	268.15	2142.25	11360
Conservation seeder (Avg.)	211.33	12.92	270.23	2295.17	11357
Turbo Happy seeder (Avg.)	212.13	12.08	266.74	2105.41	11570

The observation of crop parameters (plant height, average number of cobs/m², cob weight, grain yield and straw yield) were recorded for all the equipment as given in Table 44. Seed germination counts were taken at 15 days after sowing. Plant counts numbers of branch were taken by marking one plant of sown area at five random places. The heights of ten randomly selected plants in a plot were measured with a meter scale (range: 0-500 mm) at the maturity of crop. Samples for grain and straw yields were collected from five randomly selected field

locations in each treatment with the help of one m² wooden square frame. Various operations performed on assigned experimental field are presented in plate 27.





			
Slit-till drill	Mulcher-cum-seeder	Conservation seeder	Turbo Happy Seeder
Plate 27. Field experiment with four machines			



Plate 28. Maize crop plots

Rainfed Ecosystem / Dryland Ecosystem

A. Tillage and Residue management in Conservation Agriculture

IISS

Soybean-Wheat Cropping Systems

Weed Fresh Biomass (g/m²) in wheat crop

The table 45 presents the mean values of weed fresh biomass at three different growth stages 30 days after sowing (30 DAS), 60 DAS, and 90 DAS under different treatments involving Factor A (Tillage and Crop Residue Management) and Factor B (Nutrient Management). At 30 and 60 days after sowing there were no significant variation observed among various tillage treatments. However, it was observed significant at 90 days after sowing in wheat crop. The maximum weed biomass recorded at 60 DAS thereafter it decreased with the progression of crop stage towards maturity. At all the growth stages lowest value associated with conventional tillage treatment. At 90 DAS no tillage treatments recorded with maximum values of fresh weed biomass followed by reduced tillage treatments. Different nutrient doses were recorded with non-significant variation in fresh weed biomass.

Table 45: Weed Fresh Biomass (g/m²) in wheat crop

Treatment	Weed fresh biomass		
	30DAS	60DAS	90DAS
Factor A			
NT + 30cm CR	4.71	20.97	13.80
NT + 60cm CR	4.43	25.90	13.45
RT + 30cm CR	5.30	22.63	12.96
RT + 60 cm CR	4.26	22.42	13.01
CT	3.13	14.94	8.74
C.D.	NS	NS	2.85
SE(m)	0.48	3.01	0.98
Factor B			
RDN	4.42	20.98	12.11
75% RDN	4.45	22.01	13.79
STCR	4.23	21.12	11.28

C.D	NS	NS	NS
SE(m)	0.37	2.33	0.76
C.D(A*B)	NS	NS	NS
SE (m) (A*B)	0.84	5.22	1.69

NT + 30cm CR -No tillage + 30 cm crop residue, NT + 60cm CR -No tillage+60cm crop residues RT + 30cm CR- Reduced tillage+30 cm crop residues, RT + 60 cm CR -Reduced tillage+ 60cm crop residues, CT- conventional tillage. RDN - Recommended dose of nutrients, 75% RDN - 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Dry Weed Biomass (g/m²) in wheat crop

At 30 and 60days after sowing no variation was observed in weed dry biomass, however, at 90 days after sowing there was significant variation observed. The lowest dry weight was associated with conventional tillage, which showed an efficient weed biomass control over No tillage and Reduced tillage treatments.

Dry biomass of weeds varied with non-significant variation among at 30 and 60 days after sowing, however, it differed significantly at 90 days after sowing. The maximum weight was associated with 75% RDN followed by RDN, STCR contained lowest dry weight of weeds. This might be due to solid stem or heavy foliage weed species with low moisture content in biomass.

Table 46: Dry Weed Biomass (g/m²) in wheat crop

Treatment	Weed dry biomass		
	30DAS	60DAS	90DAS
Factor A			
NT + 30cm CR	0.88	4.00	2.12
NT + 60cm CR	0.83	4.97	1.91
RT + 30cm CR	1.00	4.26	2.16
RT + 60 cm CR	0.80	3.65	1.83
CT	0.59	2.37	1.12
C.D.	NS	NS	0.68
SE(m)	0.09	0.74	0.23
Factor B			
RDN	0.83	3.73	1.78
75% RDN	0.84	3.84	2.19

STCR	0.79	3.99	1.52
C.D	NS	NS	0.53
SE(m)	0.07	0.57	0.18
C.D(A*B)	NS	NS	NS
SE (m) (A*B)	0.16	1.28	0.40

NT + 30cm CR -No tillage + 30 cm crop residue, NT + 60cm CR -No tillage+60cm crop residues RT + 30cm CR- Reduced tillage+30 cm crop residues, RT + 60 cm CR -Reduced tillage+ 60cm crop residues, CT- conventional tillage. RDN - Recommended dose of nutrients, 75% RDN - 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Weed Density (Number of weeds /m²) in wheat crop

Total number of weeds per m² were recorded similar at 30 days after sowing and 90DAS among all the tillage treatments, however, at 60 DAS there was significant variation observed in weed density, lowest number of weeds were associated with conventional tillage. Maximum number of weeds at 60DAS were associated under reduced tillage with 30 cm crop residue height. Various nutrient doses had no significant variation among them in weed density.

Table 47: Weed Density (Number of weeds /m²) in wheat crop

Treatment	Weed density		
	30DAS	60DAS	90DAS
Factor A			
NT + 30cm CR	3.44	9.33	6.33
NT + 60cm CR	4.00	7.22	7.66
RT + 30cm CR	4.11	10.33	6.00
RT + 60 cm CR	3.22	7.77	6.00
CT	2.22	6.44	7.00
C.D.	N/A	2.26	N/A
SE(m)	0.693	0.77	0.86
Factor B			
RDN	3.60	7.26	7.70
75% RDN	3.06	8.93	5.90
STCR	3.53	8.46	6.30
C.D	NS	NS	NS
SE(m)	0.53	0.60	0.67

C.D(A*B)	NS	NS	NS
SE (m) (A*B)	1.02	1.35	1.50

NT + 30cm CR -No tillage + 30 cm crop residue, NT + 60cm CR -No tillage+60cm crop residues RT + 30cm CR- Reduced tillage+30 cm crop residues, RT + 60 cm CR -Reduced tillage+ 60cm crop residues, CT- conventional tillage. RDN - Recommended dose of nutrients, 75% RDN - 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Soybean Crop Plant height

The table 48 presents the height of soybean plants (in centimeters) recorded at 30, 60, and 90 days after sowing (DAS) under various treatment conditions, including five tillage treatments (T1 to T5) and three nutrient-based treatments (N100, N75, and STCR 150). Among the tillage treatments no variation was observed in soybean plant height at various plant growth stages, However, Plant height of soybean observed in increasing order with the progression of plant growth. For the nutrient-based treatments, plant heights of soybean were recorded similar at all stages.

Table 48: Soybean Plant Height (in cm)

Soybean Plant Height (in cm)			
Treatments	30 DAS	60 DAS	90 DAS
T1	23.59	51.96	54.48
T2	22.94	52.04	53.93
T3	24.17	50.22	56.15
T4	22.24	52.11	55.56
T5	23.35	51.44	52.44
CD	NS	NS	NS
N100	23.54	51.62	54.42
N75	23.37	51.84	53.69
STCR 150	22.87	51.20	55.42
CD	NS	NS	NS

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Number of branches in Soybean plant:

The table 49 presents the number of branches per soybean plant at 60 and 90 days after sowing (DAS) under various treatments. At 60 DAS, the number of branches ranged from 5.44 in T5 to 6.15 in T4, however there was non-significant variation among various tillage treatments. At 90 DAS, there was significant difference in number of branches per plant in soybean with values

ranging from 5.33 in T5 to 6.48 in T4. Again, T4 recorded the highest number of branches, followed by T2 (6.19) and T3 (6.04), indicating consistent superior vegetative performance. T5 remained the lowest. Various nutrient doses had no effect on number of branches in soybean at 60 DAS and 90 DAS.

Table 49: No of Branches (per plant) of Soybean

Soybean No of Branches (per plant)		
Treatments	60 DAS	90 DAS
T1	5.67	5.93
T2	6.04	6.19
T3	5.56	6.04
T4	6.15	6.48
T5	5.44	5.33
CD	N/A	0.59
N100	5.69	5.93
N75	5.76	6.11
STCR 150	5.87	5.93
CD	N/A	N/A

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Soybean Yield (q/ha)

The table 50 presents soybean yield data, highlighting grain and biomass yields (in quintals per hectare, Q/ha). There was non-significant variation observed among various tillage treatments in soybean yield. The different nutrient doses observed without any effect on grain, however, biomass yield varied significantly. The maximum biomass yield was associated with STCR dose followed by N100; the minimum biomass was produced under N75 nutrient dose.

Table 50: Soybean Yield (q/ha)

Soybean Yield (q/ha)		
Treatments	Grain	Biomass
T1	8.24	32.33
T2	8.35	29.15
T3	8.03	28.26

T4	9.30	29.70
T5	8.34	27.91
CD	NS	NS
N100	8.48	29.46
N75	8.19	27.16
STCR	8.68	31.78
CD	NS	2.63

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis

Soybean Plant biomass at various growth stages (kg/ha)

Shoot Biomass

Various tillage treatments did not affect significantly shoot biomass in terms of kg/ha at 30, 60 and 90 DAS nutrient doses also not observed with non-significant effect. However, shoot biomass showed higher values at 60DAS than 90DAS because near the maturity shattering of soybean start. Various nutrients doses also showed a non-significant effect on shoot biomass of soybean.

Table 51: Soybean Shoot Biomass (kg/ha)

Soybean Shoot Biomass (kg/ha)			
Treatments	30 DAS	60 DAS	90 DAS
T1	571.92	3884.27	3573.49
T2	487.80	4112.33	2671.72
T3	451.29	4873.79	2727.49
T4	592.01	4172.93	3001.47
T5	533.32	5136.69	2994.28
CD	NS	NS	NS
N100	521.59	4580.69	2870.00
N75	515.52	4031.67	2873.41
STCR	544.69	4695.65	3237.66
CD	NS	NS	NS

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Root Biomass

Various tillage treatments had significant effect on root biomass at 30DAS, however, at 60 and 60 DAS there was no effect was seen. At 30 DAS maximum root biomass associated with T4 (197.71 Kg/ha) followed by T5 with 172.52 kg/ha. T1 showed minimum root biomass with 136.23 Kg/ha. Various nutrient doses had no effect on root biomass. At various crop growth stages but root biomass increased with crop growth and at near to maturity root biomass showed a decreasing trend when compared with 60 DAS.

Table 52: Soybean Root Biomass (kg/ha)

Soybean Root Biomass (kg/ha)			
Treatments	30 DAS	60 DAS	90 DAS
T1	136.23	622.22	422.76
T2	140.68	624.21	373.64
T3	163.25	890.41	450.26
T4	197.71	743.50	451.03
T5	172.52	784.30	473.44
CD	31.00	NS	NS
N100	154.42	792.25	436.82
N75	163.31	667.15	369.50
STCR	168.50	739.39	496.36
CD	N/A	N/A	N/A

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Plant nodule studies in Soybean

Data on number of nodules, volume of nodules and dry weight of nodule recorded and it was observed that all the parameters were had non-significant variation among various tillage and nutrient treatments.

Table 53: Plant nodule studies in Soybean

Soybean Nodules (Per plant)			
Treatments	No of Nodules	Volume of Nodules (ml)	Dry wt. of Nodules (gm)
T1	39.00	0.54	0.19
T2	53.67	0.74	0.23
T3	60.58	0.84	0.23
T4	43.75	0.60	0.25
T5	47.25	0.65	0.21
CD	N/A	N/A	N/A

N100	48.00	0.66	0.22
N75	49.25	0.68	0.22
STCR	49.30	0.68	0.23
CD	N/A	N/A	N/A

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Harvest Index of soybean and Residue retention

Harvest index was recorded with non-significant variation under various tillage treatments and various nutrient doses. Although the values were lower side than the average, it might be due to small size of grains in the pods. Residue retention (Leaf fall) was observed with significant difference among various treatments of tillage and nutrients. Maximum leaf fall was observed with T3 treatment followed by T5, However, among nutrients doses N75 had highest leaf fall followed by STCR treatment.

Table 54: Harvest Index of soybean and Residue retention

SOYBEAN		
Treatments	Harvest Index %	Residue Retention (leaves) (kg/ha)
T1	25.53	410.00
T2	28.78	320.83
T3	29.08	494.17
T4	31.65	401.67
T5	30.15	477.50
CD	N/A	26.30
N100	29.14	400.00
N75	30.47	442.50
STCR	27.51	420.00
CD	N/A	7.14

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Soybean-Chickpea

Experiments were initiated in 2016 in soybean-chickpea system in black soils at Akola. With the following treatments in soybean in Kharif Conventional tillage (CT) - Ploughing once in 3 years + 2 pre-sowing harrowing + One hand weeding + Opening of furrow with hoe in each row at 30-35 DAS + Crop residue mulch (T₁), 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 (T₂), Reduced tillage (RT) – Broad bed and furrow every year + Pre and post emergence herbicide application + crop residue (T₃), Zero tillage + crop residue (T₄), Permanent BBF furrow after every 4 rows + crop residue mulch (T₅). In Rabi Conventional tillage (CT)- Pre-sowing harrowing + One hoeing + One hand weeding + Crop residue mulch (T₁), Conventional tillage (CT) - Pre-sowing harrowing + One hoeing + One hand weeding + No crop residue mulch (T₂), Reduced tillage (RT) – Pre sowing harrowing + Broad bed and furrow every year + Pre-emergence herbicide application + Crop residue mulch (T₃), Zero tillage + crop residue (T₄), Permanent Broad bed and furrow + Pre-emergence herbicide application + crop residue mulch (T₅).

The results of the experiment in the table revealed that the treatment effects on growth and yield attributes were significant. In terms of grain and straw yield of soybean, treatment T₃ was found to be significantly superior over other treatments however it was at par with T₁. The net monetary returns, B:C ratio and rainwater use efficiency as influenced by different treatments is given in Table 56. The NMR, B:C ratio and rainwater use efficiency was observed to be higher in the treatments T₃ as compared to other treatments.

Table 55: Growth, yield attributes and productivity of soybean as influenced by different treatment combinations during 2024

Treatments	Plant height (cm)	Number of pods / plants	Grain weight plant ⁻¹ (g)	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
T ₁	35.4	33.6	7.92	1616	1812
T ₂	33.9	33.5	7.78	1549	1796
T ₃	36.5	35.8	8.09	1706	1913
T ₄	31.8	30.5	6.96	1300	1521
T ₅	32.8	30.9	7.03	1315	1487
S. E. (m)	0.94	1.10	0.22	38.4	44.42
C.D. at 5%	2.93	3.43	0.69	119.63	138.39

Table 56. Net returns, B:C ratio and Rainwater use efficiency as influenced by different treatments for soybean

Treatments	Grain yield (kg ha ⁻¹)	GMR (Rs ha ⁻¹)	Cost of cultivation (Rs ha ⁻¹)	Net return (Rs ha ⁻¹)	B:C ratio	Rainwater use efficiency (kg ha ⁻¹ mm ⁻¹)
T ₁	1616	62412	31829	30583	1.96	2.23
T ₂	1549	58335	30649	27686	1.90	2.15
T ₃	1706	65888	29852	36036	2.21	2.42

T ₄	1300	46371	29185	17186	1.59	1.79
T ₅	1315	48170	29703	18467	1.62	1.89



Plate 29. View of soybean crop in treatment T₁ and T₂



Plate 30. View of soybean crop in treatment T₃ and T₅



Plate 31. Visit of QRT team members to CRP-CA experiment during September 2024

Rabi chickpea

Treatment wise data in respect of grain yield, straw yield and yield economics of chickpea is given in Table 8. It was observed that the treatment effects on grain and straw yield of chickpea were significant. In terms of grain as well as straw yield of chickpea, T₃ was found significantly superior over treatments T₄ and T₅ and was found at par with treatment T₁ and T₂. The NMR and B:C ratio was observed highest in treatment T₃. The soybean equivalent yield and system productivity is given in Table 57 & 58. The soybean equivalent yield (3225kg ha⁻¹) and system productivity (8.84kg ha⁻¹ day⁻¹) is observed highest in treatment T₃.

Table 57: Yield of chickpea as influenced by different treatment combinations 2024-25

Treatments	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	GMR (Rs ha ⁻¹)	Cost of cultivation (Rs ha ⁻¹)	Net return (Rs ha ⁻¹)	B:C ratio
T ₁	1393	1617	51765	26910	24855	1.92
T ₂	1371	1574	50930	26003	24927	1.96
T ₃	1448	1690	53818	24256	29562	2.22
T ₄	1117	1267	40362	25119	15243	1.61
T ₅	1141	1308	41243	24707	16536	1.67
S. E. (m)	31.67	36.94				
C.D. at 5%	98.66	115.08				

Table 58: System productivity as influenced by different treatment combinations

Treatments	Soybean equivalent yield (kg ha ⁻¹)	System productivity (kg ha ⁻¹ day ⁻¹)
T ₁	3076	8.43
T ₂	2942	8.06
T ₃	3225	8.84
T ₄	2398	6.57
T ₅	2475	6.78



Plate 32. Sowing during Rabi 2024-25 with BBF planter



Plate 33. Visit of Hon'ble Vice Chancellor, Dr. PDKV, Akola to CRP-CA, field at initial crop stage



Plate 34. View of chickpea CRP-CA treatments on flowering stage, 2024-25

Maize-Chickpea Cropping System

Maize Crop

Plant height

The plant height was significantly influenced application of various levels of crop residue and nutrient levels in maize crop (Fig 67). The maximum plant height (193.66 cm) was recorded in 90 % residue retention treatment which was significantly superior to 60% CR, 30% CR and without residue retention with the mean values of 195, 788.6, 184.2, respectively and the minimum plant height (180.41) was observed in without residue retention treatments. The different nutrient treatments have significant influence on plant height and highest plant height was observed with application of recommend dose of 100% NPK along with 90% crop residue retention followed by 75%N+100%PK which was at par with application of 75% P and 100 % NK and 75%K along with 100% NP.

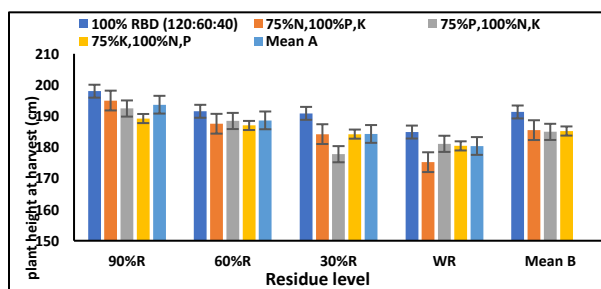


Fig 67. Effect of different levels of crop residue and nutrient doses on plant height (cm) on maize crop.

Number of leaves

The data related to the number of leaves per plant in maize (Fig 68) revealed significant differences among the treatment combinations of crop residue retention and nutrient levels. The maximum number of leaves (14.82) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 14.52, 14.13, and 13.35, respectively and the lowest number of leaves (13.35) was observed in without residue. In case of various levels of nutrient applications there was non-significant effect of nutrient doses on number of leaves. The interaction effect between residue levels and nutrient doses not show any significant difference effect on number of leaves as a result of different residue levels and nutrient doses. The maximum number of leaves (15.28) was observed in treatment R90+N1, which was found significantly superior over the lowest treatment R0+N3 (11.10 leaves). In general, treatments with higher crop residue levels (R90 and R60) recorded more number of leaves compared to lower residue levels. Among the nutrient treatments, however, the effect was non-significant, and leaves numbers varied within a narrow range of 13.5 to 14.8. The interaction effect between residue and nutrient levels was also found to be non-significant. The highest number of leaves (15.28) obtains from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest number of leaves (13.07) was observed in without residue with 75%K, 100%N, P doses.

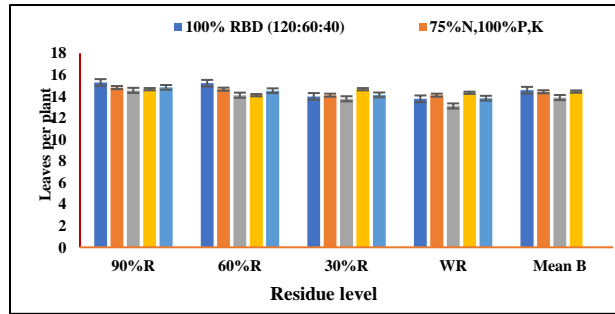


Fig 68. Effect of different levels of crop residue and nutrient doses on number of leaves on maize crop

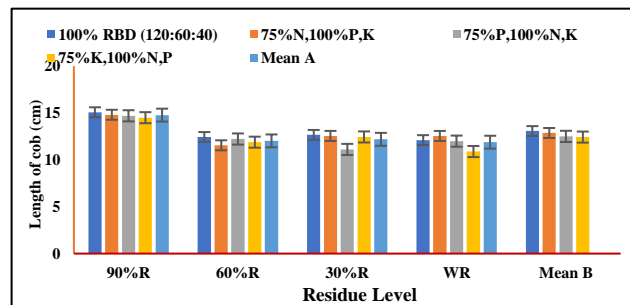


Fig 69. Effect of different levels of crop residue and nutrient doses on cob length on maize crop

Cob thickness

The data presented in Fig 70 indicates that the thickness of maize cobs was significantly influenced by different levels of crop residue retention. The maximum cob thickness (15.27 cm) was recorded under 90% crop residue retention, which was found to be significantly superior to 60%, 30%, and 0% residue levels. The average cob thickness under 60%, 30%, and without residue retention was 13.99 cm, 14.08 cm, and 1.69 cm, respectively. The lowest cob thickness (13.69 cm) was observed in the treatment without residue retention. The interaction between crop residue and nutrient levels was also non-significant. The highest cob thickness (15.66 cm) was recorded in the treatment with 90% residue retention + R1(N1), which was statistically at par with other residue combinations. On the contrary, the lowest cob thickness (13.33cm) was recorded in the treatment receiving no residue and 75% N + 100% P and K.

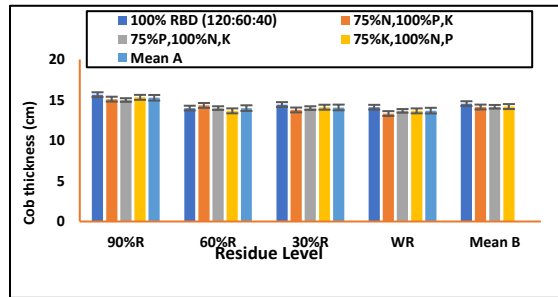


Fig 70. Effect of different levels of crop residue and nutrient doses on cob thickness on maize crop

Number of rows per cob

The data pertaining from number of rows per cob of maize crop (fig 71) shows significant differences in number of rows per cob as a result of different levels of crop residue retention. The maximum number of rows per cob (14.60) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 13.27, 13.22, 12.88 respectively and the lowest number of rows per cob (12.88) was observed in without residue. In case of various levels of nutrient applications there was non-significant effect of nutrient doses on number of rows per cob and the number of rows per cob. The interaction effect between residue levels and nutrient doses not show any significant difference effect on number of rows per cob as a result of different residue levels and nutrient doses. The highest number of rows per cob obtains from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest number of rows per cob (12.77) was observed in without residue with 75% N, 100% P, K doses.

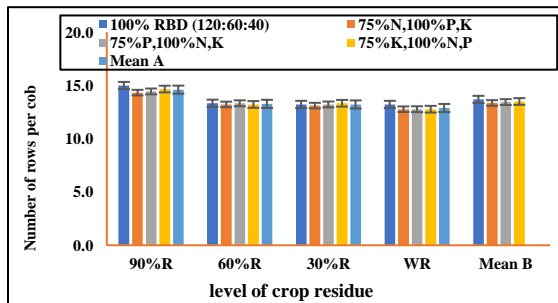


Fig 71. Effect of different levels of crop residue and nutrient doses on number of rows per cob on maize crop

Number of seeds per row

The data presented in Fig 72 reveals that the number of seed per cob in maize was significantly influenced by different levels of crop residue retention. The data pertaining from number of seeds per row of maize cob (figure 6) shows significant differences in number of rows per cob as a result of different levels of crop residue retention. The maximum number of seed per cob (27.22) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 26.22, 24.49, and 25.30, respectively and the lowest number of seed per cob (25.30) was observed in without residue. The maximum number of rows per cob (28) was recorded under 90% residue retention along with 100% RDF (R90+N1). In case of nutrient levels, though most treatments did not show significant. The interaction effect between residue levels and nutrient doses not show any significant difference effect on number of seed per row as a result of different residue levels and nutrient doses

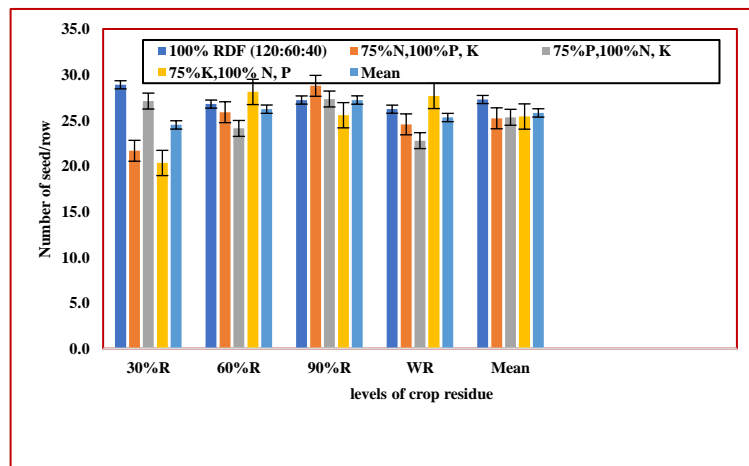


Fig 72. Effect of different levels of crop residue and nutrient doses on number of seeds per row on maize crop

Grain yield

The data pertaining to maize grain yield (Fig 73) revealed significant variations due to different levels of crop residue retention and nutrient levels. The maximum yield (6689.17 kg/ha) was observed under 90% residue retention with 100% RDF (R90+N1), which was significantly superior to other residue levels including 60%, 30%, and without residue, with their respective average yields being 6024.17 kg/ha, 5768.33 kg/ha, and 5397.50 kg/ha.

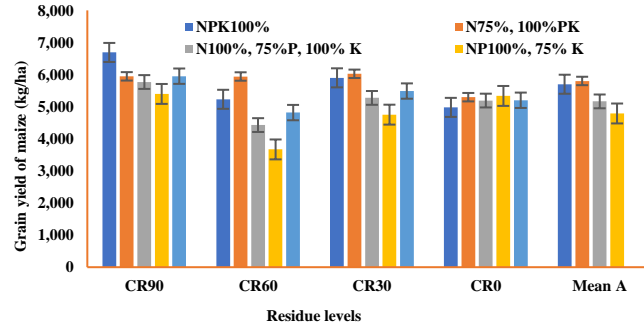


Fig 73. Effect of different levels of crop residue and nutrient doses on grain yield of maize

The minimum yield (3668.33 kg/ha) was recorded in the treatment with no residue and 75% N (R0+N2), highlighting the beneficial effect of crop residue retention and full nutrient dose on maize productivity. 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. Although nutrient levels alone showed varied effects, the interaction of residue and nutrient levels exhibited significant influence on grain yield. The combination R90+N1 performed significantly better, statistically at par with R60+N3, while lower yields were obtained from R0+N2 and R30+N2.

Straw yield

The data presented in Fig. 74 shows that straw yield of maize was significantly influenced by various levels of crop residue retention. The maximum straw yield (10050 kg/ha) was recorded under 90% residue retention combined with 100% RDF (R90+N4), which was significantly superior to all other treatments. The lowest straw yield (5591kg/ha) was recorded in the treatment without residue retention and 75% N, 100% P and K application (R30+N3). Among, the main effects, crop residue levels showed a statistically significant effect on straw yield), indicating a trend toward higher straw yield with increased residue retention. Similarly, the interaction between residue retention and nutrient levels was also non-significant, indicating that the combined effect of residue and nutrient levels did not differ statistically in terms of straw yield.

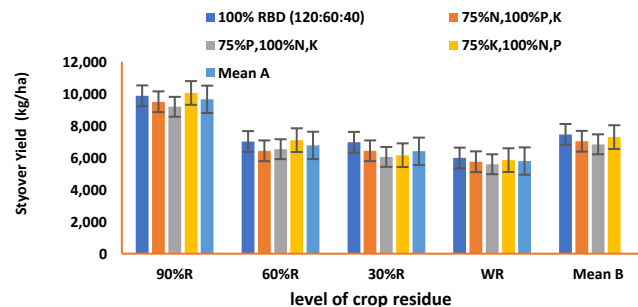


Fig 74. Effect of different levels of crop residue and nutrient doses on straw yield (kg/ha) of maize crop



Plate 35. Different levels of crop residue and nutrient doses of maize crop

Chickpea Crop

Plant height

The data regarding plant height at harvest in chickpea (Fig 75) revealed that both crop residue retention levels and nutrient management practices had a significant effect on plant height. The maximum plant height (47 cm) was recorded in 90% crop residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 44, 42, 40 (cm) respectively and the lowest plant height (36.41 cm) was observed in without residue. The maximum plant height (50.75cm) was observed under the treatment R90+N1 (90% residue + 100% RDF), which was significantly superior to all other treatments. This was followed by R90+N4 (47.00 cm) and R90+N2 (44.88 cm). The lowest plant height (39 cm) was recorded under the treatment R0+N2. Among the residue levels, 90% residue retention produced the tallest plants, while the no-residue treatment resulted in the shortest plants. This indicates the positive effect of residue retention in improving soil moisture and nutrient availability, thereby enhancing vegetative growth. The interaction effect between residue and nutrient levels was

also found to be significant. The combination of 90% residue with 100% RDF (R90+N1) resulted in the tallest plants, whereas the lowest plant height was recorded in the treatment R0+N4, showing that the absence of residue negatively affected growth regardless of nutrient supply.

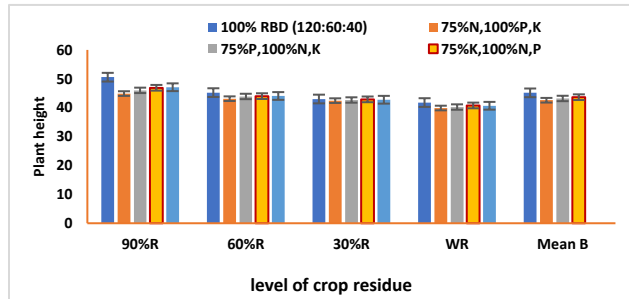


Fig 75. Effect of different levels of crop residue and nutrient doses on plant height (cm) on chickpea crop.

Number of branches

The number of branches per plant in chickpea was significantly influenced by different levels of crop residue retention (Fig 76). The mean number of branches under 90%, 60%, 30%, and 0% residue retention was 9.18, 8.33, 7.88, and 7.27 respectively in mean value. Among nutrient treatments, the differences were statistically non-significant, with the number of branches ranging narrowly between 7.11 and 10.00. The highest number of branches (10.00) was recorded under 90% residue retention with N1 nutrient level, which was significantly superior to 60%, 30%, and no residue retention treatments. The interaction effect between residue retention and nutrient levels was also found to be non-significant. The overall results suggest that higher residue retention positively influenced branch production, while nutrient level variation had limited impact. The interaction effect between residue levels and nutrient doses not show any significant difference effect on number of branches as a result of different residue levels and nutrient doses. The highest number of branches (10) was obtained from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest number of branches (7.1) was observed in without residue with R0+75% N, 100% P, K doses.

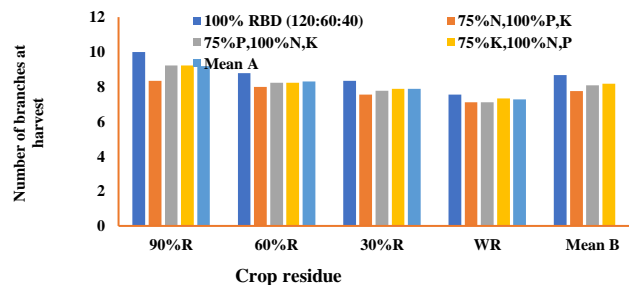


Fig 76. Effect of different levels of crop residue and nutrient doses on number of branches on chickpea crop.

Number of pods/plants

The number of pods per plant in chickpea was significantly influenced by varying levels of crop residue retention (Fig 77). The maximum number of pods/plants 54.42 was recorded in 90 %

residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 47.81, 43.64, 38.61 respectively and the lowest number of pods/plant (38.61) was observed in without residue. The maximum number of pods (59.56) was recorded under 90% residue retention with nutrient treatment (R90+N1), which was significantly superior to the lower residue levels. This indicates a clear and significant increase in pod production with higher residue retention. However, the influence of different nutrient levels on pod number was statistically non-significant, as the values ranged between 35.33 to 59.56. Similarly, the interaction between residue and nutrient treatments did not show any significant effect.

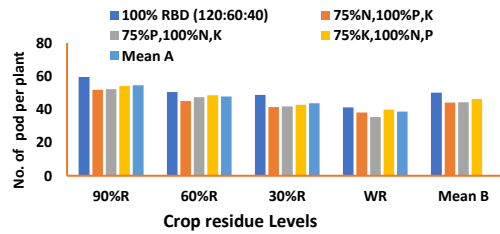


Fig 77. Effect of different levels of crop residue and nutrient doses on number of pods/plants on chickpea crop.

Number of seeds/plants

The number of seeds per plant in chickpea was significantly affected by various levels of crop residue retention (Fig 78). The maximum number of seeds/plant (69.44) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 59.66, 54.91, and 50, respectively and the lowest number of seeds/plant (50) was observed in without residue. On the other hand, nutrient levels did not significantly influence the number of seeds per plant, with mean values ranging from 48.44 to 83.44 across different treatments. The interaction effect between residue levels and nutrient application was also found to be non-significant.

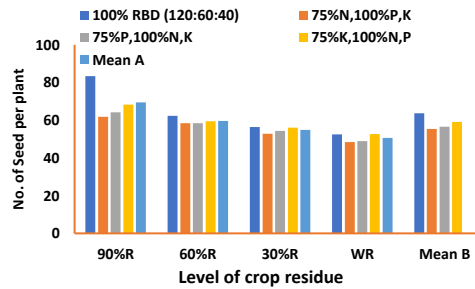


Fig 78. Effect of different levels of crop residue and nutrient doses on number of seeds/plants on chickpea crop.

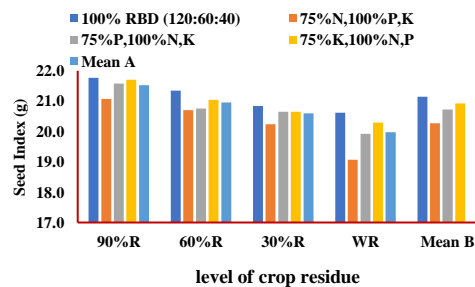


Fig 79. Effect of different levels of crop residue and nutrient doses on number of Seed index on chickpea crop

Grain yield

Grain yield of chickpea was significantly influenced by different levels of crop residue retention and nutrient levels (Fig 80). The highest grain yield (2250.0 kg/ha) was recorded under the treatment R90+N1 (90% residue + N1), which was statistically superior over all other treatments. On the other hand, the effect of different nutrient levels was statistically non-significant, with grain yields ranging from 1520.8 to 2250.0 kg/ha. Similarly, the interaction effect between crop residue and nutrient levels did not show significant variation. 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. The highest grain yield (2531.88 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 (1520.80 kg ha⁻¹) was observed in without residue with 75% N, 100% P, K doses.

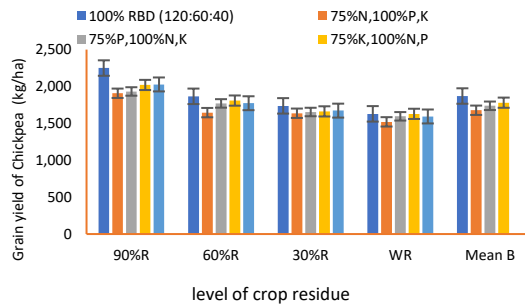


Fig 80. Effect of different levels of crop residue and nutrient doses on grain yield kg/ha on chickpea crop.

Straw yield

The data pertaining to the straw yield of chickpea crop (Fig 81) showed significant differences as a result of different levels of residue retention and nutrient applications. The maximum residue yield (2348.3 kg ha⁻¹) was recorded in the treatment with 90% residue retention along with N1 (R90+N1), which was significantly superior over the other treatments. It was followed by R90+N4 (2053.3 kg ha⁻¹) and R90+N3 (2038.3 kg ha⁻¹). The lowest residue yield (1580.0 kg ha⁻¹) was observed in the treatment without residue retention and with N2 input (R0+N2). In terms of nutrient application levels, the residue yield ranged from 1580.0 to 2348.3 kg ha⁻¹, showing significant influence of different nutrient doses. The highest yield (2348.3 kg ha⁻¹) was recorded under 90% residue retention with N1, whereas the lowest yield (1580.0 kg ha⁻¹) was found in no residue with N2. These findings indicate that higher residue retention levels, especially when combined with N1 input, enhance the residue yield of chickpea significantly.

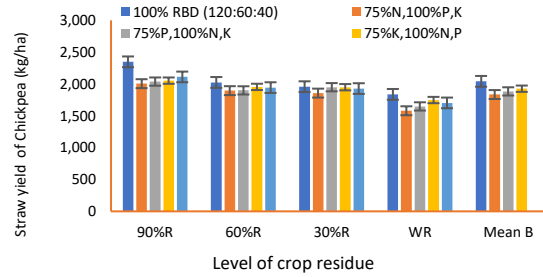


Fig 81. Effect of different levels of crop residue and nutrient doses on straw yield kg/ha on chickpea crop.



Plate 36. Different levels of crop residue and nutrient doses on chickpea crop.

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

The experiment was conducted in a RBD to study the effect of different levels of crop residue retention in soybean-wheat cropping system. The treatments comprised of five levels of residue retention.

Table 59 : Details of residue levels treatment		
Crop	Soybean	Wheat
Residue levels	(90%) Crop residue	(90%) Crop residue
	(60%) Crop residue	(60%) Crop residue

	(30%) Crop residue	(30%) Crop residue
	(0%) without Crop residue	(0%) without Crop residue
	Conventional Tillage (CT)	Conventional Tillage

Soybean Crop

Growth and yield attributes

The data pertaining from plant height of soybean at different growth stages 30, 60, and at harvest stage of soybean crop (Table 60) shows improvement in plant height as a result of different levels of crop residue retention. The maximum plant height (all different growth stages) was recorded in 90% residue retention followed by 60% and 30% residue retention, without residue and CT.

Table 60: Effect of crop in different residue levels on plant height of soybean at different growth stages

Treatment	Plant height of soybean at different growth stages		
	30 days	60 days	At harvest
CR 90%	23.32	57.99	64.5
CR 60%	22.38	57.38	62.7
CR 30%	22.10	55.49	61.4
CR 0%	20.05	49.77	55.0
CT	19.22	48.49	50.3
CD at 5%	1.83	3.64	3.73

The data pertaining from number of branches of soybean at different growth stages 30, 60 and at harvest stage of soybean crop (Table 61) shows improvement in number of branches as a result of different levels of crop residue retention. The maximum number of branches (all different growth stages) was recorded in 90% residue retention followed by 60% and 30% residue retention, without residue and CT. Similar results were also observed in case of yield attributing parameters of soybean and highest number of pods and seed/plants were also recorded under 90% residue retention as compared to other treatments.

Table 61: Effect of crop in different residue levels on number of tillers of soybean at different growth stages

Treatment	Number of branches of soybean at different growth stages			Number of pods/plants	No. of seed per plants
	30 days	60 days	At harvest		
CR 90%	3.05	7.49	8.16	47.6	94.7
CR 60%	3.05	7.21	7.83	42.8	94.1
CR 30%	2.99	7.10	7.16	44.4	88.0

CR 0%	2.44	6.66	7.00	41.4	86.3
CT	2.27	5.60	5.94	36.3	76.7
CD at 5%	0.43	1.07	0.95	NS	NS

Grain yield

The maximum grain yield was recorded under the treatment CR 90% residue with 1049.58 kg/ha, which was significantly superior over the control and at par with CR 30% (938.33 kg/ha) and CR 60% (909.58 kg/ha) treatments (Fig 82). The lowest grain yield was obtained in the control treatment (CT) with 654.58 kg/ha, which was significantly lower than all crop residue level treatments. The CR 0% treatment also resulted in a comparatively lower yield (826.25 kg/ha) and remained statistically inferior to higher residue applications. The results indicate that application of crop residues significantly improved grain yield of soybean, with the highest yield achieved at 90% crop residue.

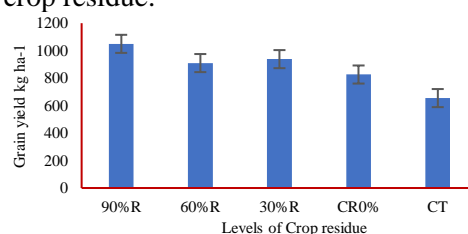


Fig 82. Effect of different levels of crop residue on grain yield kg/ha on soybean crop.

Straw yield

The data pertaining from straw yield of soybean crop (fig 83) shows improvement in straw yield as a result of different levels of crop residue retention. Among the different crop residue management treatments, the highest straw yield was observed under CR 90% (2817.08 kg/ha), which was found statistically at par with CR 30% (2717.92 kg/ha). These were significantly superior to CR 60% (2465.83 kg/ha) and CR 0% (2352.50 kg/ha). The lowest straw yield was recorded under the control treatment (CT) (2054.58 kg/ha). This indicates that higher levels of residue retention contribute positively to straw biomass production in soybean under RBD conditions.

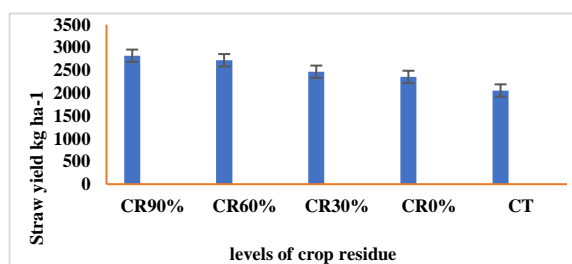


Fig 83. Effect of different levels of crop residue on straw yield kg/ha on soybean crop.



Plate 37. Different levels of crop residue on soybean crop

Plant height at different growth stages

Plant height of wheat at different growth stages 30, 60, 90 days and at harvest was recorded under different residue levels (Table 62). Results indicated that the plant height of wheat did not influence by the applied residue levels. However, the higher plant at different growth stages was noticed under the 90% crop residue retention and lowest plant height was recorded under convention tillage.

Table 62: Effect of crop in different residue levels on plant height of wheat at different growth stages

Treatment	Plant height of wheat at different growth stages			
	30 days	60 days	90 days	At harvest
CR 90%	17.11	49.72	75.06	79.44
CR 60%	13.78	49.00	73.78	78.83
CR 30%	13.75	48.94	73.78	78.16
CR 0%	13.73	48.83	71.66	78.00
CT	13.76	48.61	70.27	69.66
CD at 5%	0.23	NS	NS	3.80

Number of tillers

The data pertaining from number of tillers of wheat at different growth stages 30, 60, 90 days and at harvest of wheat crop (Table 63) shows improvement in number of tillers as a result of different levels of crop residue retention. The maximum number of tillers (all different growth stages) was recorded in 90% residue retention followed by 60%,30% residue retention, without residue and CT.

Table 63: Effect of crop in different residue levels on number of tillers of wheat at different growth stages

Treatment	Number of tillers (Meter row length) of wheat at different growth stages			
	30 days	60 days	90 days	At harvest
CR 90%	80.33	88.49	92.33	89.7
CR 60%	78.91	84.88	92.16	89.3
CR 30%	77.22	83.60	91.89	83.7
CR 0%	71.61	81.94	91.44	78.7
CT	71.44	80.33	85.89	75.7
CD at 5%	NS	3.66	3.54	7.06

Yield attributes

Among different treatment maximum ear length was recorded (Table 64) in treatment CR 90% residue (15.44 cm) which was at par with other residue level treatments, while lowest ear length was recorded in under treatment CT (13.83 cm). The maximum number of seeds/ears was recorded in treatment CR 90% residue (77.99 seeds/ear) which was at par with other residue level treatments, while lowest number of seed/ears was recorded in under treatment CT (59.55 seed/ear). The maximum grain weight/ear (gm) was recorded in treatment CR 90% residue (3.79 gm/ear) which was at par with other residue level treatments, while lowest grain weight/ear (gm) was recorded in under treatment CT (2.9gm/ear). The maximum test weight was recorded in treatment CR 90% residue (45.6 gm) which was at par with other residue level treatments, while lowest test weight (gm) was recorded in under treatment CT (42.8gm).

Table 64: Effect of crop in different residue levels on yield attributes of wheat

Treatment	Yield attributes				
	Ear length (cm)	Number of seeds/ears	Grain weight/ear (gm)	Test weight (g)	HI
CR 90%	15.44	77.99	3.79	45.6	40.00
CR 60%	15.33	69.71	3.71	45.2	41.02
CR 30%	14.27	64.88	3.22	45.2	41.63
CR 0%	14.16	62.16	3.12	43.9	42.84

CT	13.83	59.55	2.90	42.8	43.66
CD at 5%	NS	NS	NS	NS	NS

Grain yield

The data pertaining to grain yield of wheat crop (Fig 84) indicates a clear improvement in grain yield due to different levels of crop residue retention. The maximum grain yield (4922.9 kg ha⁻¹) was recorded under 90% residue retention (CR 90%), which was significantly superior to CR 60%, CR 30%, CR 0%, and conventional tillage (CT), with mean yields of 4845.8, 4712.5, 4475.0, and 4420.8 kg ha⁻¹, respectively. The lowest grain yield (4420.8 kg ha⁻¹) was observed under the conventional Tillage (CT) treatment. These results highlight the beneficial effect of higher residue retention on wheat productivity under the given conditions.

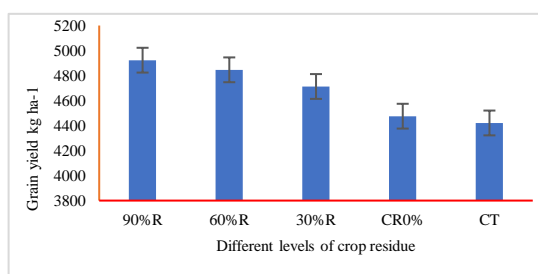


Fig 84. Effect of different levels of crop residue on grain yield of wheat crop

The data pertaining to straw yield of wheat crop (Fig 85) reveals a positive impact of varying levels of crop residue retention on straw production. The maximum straw yield (7383.3 kg ha⁻¹) was recorded under 90% residue retention (CR 90%), which was significantly superior to CR 60%, CR 30%, CR 0%, and CT treatments, with average yields of 6967.1, 6606.3, 5970.8, and 5704.2 kg ha⁻¹, respectively. The lowest straw yield (5704.2 kg ha⁻¹) was observed under Conventional Tillage (CT). These findings suggest that higher crop residue retention levels can enhance straw yield of wheat under the given field conditions.

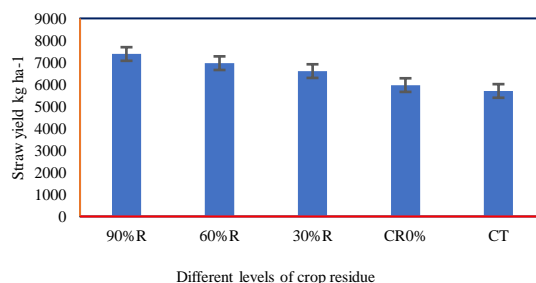


Fig 85. Effect of different levels of crop residue on straw yield of wheat crop



Plate 38. Different levels of crop residue on wheat crop

A) Strategies to enhance crop residue retention under Rainfed Agriculture

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

1. Pigeonpea+ Fox tail millet – Maize+cowpea system (Pigeonpea – castor)

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+ Fox tail millet – Maize+cowpea rotation. This year (2024-2025) Maize+cowpea intercropping system was evaluated on different levels of Pigeonpea and Fox tail millet 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 39). The crop suffered from moisture stress during the initial stages. Zero tillage and reduced tillage recorded 6% higher maize equivalent yields as compared to conventional tillage. The maize equivalent yields in 10 and 30 cm anchored pigeon pea residues was significantly higher yield as compared to no residues. 10 and 30 cm height crop residues recorded 6 and 5% higher yield as compared to no residue.

The nutrient loss and soil loss were influenced by the tillage and residue levels. Zero tillage with residues recorded 30 % lower soil and nutrient loss as compared to conventional tillage or zero tillage with residues (Fig 86).

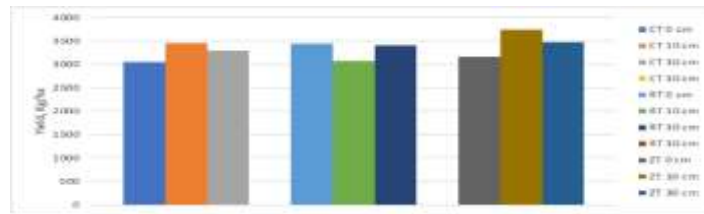


Fig 86. Influence of tillage and residue levels on Maize equivalent yield

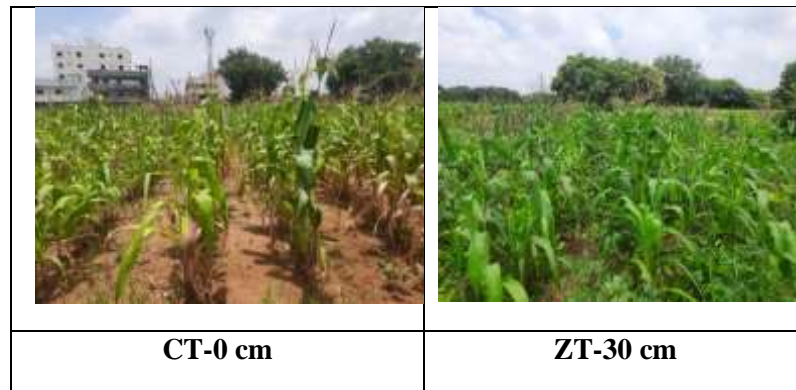


Plate 39. Strategies for enhancing residue retention in Rainfed region

2. Sorghum-Black gram system

The 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).

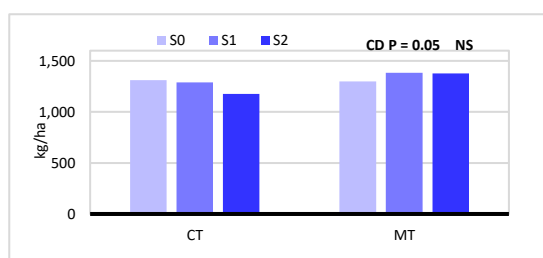
In the 12th year of the study, the crop was blackgram. The rainfall was copious and reasonably well distributed, leading to significant extension of crop duration beyond 100 days. The crop, sown on 19th June received about 600 mm of rainfall, 125 mm of this received in the last week of September led to rotting of pods and fungal damage to seeds, reducing the yield from the second picking. However, in general, the crop performance was good and yields across treatments were fairly high.



Plate 40. Blackgram (variety PU 31) under minimum tillage and maximum residue retention

Blackgram seed yields (Fig 87), ranged from 1177 to 1383 kg/ha. Differences in seed yield with tillage as well as residue management were not significant

Fig 87. Effect of tillage and residue management on seed yield of blackgram



3. Pigeonpea- Finger millet sequence cropping

The experiment was initiated in 2021 with in pigeonpea - finger millet sequence cropping in rainfed ecosystem at Bangalore (plate 3).

Among the cover crops, highest biomass yield of 17.8 t ha⁻¹ was recorded with C₃ (Horse gram) under conventional tillage followed by 16.4 t ha⁻¹ and 13.0 t ha⁻¹ under reduced and zero tillage, respectively compared to C₂ (Sunhemp) (Table 3).

Among different tillage practices (Table 4), reduced tillage recorded significantly higher finger millet and straw yield (2292 & 3368 kg ha⁻¹) compared to zero tillage (1970 & 2956 kg ha⁻¹) but was on par with conventional tillage (2087 & 3173 kg ha⁻¹). Higher net returns (Rs. 65,462 ha⁻¹), and BC-ratio (2.97) was recorded with reduced tillage over zero tillage (Rs. 54,443 & 2.79) and conventional tillage (Rs. 55,548 & 2.62) (Table 65).

The finger millet yield was significantly higher in premonsoon cover crops as compared to no cover crop. Horse gram as cover crop recorded significantly higher finger millet grain and straw yield (2344 & 3493 kg ha⁻¹) followed by sun hemp (2118 & 3172 kg ha⁻¹) and control (1888 & 2832 kg ha⁻¹), respectively. Similar was the trend with higher net returns (Rs. 66,546 ha⁻¹) and benefit cost ratio (2.94) with horse gram as cover crop. However, the interaction between tillage and cover crops was non-significant.



Plate 41: Horsegram, Sunhemp and Finger millet crops in field

Table 65: Biomass yield of cover crops under conservation agriculture

Treatment	Yield (t/ha)	
	C ₂ : Sun hemp	C ₃ : Horse gram
M ₁ : Conventional tillage	15.3	17.8
M ₂ : Reduced tillage	14.0	16.4
M ₃ : Zero tillage	12.5	13.0

B. Nutrient Management in Rainfed Conservation agriculture systems

1. 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* 2024. 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 pigeonpea crop. 2. Reduced Tillage- One-time cultivator+ Disc harrow before sowing+ Residue retention up to 60 cm plant height of previous maize crop and 3. No Tillage- Direct sowing + Residue retention up to 60 cm stem height of previous maize 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. Due to continuous omission of the nitrogen in N-0 (control plot) the maize grain yield recorded very low as compared to the other nitrogen levels. The per cent increase in maize grain yield in N-75, N-100 and N-125 was 592, 817 and 879%, respectively as compared to the N-0. About 24.6 and 13.01% significantly higher mean maize grain yield recorded in NT and RT as compared to the CT, respectively. About 10.2 % higher maize grain yield recorded in the NT as compared to the RT. The interactive effect of tillage practices and nitrogen levels found to be non-significant.

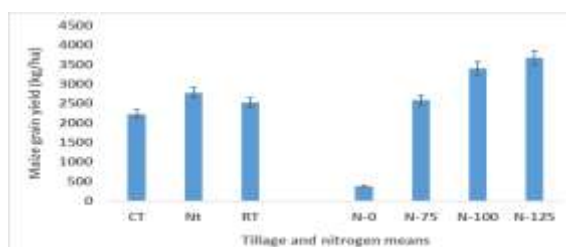


Fig 88. Mean effect of tillage practices and nitrogen levels on maize grain yield (kg/ha)

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 and Pigeon pea: 20-50-0 kg N, P₂O₅, K₂O ha⁻¹) and 125% RDF as subplots under Pearl millet (MPMH 21) and Pigeonpea (WRG 93) rotation to study the effect of tillage practices and different doses of fertilizers on performance of pearl millet and pigeonpea rotation. The spacing of pigeonpea and pearl millet was 75 × 20 cm 45 × 12 cm.

The grain yield of pigeonpea was significantly influenced by both tillage practices and nutrient management. Among the tillage practices, zero tillage (1018 kg/ha) performs better which is on par with minimum tillage (998 kg/ha) followed by conventional tillage (816 kg/ha). Progressive increase in grain yield was observed with each successive increment in NPK levels (75, 100 and 125% RDF). Application of 125% RDF resulted in higher grain yield (1002 kg/ha) followed by 100% RDF (973 kg/ha) and significantly lowest yield was observed in 75% RDF (857 kg/ha).

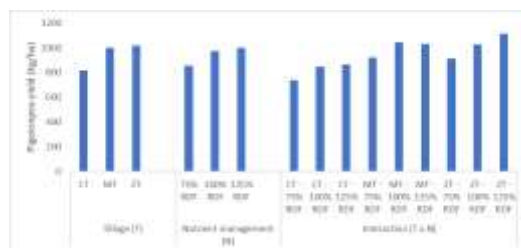


Fig 89. Effect of tillage and different fertilizer doses on grain yield of pigeonpea



Plate 42: Effect of conservation agriculture and nutrient management on the performance of pigeonpea

3. Cotton – Pigeonpea system

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 zero tillage (ZT- no till, direct seeded with residue retention), minimum tillage (MT- One ploughing, sowing with residue retention) and conventional tillage (CT- two ploughings with disk plough, one harrowing and sowing) as main plots and 75% RDF, 100% RDF (cotton: 100-50-50 and Pigeon pea: 20-50-0 kg N, P₂O₅, K₂O ha⁻¹) and 125% RDF as subplots. The subplots

were again divided into normal density planting (NDP) and high density planting (HDP) of cotton with a spacing of 90 × 30 cm and 90 × 15 cm respectively, to study the effect of tillage practices, different doses of fertilizers and planting density on performance of cotton (Suraksha) - pigeon pea (WRGE 93) rotation. Significantly higher seed cotton yield (2736.7 kg ha⁻¹), dry matter production (3675.07 kg ha⁻¹) and number of Sympodial branches per plant (9.66) was obtained in ZT at 100% RDF with HDP. Significantly higher boll weight (6.10 g) and number of bolls/plant (17.8) was observed in ZT at 125% RDF with NDP.

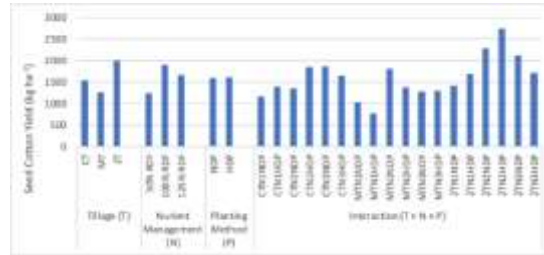


Fig 90. Effect of tillage, fertilizer doses and planting methods on seed cotton yield



Plate 43: Effect of conservation agriculture, nutrient management and planting density on the performance of cotton

C. Water Management in Conservation Agriculture

Soybean-Wheat Cropping Systems

IISS

Wheat crop 2023-2024

During the winter season wheat (cv. HI 1544) was grown with three irrigation methods (flood, sprinkler and drip irrigation), three tillage management treatments (CT, RT and NT) and four levels of fertilizer treatments (100% RDF, 75% RDF, STCR and Leaf colour chart-based fertilizer management, LCC). Measured amount of irrigation water was applied in each of the irrigation treatment plots. Flood irrigated plots in wheat received 5 post sowing irrigations and a seasonal total of 345 mm water was applied with 61 mm rainfall during the cropping season. In sprinkler irrigation plots a measured total amount of 285 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 224 mm of irrigation water (about 60% of the flood irrigation

water) was applied through drip system at alternate day interval throughout the season. Data showed that plant height, plant dry matter and tillers number did not of wheat did not affect significantly among the irrigation methods, tillage systems and different nutrient doses significantly affected the straw and grain yield of wheat crop. The data of NDVI value showed at 60 and 90 days after sowing of wheat. The NDVI value of wheat was significantly higher under drip and sprinkler irrigation as compared to flood irrigation. Similarly, the NDVI value of wheat was recorded significantly higher conventional tillage (CT) and reduced tillage RT) recorded significantly as compared to no tillage. Among the different nutrient doses, The NDVI value of wheat was also significantly higher under 100% RDF, STCR and LCC dose as compared to 75% RDF. The data of SPAD value showed at 60 and 90 days after sowing of wheat. The SPAD value of wheat did not affect by irrigation methods and tillage systems. But STCR and LCC dose recorded significantly higher SPAD value over 100% and 75 RDF. The average soil penetration resistance of 0-30 cm soil depth is higher under sprinkler irrigation and lower under drip irrigation followed by flood irrigation. Similarly, in case of tillage system, the higher soil penetration resistance recorded under no tillage system followed by flood irrigation and sprinkler irrigation (Table 3). The data of soil moisture content in different depth of 0-30 cm soil depth that soil moisture content was recorded slightly higher under drip irrigation followed by flood irrigation and lower was in sprinkler irrigation. Similarly, in case of tillage system, the higher soil moisture was recorded under no tillage system followed by flood irrigation and sprinkler irrigation. Data showed that the grain and straw yield of wheat did not affect significantly among the irrigation method, tillage system but different nutrient doses significantly affected the straw and grain yield of wheat crop. But water use efficiency (WUE) was significantly higher under drip irrigation follow by the sprinkler and lowest was under flood irrigation. The higher water productivity was attained under drip and sprinkler system of irrigation compared to that under flood irrigation where losses of water through surface evaporation, deep drainage was higher. Due to 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 crop. Conservation agricultural 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. Based on data, it can be concluded that the irrigation water can be saved 40% of flood requirement (12 cm) under drip irrigation and 20% of flood requirement (6 cm) under sprinkler irrigation as compared to flood irrigation requirement of wheat crop. The energy can be saved in term of fuel and labour by adopting reduced and no tillage conventional tillage system. Similarly, in case of fertilizer application, the fertilizer can be saved by 25% by because all the nutrient doses treatments recorded significantly similar grain yield of wheat.

Table 66: Effect of tillage systems and different nutrients doses under different irrigation systems on plant growth of wheat crop year 2023-2024

Treatments	Plant height (cm)		Plant dry matter (g/plant)			Root dry matter (g/plant)			Tiller Nos./plant
	60 DAS	90DAS	30DAS	60DAS	90DAS	30DAS	60DAS	90DAS	60DAS
Irrigation Methods									

FI	51.1	87.5	1.0	3.9	6.8	0.26	0.80	0.98	4.9
SI	49.9	86.5	1.2	4.1	7.1	0.28	0.89	1.54	5.5
DI	49.2	86.1	0.9	3.19	6.7	0.22	0.66	1.43	5.1
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tillage systems									
CT	50.8	86.9	1.1	3.92	6.6	0.27	0.85	1.25	4.9
RT	50.2	86.4	1.1	3.76	6.9	0.24	0.76	1.32	5.3
NT	49.3	86.8	1.0	3.50	7.1	0.24	0.74	1.38	5.2
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient doses									
F1	50.9	86.8	1.1	4.05	6.6	0.29	0.89	1.22	5.8
F2	50.4	86.6	1.0	3.54	7.1	0.23	0.74	1.38	4.8
F3	50.4	86.9	1.0	3.55	7.5	0.24	0.75	1.51	4.7
F4	48.8	86.5	1.1	3.79	6.3	0.24	0.77	1.15	5.3
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 67: Effect of tillage systems and different nutrients doses under different irrigation systems on NDVI and SPAD of wheat crop year 2023-2024

Treatments	NDVI value		SPAD (g/plant)	
	60 DAS	90DAS	60DAS	90DAS
Irrigation Methods				
FI	0.79	0.77	20.7	19.9
SI	0.81	0.80	22.7	19.9
DI	0.80	0.78	20.3	19.1
LSD (0.05)	0.014	0.017	NS	NS
Tillage systems				

CT	0.80	0.79	21.1	19.7
RT	0.80	0.79	20.7	20.2
NT	0.79	0.78	21.1	19.8
LSD (0.05)	0.005	0.005	NS	NS
Nutrient doses				
F1	0.80	0.79	20.5	19.1
F2	0.79	0.78	20.4	19.1
F3	0.80	0.79	21.5	20.8
F4	0.80	0.79	21.6	20.6
LSD (0.05)	0.005	0.006	1.002	0.77

Table 67: Effect of tillage systems and different nutrients doses under different irrigation systems on soil penetration resistance (SPR) under wheat crop year 2023-2024

Treatments	SPR (MPa) at 60 DAS				SPR (MPa) at 90 DAS			
	0-10 cm	10-20 cm	20-30 cm	Mean	0-10 cm	10-20 cm	20-30 cm	Mean
Irrigation Methods								
FI	0.76	1.10	1.34	1.07	0.84	1.47	1.65	1.32
SI	0.86	1.19	1.40	1.15	0.82	1.53	1.71	1.35
DI	0.59	0.91	1.21	0.90	0.82	1.40	1.53	1.25
LSD (0.05)	0.045	0.033	NS					
Tillage systems								
CT	0.69	1.03	1.31	1.01	0.85	1.45	1.51	1.27
RT	0.78	1.14	1.44	1.12	0.79	1.54	1.74	1.36
NT	0.74	1.03	1.22	0.99	0.83	1.40	1.64	1.29
LSD (0.05)	NS	NS	0.130					

Nutrient doses								
F1	0.70	1.01	1.22	0.98	0.83	1.44	1.57	1.28
F2	0.78	1.07	1.38	1.08	0.78	1.47	1.71	1.32
F3	0.75	1.11	1.35	1.07	0.85	1.43	1.55	1.27
F4	0.71	1.08	1.33	1.04	0.83	1.53	1.68	1.35
LSD (0.05)	NS	NS	NS		NS	NS	NS	

Table 68: Effect of different irrigation methods and tillage systems on soil moisture content in 0-30 soil depth in different dates under wheat crop year 2023-2024

	23/2/24	1/3/24	4/3/24	11/3/24	18/3/24	3/4/24	9/4/24	17/4/24	Mean
Irrigation methods									
FI	19.99	26.78	25.99	17.11	14.99	14.38	14.08	22.39	19.87
SI	16.23	25.22	22.60	15.74	15.10	14.05	13.25	20.54	18.16
DI	18.19	24.66	26.91	20.47	17.88	16.96	13.53	24.12	20.85
Tillage systems									
CT	19.82	25.21	24.19	17.48	15.03	14.76	13.19	21.73	19.42
RT	16.23	25.92	25.21	17.81	16.48	15.24	13.51	22.65	19.48
NT	18.36	25.52	26.09	18.03	16.46	15.38	14.15	22.68	19.98

Table 69: Effect of tillage systems and different nutrients doses under different irrigation systems on grain yield of wheat crop year 2023-2024.

	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Harvest Index (%)	WUE (kg ha ⁻¹ mm ⁻¹)
Irrigation Methods				
FI	52.3	59.6	0.46	15.0
SI	51.6	59.2	0.46	18.2
DI	51.3	58.5	0.46	22.9
LSD (0.05)	NS	NS	NS	2.92
Tillage systems				
CT	52.1	59.8	0.46	19.0

RT	52.2	59.3	0.46	18.5
NT	51.9	58.2	0.46	18.7
LSD (0.05)	NS	NS	NS	NS
Nutrient doses				
F1	51.6	59.6	0.46	18.7
F2	49.9	58.1	0.44	17.9
F3	53.0	59.2	0.47	19.4
F4	52.5	59.3	0.46	18.8
LSD (0.05)	NS	NS	NS	NS

Soybean Crop 2024

A field experiment conducted on soybean crop in kharif season in 2024. There were three levels of tillage systems (CT-Conventional tillage, RT-Reduced tillage and NT- No tillage) and three levels of fertilizer doses (F1=100 % RDF, F2=75% DRF, F3=STCR (soil test crop response) were tested in kharif season. The soybean was sown in month of June, 2024 and harvested in the month of October, 2024. The data showed on crop growth of soybean at 30, 60 and 90 days after sowing of soybean (DAS). The plant height and numbers of branches were increased with growth period. The tillage systems and nutrient doses did not affect the plant height and number of branches. There was no perfect trend under tillage systems and nutrient doses. during crop growth period. The nodule numbers, nodule dry wight and nodules volume did not affect by tillage systems and nutrient doses. The conventional tillage and no tillage recorded slightly higher numbers of nodules, nodules dry weight and nodule volume as compared to reduced tillage. The 100% RDF and STCR doses recorded higher number of nodules and nodule dry weight as compared to 75% RDF. The leaf area index of soybean did not affect by tillage systems and nutrient doses. There was no perfect trend under tillage system sand nutrient doses. The chlorophyll content of leaves was increased with growth period up to 60 days after sowing and it decreased at 90 days after sowing of soybean. The chlorophyll content did not affect by tillage systems and nutrient doses. There was no trend in chlorophyll content in soybean leaves (Table 5). The grain and straw yield of soybean was also not affected significantly by tillage system and nutrient doses. The grain and straw yield were slightly higher under reduced tillage as compared to conventional and no tillage. Similarly, grain and straw yield was slightly higher under 100% RDF and STCR dose as compared to 75% RDF. The based-on data, it can be concluded that the energy can be saved in term of fuel and labour by adopting reduced and no tillage conventional tillage system. Similarly in case of fertilizer application, the fertilizer can be saved by 25% by because all the nutrient doses treatments recorded significantly similar grain yield of soybean.

Table 70: Effect of tillage systems and fertilizer doses on plant height of soybean crop in 2024

	Plant height (cm)

Treatments	30 DAS				60 DAS				90 DAS			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	16.3	17.1	16.6	16.7	33.1	33.4	31.0	32.5	36.4	37.5	35.9	36.6
RT	17.9	17.0	17.5	17.4	34.4	34.2	33.7	34.1	36.4	38.0	39.0	37.8
NT	18.1	17.5	18.4	18.0	34.1	33.2	33.0	33.4	37.7	36.8	36.3	36.9
Mean	17.4	17.2	17.5	--	33.9	33.6	32.6	--	36.9	37.4	37.1	--
	Tillage (T): NS, Dose (D): NS T X D: NS				Tillage (T): NS, Dose (D): NST X D: NS				Tillage (T): NS, Dose (D): NST X D: NS			

Table 71: Effect of tillage systems and fertilizer doses on branch numbers of soybean crop in 2024

Treatments	Branches (Nos /plant)							
	30 DAS				60 DAS			
	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	3.3	3.0	3.2	3.2	3.8	4.1	3.8	3.9
RT	3.6	3.2	2.9	3.2	4.1	4.0	4.1	4.1
NT	4.0	3.5	3.5	3.7	4.5	4.0	4.2	4.3
Mean	3.6	3.2	3.2	--	4.2	4.1	4.0	--
	Tillage (T): NS, Dose (D): NS T X D: NS				Tillage (T): NS, Dose (D): NS T X D: NS			

Table 72: Effect of tillage systems and fertilizer doses on nodules numbers, nodule volume and nodule dry weight of soybean crop in 2024

Treatments	Nodule Numbers (nos./ plant)	Nodule dry weight (g/plant)	Nodule volume (cc/Plant)
	45 DAS		

	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	48.4	37.4	59.5	48.4	0.17	0.18	0.21	0.19	0.67	0.52	0.82	0.67
RT	50.2	40.4	41.9	44.2	0.16	0.16	0.16	0.16	0.69	0.56	0.58	0.61
NT	48.5	48.2	51.3	49.3	0.20	0.24	0.19	0.21	0.67	0.67	0.71	0.68
Mean	49.0	42.0	50.9	--	0.18	0.20	0.19	--	0.68	0.58	0.70	--
	Tillage (T): NS, Dose (D): NST X D: NS				Tillage (T): NS, Dose (D): NST X D: NS				Tillage (T): NS, Dose (D): NST X D: NS			

Table 73: Effect of tillage systems and fertilizer doses on LAI of soybean crop in 2024

Treatments	Leaf area index (LAI)											
	30 DAS				60 DAS				90 DAS			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	1.4	1.2	1.1	1.2	2.7	2.7	2.7	2.69	3.3	3.2	3.0	3.2
RT	1.2	1.2	1.2	1.2	2.8	3.1	3.3	3.05	3.0	3.3	3.3	3.2
NT	1.5	1.2	1.2	1.3	2.8	3.0	3.3	3.03	2.8	3.3	3.0	3.0
Mean	1.4	1.2	1.2		2.8	2.9	3.1		3.0	3.3	3.1	
	Tillage (T): NS, Dose (D): NST X D: NS				Tillage (T): NS, Dose (D): NST X D: NS				Tillage (T): NS, Dose (D): NST X D: NS			

Table 74: Effect of tillage systems and fertilizer doses on grain and straw yield of soybean crop in 2024

Treatments	Grain yield (Q ha ⁻¹)				Straw yield (Q ha ⁻¹)				Harvest index (%)			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	6.18	6.02	6.15	6.12	19.5	18.4	18.1	18.7	0.29	0.30	0.32	0.30
RT	6.04	6.33	6.98	6.45	20.2	20.6	23.3	21.4	0.29	0.30	0.31	0.30
NT	6.46	6.06	6.03	6.18	18.8	17.9	18.3	18.4	0.33	0.34	0.31	0.32
Mean	6.23	6.14	6.39		19.5	19.0	19.9		0.31	0.31	0.31	

	Tillage (T): NS, Dose (D): NST X D: NS	Tillage (T): NS, Dose (D): NST X D: NS	Tillage (T): NS, Dose (D): NST X D: NS
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Integration of in situ moisture conservation and weed management practices as complementary practices along with CA

An experiment was initiated at CRIDA with integration of in situ moisture conservation and weed management practices along with CA practices as complimentary practices. In 2024-2025 pigeonpea was the test crop. The *in-situ* moisture conservation practices were integrated with CA practices and different weed management practices were tested in split plot design. The *in situ* moisture conservation practices permanent bed and furrow (bed and furrow was made with raised bed planter in first year and in subsequent years the bed is reshaped during sowing), permanent conservation furrow (The conservation furrow was made in first year, every year the furrow was reshaped during sowing), CA (crop was sown directly without tillage, dhaincha was sown in between the maize/pigeonpea rows, dhaincha was cut at 45 DAS and applied as mulch), conventional tillage were taken as main plots and different weed management practices were tested in sub plots. This year integration of in-situ moisture conservation practices through permanent bed and furrow, permanent conservation furrow recorded 9% and 6 % 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. It was observed that ZTF recorded higher yield in control since dhaincha is grown as intercrop. (Fig. 91)

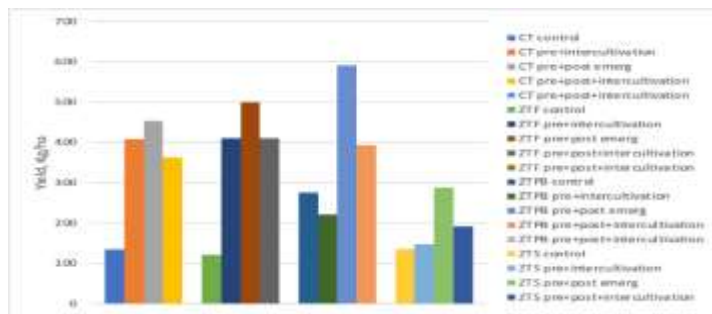
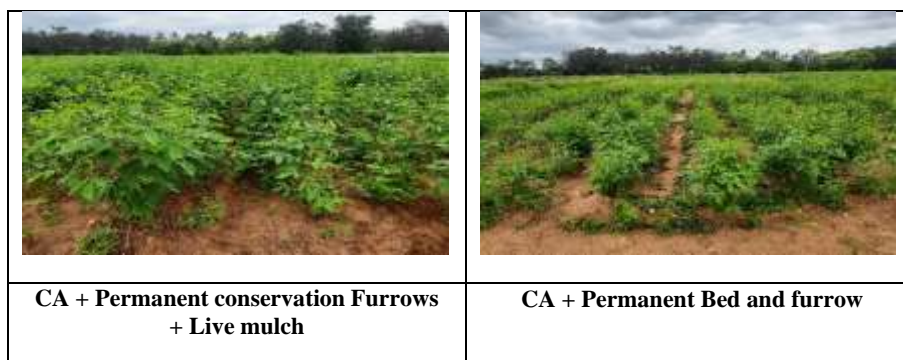


Fig 91. Influence of different treatments on Pigeonpea seed yield



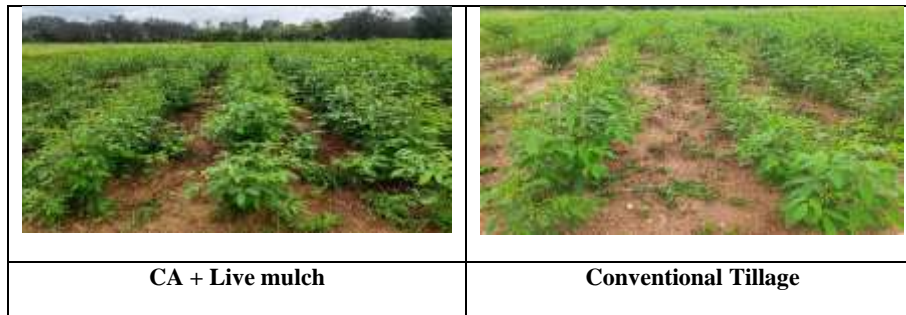


Plate 8: Performance of Pigeonpea in different treatments

Objective 2: Quantification of tangible and non-tangible effects

1. Physical Property

A. Mean Weight Diameter (MWD)

Rice-Wheat Cropping System

IARI

In rice-wheat system residue retention plots, T6 (triple cropping system) showed a significant increase in both mean weight diameter (MWD) (Table 75). MWD values in T6 were also highest at every depth, with 1.50 mm at 0–15 cm, indicating better aggregate stability and soil structure. Conversely, T7, the conventional system, consistently exhibited lower MWD, reflecting poor soil physical and biological health. These findings of our study are of significant importance to farmers, agricultural researchers, and agronomists, as they highlight the potential of CA practices to enhance soil health and yield.

Table 75: Effect of CA and CT on Mean Weight Diameter

Tr	Mean Weight Diameter MWD (mm)					
	0-15cm	15-30cm	30-45cm	45-60cm	60-75 cm	75-90 cm
T1	0.35e	0.36e	0.25cd	0.26cd	0.17c	0.25c
T2	0.55d	0.42d	0.29bc	0.23d	0.21b	0.3b
T3	0.60c	0.40e	0.26bcd	0.25d	0.21b	0.22d
T4	0.90b	0.76b	0.32b	0.3ab	0.24a	0.24cd
T5	0.57d	0.57c	0.23cd	0.25cd	0.24a	0.24c
T6	1.50a	1.51a	1.20a	0.30a	0.23a	0.43a
T7	0.35e	0.35e	0.22d	0.28bc	0.21b	0.25c

Maize-Wheat Cropping System

Conservation agriculture (CA) based crop management practices may improve crop productivity, while conserving and sustaining natural resources and improving soil physical properties. Therefore, we evaluated soil physical properties and their influence on crop productivity under a long-term CA based farming of maize -wheat cropping system. The CA based treatments were: Zero tillage with and without residue (ZT and ZT+R), Permeant broad bed with and without residue (PBB and PBB+R), permanent narrow bed with and without residue (PNB and PNB+R) and conventional tillage (CT). Residue application had improved MWD by 34.3% over non-residue plots where as 22.6% increase in K_{sat} was observed in the study (Fig 92).

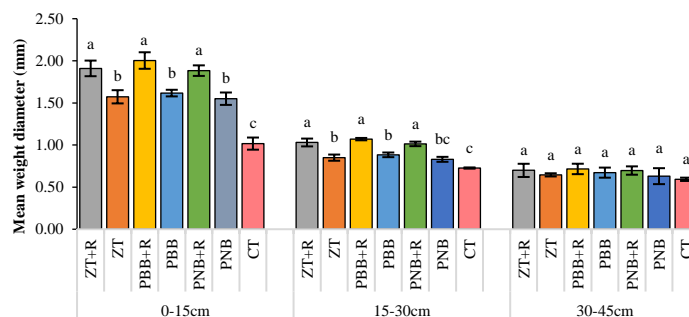


Fig 92. Effect of CT and CA-based management practices on mean weight diameter

**B. Bulk Density (BD)
Rice-Wheat Cropping System**

IARI

The use of intensive tillage and other management practices in crop production systems can cause soil erosion, decrease soil quality, water quality, and crop yield, and hinder the attainment of sustainable agricultural production systems. In the soil health indicators, were assessed under long-term conservation agriculture (CA)-based rice-wheat cropping system with seven treatments i.e., T1, Zero-till direct seeded rice (ZTDSR) –zero till wheat (ZTW); T2, ZTDSR + BM (Sesbania brown manuring)-ZTW; T3, Zero-till direct seeded rice (ZTDSR) + wheat residue (WR) -zero till wheat (ZTW) + rice residue (RR); T4, (ZTDSR)+wheat residue (WR) +sesbania brown manuring (SBM) –zero till wheat (ZTW) +rice residue (RR); T5, (ZTDSR) –zero till wheat (ZTW) –zero till mungbean (ZTMB); T6, (ZTDSR) + mungbean residue (MR) – (ZTW) + rice residue (RR) - zero till mungbean (ZTMB) + wheat residue (WR); T7, Transplanted rice (TPR)-conventional till wheat (CTW) – conventionally tilled mungbean (CTMB). The findings revealed that triple cropping systems with residue retention (T6) showed a significantly lower (5.1%) bulk density (BD) in the surface soil layer than triple cropping systems without residue retention (T5) (Table 76).

Table 76: Effect of different CA practices and CT on soil bulk density Treatments

Treatments	Soil bulk density B.D (Mg/m ³)			
	0-15cm	15-30cm	30-45cm	45-60cm
T1	1.50 ^b	1.66 ^b	1.79 ^a	1.49 ^d
T2	1.48 ^{cd}	1.80 ^a	1.68 ^{cd}	1.53 ^{cd}
T3	1.47 ^{cd}	1.70 ^b	1.68 ^{cd}	1.61 ^b
T4	1.47 ^{cd}	1.76 ^a	1.76 ^{ab}	1.56 ^{bc}
T5	1.54 ^a	1.79 ^a	1.64 ^d	1.70 ^a
T6	1.46 ^d	1.67 ^b	1.71 ^{bc}	1.69 ^a
T7	1.47 ^{cd}	1.76 ^a	1.76 ^{ab}	1.56 ^{bc}

**Maize-Wheat Cropping System
IARI**

Conservation agriculture (CA) based crop management practices may improve crop productivity, while conserving and sustaining natural resources and improving soil physical properties. Therefore, we evaluated soil physical properties and their influence on crop productivity under a long-term CA based farming of maize -wheat cropping system. The CA based treatments were: Zero tillage with and without residue (ZT and ZT+R), Permeant broad bed with and without residue (PBB and PBB+R), permanent narrow bed with and without residue (PNB and PNB+R) and conventional tillage (CT). Over the top 15 cm of soil, there was a 7.8% decrease in BD across the residue plots over non-residue plots, including CT (Fig 93). In 15–30 cm soil, under residue retention plots, BD decreased by 4.7% over non-residue plots.

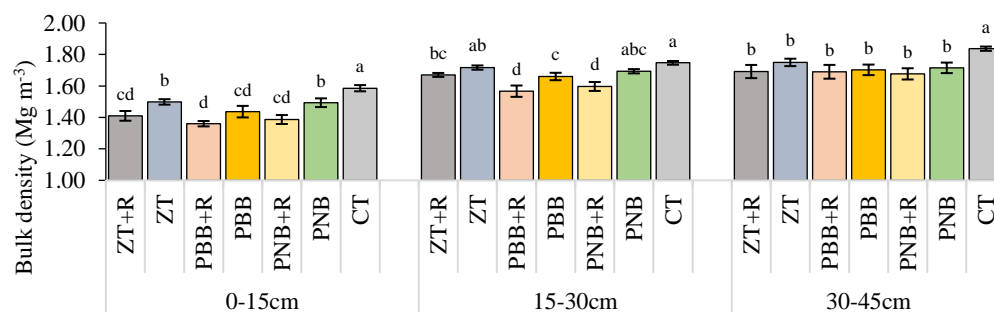


Fig 93. Effect of CT and CA–based management practices on bulk density

Maize-Pigeonpea Cropping System

In Maize-Pigeonpea cropping system 12.9% lower soil bulk density observed in NT and 6.8% lower soil bulk density observed in RT as compared to the CT. The difference between the NT and RT was 6.5%. 8.7% lower soil bulk density recorded in N125 as compared to the N-0. 21.9% and 11.6% higher soil total porosity observed in NT and RT as compared to the CT, respectively. The difference between NT and RT was 9.2%. 14.2% higher soil total porosity observed in N125 as compared to the N0.

In pigeonpea- finger millet sequence cropping system the initial soil properties of experimental site is depicted in Table 77. The soil is sandy loam in texture with porosity of 51.39% and moderate water holding capacity (44.26%).

Table 77: Physical, chemical and biological properties of initial soil in the experimental site (2017)

Bulk density (kg/m ³)	1.41
Porosity (%)	51.39
Maximum water holding capacity (%)	44.26
Particle density (g/cc)	3.13
Infiltration rate (cm hr ⁻¹)	6.3
Soil texture	Sandy loam

Soil Moisture and Bulk Density in Soybean

Both the parameters i.e. soil moisture content and bulk density at 0-7.5 cm and 7.5 – 15 cm were recorded and it was found that there was no significant difference in soil moisture content and bulk density among various tillage and nutrient treatments.

Table 78: Soil Moisture and Bulk Density in Soybean crop

Treatments	Moisture (%)		BD (gm/cc)	
	0-7.5 CM	7.5-15 CM	0-7.5 CM	7.5-15 CM
T1	22.29	21.74	1.16	1.20
T2	20.99	26.72	1.15	1.17
T3	18.04	23.96	1.07	1.16
T4	18.26	27.11	1.10	1.16
T5	17.41	27.93	1.12	1.18
CD	N/A	N/A	N/A	N/A
N100	19.80	27.55	1.12	1.17
N75	16.81	24.62	1.14	1.17
STCR	21.58	24.31	1.10	1.18
CD	N/A	N/A	N/A	N/A

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Moisture content and bulk density of soil as influenced by various treatments in Maize crop

Moisture content and bulk density of soil under different tillage and nutrient management treatments remained similar at both the soil depth i.e. 0-7.5 cm and 7.5 to 15 cm.

Table 79: Moisture content and bulk density of soil as influenced by various treatments in Maize crop

Treatments	Moisture (%)		BD (gm/cc)	
	0-7.5 CM	7.5-15 CM	0-7.5 CM	7.5-15 CM
T1	24.17	22.55	1.22	1.31
T2	24.88	22.28	1.22	1.28
T3	23.36	23.85	1.27	1.34
T4	24.38	23.18	1.23	1.29

T5	22.30	25.44	1.27	1.35
CD	N/A	N/A	N/A	N/A
N100	23.94	24.08	1.24	1.33
N75	23.46	22.96	1.23	1.28
STCR	24.05	23.34	1.21	1.32
CD	N/A	N/A	N/A	N/A

T1- No tillage + 30 cm crop residue, T2- No tillage+60cm crop residues T3- Reduced tillage+30 cm crop residues, T4- Reduced tillage+ 60cm crop residues, T5- conventional tillage. N100- Recommended dose of nutrients, N75- 75 % Recommended dose of nutrients, STCR- Nutrient dose on soil test crop response basis.

Bulk density in different cropping system

At 0-5 cm soil depth various cropping systems and tillage had no-significant influence on soil bulk density, however it ranged from 1.317 ± 0.007 to 1.34 ± 0.013 g/cm³ in upper soil layer. In deeper soil layer (5-10 cm) the values of bulk density were not influenced significantly by various cropping systems and tillage treatments, the values ranged from 1.413 ± 0.003 to 1.427 ± 0.003 g/cm³. It was observed that values of bulk density in upper layer of soil were lower than deeper layer.

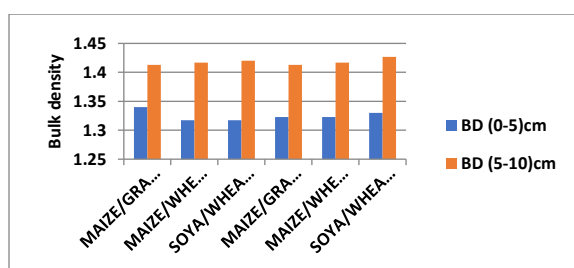


Fig 94. Bulk density in different cropping system

Maize-Chickpea Cropping System

Maize-Pigeonpea cropping system, pigeonpea- finger millet and cotton - pigeon pea cropping system

CRIDA

In Maize-Pigeonpea cropping system 12.9% lower soil bulk density observed in NT and 6.8% lower soil bulk density observed in RT as compared to the CT. The difference between the NT and RT was 6.5%. 8.7% lower soil bulk density recorded in N125 as compared to the N-0. 21.9% and 11.6% higher soil total porosity observed in NT and RT as compared to the CT, respectively. The difference between NT and RT was 9.2%. 14.2% higher soil total porosity observed in N125 as compared to the N0.

In pigeonpea- finger millet sequence cropping system the initial soil properties of experimental site is depicted in Table 9. The soil is sandy loam in texture with porosity of 51.39% and moderate water holding capacity (44.26%).

In cotton - pigeon pea cropping system a slight decrease in bulk density (1.55 Mg m^{-3}) in ZT as compared to CT (1.61 Mg m^{-3}) was observed.

Table 80: Physical, chemical and biological properties of initial soil in the experimental site (2017)

Bulk density (kg/m^3)	1.41
Porosity (%)	51.39
Maximum water holding capacity (%)	44.26
Particle density (g/cc)	3.13
Infiltration rate (cm hr^{-1})	6.3
Soil texture	Sandy loam

2. Soil Chemical Properties

A. Soil Organic Matter

The soil organic carbon contents remain unchanged under various cropping system in combination with different tillage practices at both the soil depth i.e. 0-5 and 5-10 cm. However, at upper soil layer (0-5 cm) organic carbon content values were tending on higher side over deeper soil layer (5-10 cm). But over all non-significant variation was observed with respective soil depth under various treatments. At 0-5 cm soil depth 0.66 ± 0.05 percent was observed low organic carbon content was associated with conventional tillage treatment in soybean-wheat system and high value 1.0 ± 0.061 percent associated with maize-chickpea cropping system along with no-tillage. However, at 5-10 cm soil depth organic carbon content varied from 0.64 ± 0.015 to 0.73 ± 0.025 percent

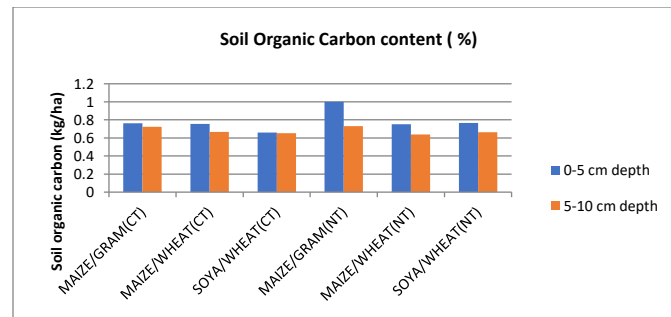


Fig 95. Effect of various cropping systems on SOC under different tillage practices

Soil Organic Carbon and Total Carbon in Rice - Wheat Cropping System

Tillage, crop establishment and residue management practices showed significant ($p < 0.001$) effect on SOC and TOC at both 0-15 and 15-30 cm soil depths. Higher SOC and TOC were recorded at surface soil (0-15 cm) in comparison to subsurface soil (15-30 cm). As compared to Sc-1 the SOC significantly increased by 20.50-30.43% in 0-15 cm and 12.41-21.90 % in 15-30

cm depth in rest of the scenarios (Sc-2 to Sc-5). TOC varied from 7.87-10.59 g kg⁻¹ showing an increase of about 15.89-34.58% in comparison to Sc-1 at surface soil. At subsurface depth, TOC varied from 7.43-10.07 g kg⁻¹ with an increase of 10.89-35.64% in comparison to Sc-1. The SOC and TOC stock statistically underscore difference with different tillage, crop establishment and residue management practices at both the soil depths. At surface soil SOC stock varied from 13.74-16.77 Mg ha⁻¹. An increase of 11.41-17.28 % in SOC stock was recorded in Sc-2 to Sc-5 in comparison to Sc-1. An overall reduction in SOC stock was recorded in subsurface depth, in comparison to surface soil. Whereas, higher TOC stock was recorded at subsurface soil depth in comparison to surface soil. Sc-5 recorded significantly higher TOC stock at both soil depth in comparison to Sc-1. The higher levels of SOC stock, in various scenarios compared to Sc-1 can be attributed mostly to the increased carbon input into the soil through various plant components such as straw, stubble, roots, and rhizodeposition (Datta et al., 2018; Mandal et al., 2007). Crop residue is a valuable source of organic matter that contributes to the increase of carbon stock in soil and its incorporation in fields reduces the incidence of residue burning (Liang et al., 2016). Furthermore, the implementation of long-term CTRM practice has been found to enhance soil aggregation and increase soil microbial activities, also demonstrated by studies conducted by Choudhury et al. (2018), Choudhury et al. (2014), Das et al. (2021), and Singh et al. (2019). These improvements are likely to lead to a substantial increase in SOC stock. In contrast conventional farming practices accelerate the oxidation of SOC by disrupting the soil and exposing the protected carbon to a process that ultimately reduces SOC levels (Six et al., 2002) which might be the reason for lower organic carbon levels in Sc-1. Multiple studies have documented a decrease in total organic carbon as a result of prolonged cultivation of annual crops without proper tillage and residue management practices in semiarid and sub-tropical areas (Majumder et al., 2008b; Srinivasarao et al., 2012; Anantha et al., 2022). Moreover, the highest SOC stock in Sc-3 can be attributed to the long-term integration of residues, which leads to increased carbon inputs (4.61 Mg ha⁻¹ yr⁻¹) and improved soil aggregation (Choudhury et al., 2014; Yadav et al., 2021).

Table 81: Effect of tillage, crop establishment and residue management practices on change in soil organic carbon (SOC), total organic carbon (TOC) and SOC and TOC stock after 17 years in rice-wheat system.

Scenarios/ treatments	SOC (g kg ⁻¹)	TOC (g kg ⁻¹)	SOC stock (Mg ha ⁻¹)	TOC stock (Mg ha ⁻¹)
0-15 cm				
Sc-1	5.96 ^d	7.87 ^d	13.74 ^b	18.12 ^c
Sc-2	7.19 ^c	9.12 ^c	16.30 ^a	20.69 ^b
Sc-3	7.30 ^{bc}	9.71 ^b	16.35 ^a	21.75 ^b
Sc-4	7.48 ^b	9.93 ^b	16.38 ^a	21.74 ^b
Sc-5	7.78 ^a	10.59 ^a	16.77 ^a	22.83 ^a
Trt	***	***	***	***

	15-30 cm			
Sc-1	5.07 ^d	7.43 ^d	12.69 ^c	18.58 ^d
Sc-2	5.70 ^c	8.24 ^c	14.14 ^b	20.42 ^c
Sc-3	6.00 ^{ab}	9.04 ^b	14.74 ^a	22.22 ^b
Sc-4	5.89 ^{bc}	9.49 ^{ab}	14.42 ^{ab}	23.23 ^{ab}
Sc-5	6.19 ^a	10.07 ^a	14.89 ^a	24.25 ^a
Trt	***	***	***	***

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. Where, Sc-1: Puddle transplanted rice - conventional tilled wheat, Sc-2: Reduce tilled direct seeded rice (RTDSR) - reduce tilled wheat (RTW); Sc-3: RTDSR-RTW + 1/3rd residue incorporation; Sc-4: Zero tilled direct seeded rice (ZTDST)-zero tilled wheat (ZTW); and Sc-5: ZTDST-ZTW + 1/3rd residue retention (RR)

Carbon pools and management indices

Soil organic carbon (SOC), and its various fractions were determined using a modified Walkley-Black method (Chan et al., 2001). Fractions were determined by utilizing different concentrations of sulphuric acid (H_2SO_4) 12 N, 18 N, and 24 N using 5, 10, and 20 mL of concentrated H_2SO_4 (36 N) and potassium dichromate ($K_2Cr_2O_7$) solution. The SOC was fractionated into four pools based on their decreasing oxidizing ability: very labile (VL), labile (L), less labile (LL), and non-labile (NL). VL carbon represented the carbon oxidized by 12 N H_2SO_4 , L carbon determined by the difference between 18 N and 12 N H_2SO_4 , LL is the difference between 24 N and 18 N H_2SO_4 (Walkley-Black oxidizable organic C, WBOC), and NL carbon represents the difference between total oxidizable carbon and that oxidized by 24 N H_2SO_4 . The active pool of SOC comprised VL and L carbon, while the passive pool was the sum of LL and NL carbon. Across the treatments, larger proportion of active pool (very labile + labile) was found in the surface soil layer (0-15 cm) compared to sub-surface soil (15-30 cm) (Figure 5).

Compared to surface soil (0-15 cm), very labile (VL), labile (L), and less labile (LL) carbon recorded a decline of 27.74, 11.61 and 10.33 %, respectively in sub-surface soil, whereas non-labile (NL) carbon increased by 33.91%. Sc-5 had the highest level of VL, L and NL carbon and the lowest was observed in the Sc-1 at both the soil depths. LL carbon was highest in Sc-4 (2.31 $g\ kg^{-1}$) at surface depth and Sc-2 (2.25 $g\ kg^{-1}$) at subsurface depth. Of the total soil organic carbon, VL and L (active pools) constituted more than 50% and are liable to be easily lost. LL and NL (passive pools) have lower proportion in total TOC but with tillage and residue management practice increased up to 26% in comparison to conventional tillage (Sc-1). The variation in soil carbon fractions is associated with the decomposition process. Initially, organic carbon from crop residues enters labile carbon pools and, over time, accumulates and transforms into more stable, recalcitrant carbon forms in the soil (Six et al. 2000). The increase in labile carbon pools under zero tillage with residue retention can be attributed to the addition of organic matter from the residue, while the rise in non-labile carbon is likely due to minimal soil disturbance, suggesting limited organic carbon oxidation in conservation tillage (Nandan et al. 2019; Dinesh et al. 2023). Previously, Chatterjee et al. (2018) also reported that application of wheat residue along with application of nitrogen through inorganic fertilizers can significantly

increase the total and labile carbon pool. Similarly, Dinesh et al. (2023), Sarkar et al. (2020) and Nandan et al. (2019) also reported that the adoption of zero tillage and residue retention in rice-wheat system led to enhanced labile and non-labile carbon pools.

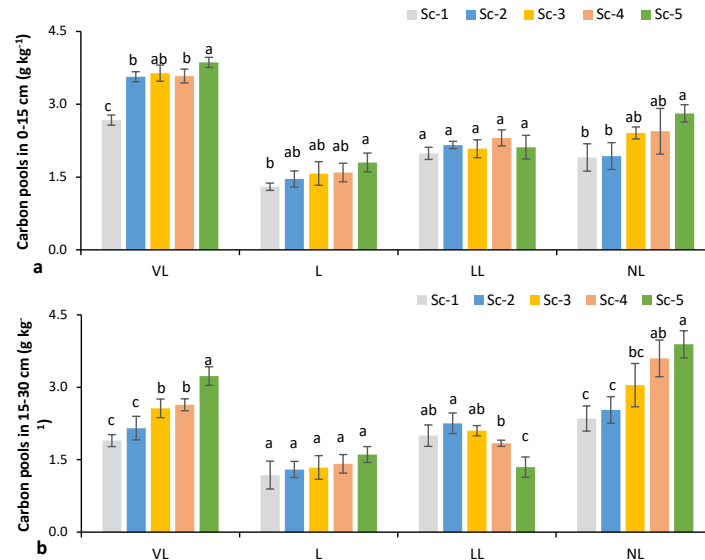


Fig 96. Effect of tillage, crop establishment and residue management practices on carbon pools at (a) 0-15 cm and (b) 15-30 cm soil depth in rice-wheat system.

Treatments with different lowercase letters differed significantly ($P < 0.05$, Tukey's Honest Significant Difference). Capped lines indicate \pm standard error from the mean. VL: very labile, L: labile, LL: less labile, and NL: non-labile. Where, Sc-1: Puddle transplanted rice - conventional tilled wheat, Sc-2: Reduce tilled direct seeded rice (RTDSR) - reduce tilled wheat (RTW); Sc-3: RTDSR-RTW + 1/3rd residue incorporation; Sc-4: Zero tilled direct seeded rice (ZTDST)-zero tilled wheat (ZTW); and Sc-5: ZTDSR-ZTW + 1/3rd residue retention (RR). The higher value for RI1, and RI mean were recorded in 15-30 cm compared to 0-15 cm depth (Figure 6; Table 6). Significantly higher RI1 (0.98; 1.43), and RI mean (0.61; 0.87) was recorded in Sc-1 at both the soil depths, respectively. RI2 increased with CTRM practices and Sc-5 recorded highest (0.27; 0.39) at both the soil depths, respectively. Sc-2 recorded lowest RI mean at 0-15 cm whereas at 15-30 cm depth, Sc-5 recorded lowest RI mean. Carbon Lability Index (CLI) was determined through relative proportions of different SOC pools (VL, L, LL) using equation 8 specified by Majumder et al. (2007). To derive a carbon management index, it is essential to consider both the carbon pool index (CPI) and its lability. The carbon pool index gives the total amount of carbon stored within a given system and indicates the overall capacity of the system to sequester and store carbon. Carbon Management Index (CMI) is a critical attribute for assessing the effectiveness of carbon management practices and understanding carbon dynamics. The determination of the CMI was carried out using the equation (9-12) proposed by Blair et al. (1995). The Stratification ratio (SR) measures the distribution of total organic carbon between the surface (0-15) and sub-surface (15-30 cm) layer and was computed using equation 13, as described by Franzluebbbers (2002). C build up rate was estimated using equation 14 described by Mishra et al., 2015. The Sensitivity index (SI) quantifies the magnitude of variation in TOC in treatments with different tillage and residue management practices. SI calculation was done using equation 15 (Banger et al., 2010).

$$CLI = \left(\frac{VL}{TOC} \times 3\right) + \left(\frac{L}{TOC} \times 2\right) + \left(\frac{LL}{TOC} \times 1\right) \quad (8)$$

$$CPI = \frac{TOC(\text{Treatment})}{TOC(\text{control})} \quad (9)$$

$$LI = \frac{LC(\text{Treatment})}{LC(\text{control})} \quad (10)$$

$$LC = \frac{\text{Very labile carbon}}{\text{Total Organic carbon-Very labile carbon}} \quad (11)$$

$$CMI = CPI \times LI \times 100 \quad (12)$$

$$SR = \frac{\text{Total Organic Carbon (0-15 cm)}}{\text{Total Organic carbon (15-30 cm)}} \quad (13)$$

$$C \text{ build up rate} = \frac{TOC(\text{Treatment}) - TOC(\text{control})}{\text{Year of experiment}} \quad (14)$$

$$SI = \frac{TOC(\text{Treatment}) - TOC(\text{control})}{TOC(\text{control})} \times 100 \quad (15)$$

Table 82: Effect of tillage, crop establishment and residue management practices on carbon lability index, recalcitrant index (mean) and carbon pool index after 17 years in rice wheat system.

Scenarios/ treatments	Recalcitrant index (mean)	Carbon lability index (CLI)	Carbon pool index (CPI)	Lability of Carbon (LC)	Lability index (LI)
	0-15 cm				
Sc-1	0.61 ^a	1.61 ^b	1.00 ^d	0.52 ^b	1.00 ^b
Sc-2	0.51 ^b	1.73 ^a	1.16 ^c	0.64 ^a	1.27 ^a
Sc-3	0.56 ^{ab}	1.66 ^{ab}	1.24 ^b	0.60 ^{ab}	1.17 ^{ab}
Sc-4	0.58 ^{ab}	1.64 ^{ab}	1.26 ^b	0.57 ^{ab}	1.10 ^{ab}
Sc-5	0.57 ^{ab}	1.63 ^{ab}	1.35 ^a	0.57 ^{ab}	1.12 ^{ab}
Trt	*	*	***	.	*
15-30 cm					
Sc-1	0.87 ^a	1.35	1.00 ^d	0.34 ^b	1.00 ^b
Sc-2	0.85 ^b	1.37	1.11 ^c	0.36 ^b	1.06 ^{ab}
Sc-3	0.83 ^c	1.38	1.22 ^b	0.40 ^{ab}	1.17 ^{ab}
Sc-4	0.86 ^{ab}	1.33	1.28 ^{ab}	0.39 ^{ab}	1.14 ^{ab}

Sc-5	0.74 ^d	1.42	1.36 ^a	0.48 ^a	1.39 ^a
Trt	***	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. Where, Sc-1: Puddle transplanted rice - conventional tilled wheat, Sc-2: Reduce tilled direct seeded rice (RTDSR) - reduce tilled wheat (RTW); Sc-3: RTDSR-RTW + 1/3rd residue incorporation; Sc-4: Zero tilled direct seeded rice (ZTDSR)-zero tilled wheat (ZTW); and Sc-5: ZTDSR-ZTW + 1/3rd residue retention (RR)

Irrespective of the treatments, carbon lability index (CLI) decreased with depth recording higher values at topsoil (0-15 cm) (Table 6). Sc-2 (1.73) and Sc-5 (1.42) recorded comparatively higher CLI values at both soil depth, respectively while the lowest (1.61, 1.35) CLI was obtained in Sc-1 for both the depths. While the treatments had no significant effect on CLI at the 15-30 cm depth, CTRM practices showed improved CLI when compared to Sc-1.

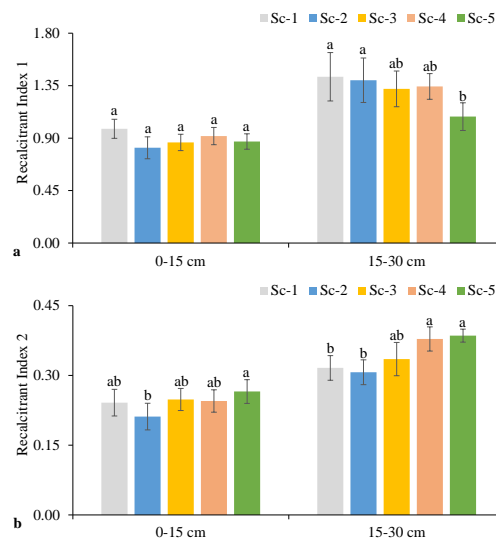


Fig 97. Effect of tillage, crop establishment and residue management practices on carbon recalcitrant index 1 (a) and recalcitrant index 2 (b) a 0- 15 cm and 15-30 cm soil depth in rice wheat system.

Vertical bars with different lowercase letters differed significantly ($P < 0.05$, Tukey's Honest Significant Difference). Capped lines indicate \pm standard error from the mean. Where, Sc-1: Puddle transplanted rice - conventional tilled wheat, Sc-2: Reduce tilled direct seeded rice (RTDSR) - reduce tilled wheat (RTW); Sc-3: RTDSR-RTW + 1/3rd residue incorporation; Sc-4: Zero tilled direct seeded rice (ZTDSR)-zero tilled wheat (ZTW); and Sc-5: ZTDSR-ZTW + 1/3rd residue retention (RR) CPI also significantly increased among different tillage, crop establishment and residue management practices and showed an increasing trend Sc-1 (1.00; 1.00) > Sc-2 (1.16; 1.11) > Sc-3 (1.24; 1.22) > Sc-4 (1.26; 1.28) > Sc-5 (1.35; 1.36) at both soil depth, respectively. Higher lability index (LI) and lability of carbon (LC) was recorded with different tillage, crop establishment and residue management practice in comparison to

farmer's practice at both the soil depths. Significantly higher LI (1.27) and LC (0.64) were recorded in Sc-2 at 0-15 cm soil depth and in Sc-5 (LI: 0.48; LC:1.39) at 15-30 cm.

Table 83: Effect of tillage, crop establishment and residue management practices on Sensitivity indices (SI), carbon management index (CMI), and C build up rate after 17 years in rice wheat system.

Scenarios/ treatments	Carbon management Index (CMI)	Sensitivity Index (%)	C build up rate (Mg C ha ⁻¹ yr ⁻¹)
	0-15 cm		
Sc-1	100.00 ^b	-	-
Sc-2	145.62 ^a	16.07 ^c	0.07 ^c
Sc-3	143.55 ^a	23.55 ^b	0.11 ^b
Sc-4	138.82 ^a	26.23 ^b	0.12 ^b
Sc-5	150.56 ^a	34.67 ^a	0.16 ^a
Trt	***	***	***
	15-30 cm		
Sc-1	100.00 ^c	-	-
Sc-2	117.35 ^{bc}	10.97 ^c	0.05 ^c
Sc-3	142.32 ^b	22.06 ^b	0.10 ^b
Sc-4	145.69 ^b	27.71 ^{ab}	0.12 ^{ab}
Sc-5	188.11 ^a	35.92 ^a	0.16 ^a
Trt	***	***	***

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. Where, Sc-1: Puddle transplanted rice - conventional tilled wheat, Sc-2: Reduce tilled direct seeded rice (RTDSR) - reduce tilled wheat (RTW); Sc-3: RTDSR-RTW + 1/3rd residue incorporation; Sc-4: Zero tilled direct seeded rice (ZTDST)-zero tilled wheat (ZTW); and Sc-5: ZTDSR-ZTW + 1/3rd residue retention (RR)

A significant improvement in CMI was recorded with different tillage, crop establishment and residue management practices at surface and subsurface soil depth (Table 83). The CMI is based on the SOC and C lability content and may represent soil management activities in promoting soil quality (Yang et al., 2018). Sc-5 recorded highest CMI (150.56; 188.11) at 0-15 and 15-30 cm depth, respectively. Higher CMI values in zero tillage with residue retention (Sc-5) implies requirement of relatively lesser carbon management practices compared to conventional practice

(Sc-1) attributed to fewer carbon fractions in Sc-1. Venkatesh et al (2013) and Blair et al (2006) also found that crop residues along with inorganic fertilizer significantly enhanced CMI in long run.

The SI has proven to be a valuable indicator for predicting the carbon build up in soil resulting from tillage and residue management strategies, as compared to conventional tillage. SI ranged from 16.07 to 34.67 % and 10.97 to 35.92 % at 0-15 and 15-30 cm depth, respectively (Table 83). Residue retention increased the sensitivity index by 46.98 and 32.18 % under reduced and zero tillage, respectively at 0-15 cm soil depth. Similarly at 15-30 cm depth also increased SI was obtained in residue amended treatments. To study the effect of long term (170-years) addition of crop residue and minimum/ zero tillage on carbon add up in soil, carbon build up rate was calculated. The results showed an annual build of 0.07-0.11 and 0.12-0.16 Mg C ha⁻¹ yr⁻¹ in reduced and zero tillage, respectively at the depth of 0-15 cm. Following the same trend higher C build up rate was recorded under zero tillage than reduced tillage. The large organic matter returns and minimum soil disturbance protected the organic carbon from oxidation and were responsible for greater carbon build up under zero tillage with residue retention (Sc-5).

The stratification ratio (SR) measuring the distribution of total organic carbon between the surface (0–15) and sub-surface (15–30 cm) layer recorded a significant effect CTRM. The results revealed that the significantly highest (1.11) stratification ratio (SR) was observed under Sc-2, while the lowest SR was recorded in Sc-5 (1.05) and Sc-4 (1.05), which was statistically at par with Sc-1 (1.06). The higher SR under Sc-2 (reduced tillage) can be attributed to the higher soil organic carbon (SOC) content in the surface layer (0–15 cm). This is likely due to the reduced soil disturbance and the incorporation of residues into the soil, which promotes SOC accumulation at the surface whereas in Sc-1 (conventional tillage with residue removal), the continuous mixing of soil through intensive tillage operations and the removal of crop residues resulted in a relatively uniform distribution of SOC across soil depths, thereby diminishing the SOC difference between the surface and subsurface layers. Sc-5 (zero tillage with residue retention) exhibited the lowest SR, which can be explained by the distribution of organic matter. In zero tillage, residues or stubbles remain anchored on the soil surface, contributing to a relatively uniform SOC distribution. Given that the rooting depth of rice and wheat often exceeds 50 cm, the organic matter content tends to be relatively stable down to 30 cm, leading to similar total organic carbon (TOC) levels in both the surface and subsurface layers hence the lowest SR under zero tillage.

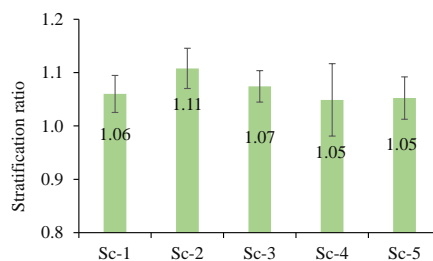


Fig 98. Effect of tillage, crop establishment and residue management practices on stratification ratio in rice-wheat system.

Vertical bars with different lowercase letters differed significantly ($P < 0.05$, Tukey's Honest Significant Difference). Capped lines indicate \pm standard error from the mean. Where, Sc-1: Puddle transplanted rice - conventional tilled wheat, Sc-2: Reduce tilled direct seeded rice (RTDSR) - reduce tilled wheat (RTW); Sc-3: RTDSR-RTW + 1/3rd residue incorporation; Sc-

4: Zero tilled direct seeded rice (ZTDST)-zero tilled wheat (ZTW); and Sc-5: ZTDSR-ZTW + 1/3rd residue retention (RR)

Maize- Wheat Cropping System

IARI

Conservation agriculture (CA) based crop management practices may improve crop productivity, while conserving and sustaining natural resources and improving soil physical properties. Therefore, we evaluated soil physical properties and their influence on crop productivity under a long-term CA based farming of maize -wheat cropping system. The CA based treatments were: Zero tillage with and without residue (ZT and ZT+R), Permeant broad bed with and without residue (PBB and PBB+R), permanent narrow bed with and without residue (PNB and PNB+R) and conventional tillage (CT). At the plough layer (0–15cm), the SOC was recorded under PBB+R (9.98 g kg⁻¹).

Table 84: Effect of CT and CA–based management practices on soil organic carbon content

Treatment	Soil organic carbon (g kg ⁻¹)		
	0–15 cm	15–30 cm	30-45cm
ZT+R	9.47 ^{a*}	6.20 ^a	4.78 ^a
ZT	7.21 ^b	5.59 ^c	4.65 ^a
PBB+R	9.98 ^a	6.28 ^{ab}	4.84 ^a
PBB	7.24 ^b	5.69 ^b	4.71 ^a
PNB+R	9.29 ^a	6.13 ^{ab}	4.73 ^a
PNB	6.89 ^b	5.49 ^c	4.57 ^a
CT	6.04 ^c	4.97 ^d	4.53 ^a

Soybean-Wheat Cropping System

IISS

Modelling the soil organic carbon dynamics under no till system with different levels of residue retention using Rothamsted carbon model

Soil carbon storage and sequestration through better management practices produce several benefits in terms of enhancement in soil fertility, microbial diversity and soil water storage capacity and overall crop productivity as well as greenhouse gas mitigation. Long-term conservation agriculture experiment conducted at ICAR-IISS, Bhopal since 2015 provides an opportunity to assess the impact of different levels of residue retention under no tillage soybean-wheat cropping system on soil carbon storage and sequestration in Vertisols of central India. Here, an attempt was made to

parameterize and validate the global carbon model-RothC using the data of CRP on CA and further simulate the long-term impact of retention of different levels of residues on soil carbon dynamics in high clayey soils of Madhya Pradesh. The experiment was having four different levels of residues (0, 30, 60, and 90%) under no tillage system along with a treatment of conventional agriculture. The site was established on a Vertisol under sub-humid, dryland conditions. Using long-term climate, soil, and residue management inputs, the Rothamsted Carbon (RothC) model was applied to assess the current and future SOC stocks in the Vertisols. The carbon input varies from 2.02, 2.54, 3.08, 3.970 and 5.1 Mg ha⁻¹ yr⁻¹ under the treatments of conventional agriculture (CA), NT (0%), NT (30%), NT (60%) and NT (90%), respectively. Carbon input under the different treatments were calculated using the equation of Bolinder et al, (2007). Carbon input under the different treatments of residue retention under soybean-wheat cropping system was computed using average grain yield data of 2015-2021 (Bolinder et al., 2007). Soil carbon content was determined using dry combustion method. Accordingly, soil carbon stock was determined to the depth of 20 cm. The IOM value for the 0–20 cm soil layer was calculated using the formula ($IOM = 0.049 \times SOC^{1.139}$) of Falloon et al. (1998), based on measured SOC stock at the start of the experiments. The IOM, along with the other carbon pools (Decomposing Plant Material - DPM, Resistant Plant Material - RPM, and Humus - HUM), contribute to the total soil organic carbon (SOC). The IOM pool was 1.9189 Mg ha⁻¹. The conventional agriculture treatment was used to calibrate the model because average annual C inputs required to maintain SOC stocks in this treatment were assumed to be the same before and after equilibrium as these fields were previously under soybean-wheat cropping system. In fitting the RothC model to experimental data, the model was initialized by running for weather and soil conditions of Bhopal for 10,000 years ending in 2015 for the soybean-wheat cropping system. The DPM:RPM ratios used in this study were 1.44 for conventional agriculture system and residue retention under the no tillage system. Soil organic C stocks significantly differed across treatments of residue retention under no tillage system. Annual carbon input bears positive and significant relationship with soil carbon stock (Fig 99). It was highest (32.87Mg ha⁻¹) in 90% residue retained plot. Retention of 0, 30 and 60% of residue of previous crops accumulated 28.35, 29.24, and 29.75 Mg ha⁻¹ of carbon storage, respectively. The RMSE of modelled output is 0.80. In this case, the RMSE represents a relatively small average deviation between the observed and predicted values, suggesting reasonable model performance. The Roth C model can be parameterized to predict soil carbon storage under the practice of no till system with different levels of residue retention (Fig 99 & 100). The changes in soil carbon pools under different levels of residue retention is depicted in table 1. It was observed that retention of residue to the tune of 0, 30, 60 and 90% under no till system resulted in improvement in 6, 11, 21 and 36% improvement in soil total carbon stock over the conventional agriculture system, respectively. Among the different pools of soil organic carbon, maximum improvement in soil carbon stock was recorded in decomposable plant material pool. DPM pool increased by 30, 56, 100 and 159% under 0, 30, 60 and 90% of residue retention treatment, respectively.

Table 85: Changes in soil carbon pools under different levels of residue retention in soybean-wheat cropping system

Carbon pools	NT-90%	NT-60%	NT-30%	NT-00%	CT-00
DPM	0.7	0.54	0.42	0.35	0.27
RPM	7.41	5.76	4.53	3.78	3.05
BIO	1.12	0.89	0.71	0.6	0.5
HUM	22.76	21.24	20.35	19.8	19.27
IOM	1.91	1.91	1.91	1.91	1.91
Total	33.92	30.35	27.94	26.46	25.03

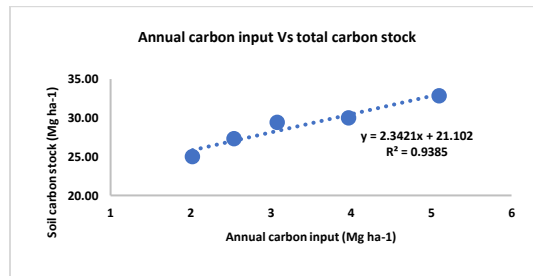


Fig 99. Relationship between annual carbon input and soil carbon stock

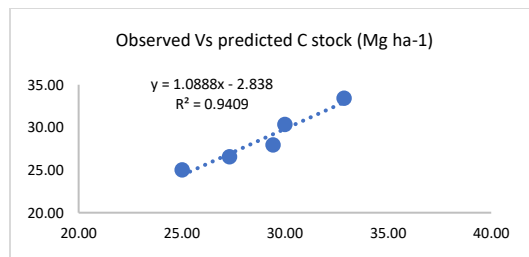


Fig 100. Relationship between observed and predicted carbon stocks using RothC model

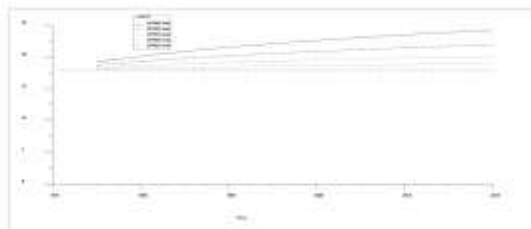


Fig 101. Predicted soil carbon stocks under different levels of residue retention under no till system in soybean-wheat cropping system of central India

Maize-chickpea cropping system

Cotton-Wheat System

IIFSR

Various cropping system

The data related to changes in WBC over the years of conservation agriculture practices are depicted in fig. 102 a and b. A significant improvement in the in soil organic carbon measured using the Walkley Black method was recorded in CA based management practices over the years. Data showed 49.5% increase in WBC across the CA based treatments in 2024 over the year 2017. WBC also showed an improvement in conventional practices, which might be due to inclusion of green gram in the cropping systems. At the same time significantly 16.3% reduction in soil bulk density across the CA based management practice were also recorded after 9 years of CA management practices in diverse cropping systems.

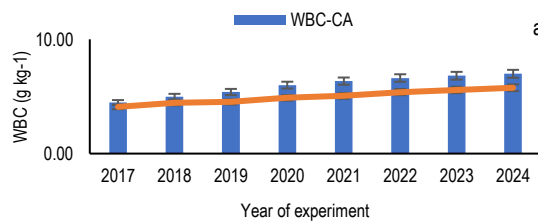


Fig. 102. (a) Changes in Walkley Black Carbon (WBC) over the years in CA and CP based management practices.

CRIDA

In maize-pigeonpea cropping system integration of in situ moisture conservation and weed management along with CA practices influenced the Organic carbon. Permanent conservation furrow and permanent bed and furrow and Zero tillage recorded 20%, 23% and 64% higher organic carbon as compared to conventional tillage respectively. In Sorghum-Blackgram cropping system, Soil samples were collected after harvest of horsegram from 0-7.5, 7.5-15 and 15-30 cm depths and analyzed for organic carbon showed no significant difference with tillage or residue management at any of the depths (Fig 103).

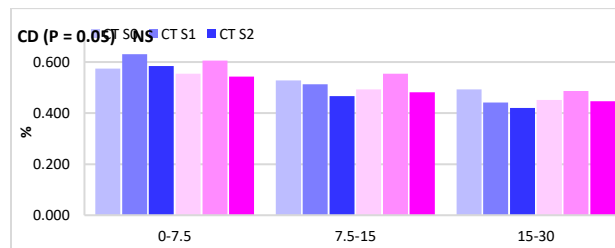


Fig. 103. Effect of tillage and residue management on soil organic carbon

In cotton – Pigeonpea system, higher soil organic carbon (SOC) was observed in ZT (0.67) and MT (0.66) as compared to CT.

In Soyabean-Chickpea cropping system, the data on organic carbon content in soil as influenced by various treatments was found to be significant. However, significantly higher organic carbon content (6.66 g kg^{-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 organic carbon(5.92 g kg^{-1})was recorded with Conventional tillage (CT) - Pre sowing harrowing + One hoeing + One hand weeding + No crop residue mulch(T_2).

Table 86: Organic carbon status of soil as influenced by various treatments during 2024-25

Treatment	Organic carbon (g/kg)
T ₁	6.45
T ₂	5.92
T ₃	6.66
T ₄	6.20
T ₅	6.11
SE(m±)	0.07
CD(5%)	0.23

Maize-Mustard System

B. Active or KMnO4 oxidizable carbon

IARI

In the soil health indicators, were assessed under long-term conservation agriculture (CA)-based rice-wheat cropping system with seven treatments i.e., T1, Zero-till direct seeded rice (ZTDSR) –zero till wheat (ZTW); T2, ZTDSR + BM (Sesbania brown manuring)-ZTW; T3, Zero-till direct seeded rice (ZTDSR) + wheat residue (WR) -zero till wheat (ZTW) + rice residue (RR); T4, (ZTDSR)+wheat residue (WR) +sesbania brown manuring (SBM) –zero till wheat (ZTW) +rice residue (RR); T5, (ZTDSR) –zero till wheat (ZTW) –zero till mungbean (ZTMB); T6, (ZTDSR) + mungbean residue (MR)

– (ZTW) + rice residue (RR) -zero till mungbean (ZTMB) + wheat residue (WR); T7, Transplanted rice (TPR)-conventional till wheat (CTW) – conventionally tilled mungbean (CTMB). The findings revealed that T6 recorded highest labile organic carbon (LOC) (Table 87). Conversely, T7, the conventional system, consistently exhibited lower LOC.

Table 87: Effect of CA and CT on Soil Labile Carbon and Mean Weight Diameter

Tr	Labile Organic Carbon (g/kg)					
	0-15cm	15-30cm	30-45cm	45-60cm	60-75 cm	75-90 cm
T1	1.84c	1.15cd	0.95d	0.38f	0.31e	0.27d
T2	2.01bc	1.27c	1.17c	0.47e	0.46d	0.31d
T3	2.05bc	1.43b	1.15c	0.78c	0.61b	0.39bc
T4	2.35b	1.66a	1.27b	1.02b	0.54c	0.43b
T5	2.14bc	1.43b	1.11c	0.82c	0.46d	0.39c
T6	3.06a	1.76a	1.43a	1.193a	0.77a	0.49a
T7	1.30d	1.12d	0.80e	0.63d	0.47d	0.15e

CRIDA

C. Carbon Sequestration in Rice-Wheat System

Although conservation agriculture (CA) has been promoted for sustainable agriculture, limited information is available on the long-term effect on CA on carbon stabilization, soil carbon pools, temperature sensitivity of soil organic carbon (SOC) decomposition, soil aggregation and aggregate-associated C and C cycling enzyme activities in rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) cropping system. Hence, a nine year CA field experiment was selected with seven treatments namely, zero tilled direct seeded rice (ZTDSR)- zero tilled wheat (ZTW), Wheat residue (WR) + ZTDSR – rice residue (RR) + ZTW, WR + ZTDSR + brown manuring (BM) – RR + ZTW, ZTDSR – ZTW – ZT mungbean (MB), Mungbean residue (MBR) + ZTDSR – RR + ZTW – WR + ZTMB, Puddled transplanted rice (TPR) – ZTW, TPR – conventionally tilled wheat (CTW) laid out in a randomized block design with three replications. Results revealed that the total SOC sequestration rates of MBR+ZTDSR-RR+ZTW-WR+ZTMB ($0.752 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) was highest followed by WR+ZTDSR+BM-RR+ZTW ($0.553 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) and WR+ZTDSR-RR+ZTW ($0.514 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) plots (Table 88). After nine years of CA practices, the MBR+ZTDSR-RR+ZTW-WR+ZTMB plots had around ~29.9% more total SOC concentrations in the topsoil (0-5 cm) than TPR-CTW plots (7.77 g kg^{-1}). In the topsoil (0-5 cm), the MBR+ZTDSR-RR+ZTW-WR+ZTMB plots had ~23.0% more total SOC stock than CT plots ($6.07 \text{ Mg C ha}^{-1}$).

Table 88: Effect of long-term conservation agriculture on total organic carbon sequestration rate ($\text{Mg C ha}^{-1} \text{ yr}^{-1}$) in bulk soils under a rice-wheat cropping system in an Inceptisol

Total organic carbon sequestration rate (Mg C ha ⁻¹ yr ⁻¹)		
Treatments	0-30 cm	30-60 cm
ZTDSR-ZTW	0.282bc	0.064a
WR+ZTDSR-RR+ZTW	0.514abc	0.029a
WR+ZTDSR+BM-RR+ZTW	0.553ab	0.059a
ZTDSR-ZTW-ZTMB	0.387abc	0.053a
MBR+ZTDSR-RR+ZTW-WR+ZTMB	0.752a	0.070a
TPR-ZTW	0.233c	0.05a

*Means with different lowercase letters within a column are significantly different at $p < 0.05$ according to Tukey's HSD test.

The MBR+ZTDSR-RR+ZTW-WR+ZTMB had ~27.9% higher labile C than TPR-CTW plots (4.55 g kg⁻¹) in bulk soil. The MBR+ZTDSR-RR+ZTW-WR+ZTSOC plots had ~31% higher macroaggregate-associated carbon than TPR-CTW plots and ~46.3% higher labile C within macroaggregates than TPR-CTW plots (5.21 g kg⁻¹) showing that residue retention had positively influenced the SOC pool (Table 89).

Table 89: Effect of long-term conservation agriculture on aggregate-associated C (g kg⁻¹) in the 0-5 cm soil depth under a rice-wheat cropping system in an Inceptisol

Treatments	Macroaggregate-C	Microaggregate-C	Silt+Clay-C
ZTDSR-ZTW	10.9 ^{cd}	6.42 ^{cd}	4.45 ^{bc}
WR+ZTDSR-RR+ZTW	12.0 ^b	7.05 ^{abc}	4.72 ^{abc}
WR+ZTDSR+BM-RR+ZTW	12.1 ^{ab}	7.15 ^{ab}	4.91 ^{ab}
ZTDSR-ZTW-ZTMB	11.9 ^{bc}	6.47 ^{bcd}	4.53 ^{bc}
MBR+ZTDSR-RR+ZTW-WR+ZTMB	13.5 ^a	7.20 ^a	5.12 ^a
TPR-ZTW	10.7 ^d	6.33 ^d	4.31 ^c
TPR-CTW	10.3 ^d	6.20 ^d	4.22 ^c

*Means with different lowercase letters within a column are significantly different at $p < 0.05$ according to Tukey's HSD test

The MBR+ZTDSR-RR+ZTW-WR+ZTMB had ~35.5% higher recalcitrant C concentrations than TPR-CTW plots (3.14 g kg⁻¹) in the 0-5 cm soil layer. The highest C_t value was recorded in the MBR+ZTDSR-RR+ZTW-WR+ZTMB plots in all the three temperatures for bulk soil, macroaggregates and microaggregates (Table 89). Higher K_c values were observed in TPR-CTW plots, while CA plots had lower decay rates in the topsoil due to higher recalcitrant C to total SOC concentration. The Q₁₀ values revealed that SOC in TPR-CTW plots was more sensitive to temperature changes than ZT plots with residue retention (CA plots). The plots under TPR-CTW were more sensitive to temperature rise in bulk soils, macroaggregates and microaggregates. The ZT plots with residue retention had a higher proportion of macroaggregates and lower microaggregates than TPR-CTW plots in both soil depths, indicating the positive effect of CA practices on soil aggregation. The MBR+ZTDSR-RR+ZTW-WR+ZTMB plots had ~31% higher macroaggregate-associated carbon than TPR-CTW plots and ~46.3% higher labile C within macroaggregates than TPR-CTW plots (5.21 g kg⁻¹) in the 0-5 cm soil depth, showing that residue retention had positively influenced the SOC pool. The MBR+ZTDSR-RR+ZTW-WR+ZTMB plots had higher proportions of coarse particulate organic matter within macroaggregates (cPOM_M) and lower silt+clay within macroaggregates (s+c_M) than TPR-CTW plots in the 0-5 and 5-15 cm soil depths (Table 90), indicating the positive impact of CA on organic matter retention within aggregates.

Table 90: Effect of long-term conservation agriculture on temperature sensitivity of soil organic carbon mineralization from bulk soils and within aggregates under a rice-wheat cropping system in an Inceptisol.

Treatments	Bulk Soil	Macroaggregates	Microaggregates
WR+ZTDSR-RR+ZTW	1.21 ^c	1.19 ^b	1.10 ^{cd}
WR+ZTDSR+BM-RR+ZTW	1.14 ^d	1.14 ^b	1.09 ^{cd}
ZTDSR-ZTW-ZTMB	1.24 ^{bc}	1.23 ^b	1.15 ^{bc}
MBR+ZTDSR-RR+ZTW-WR+ZTMB	1.20 ^{cd}	1.13 ^b	1.08 ^d
TPR-ZTW	1.44 ^a	1.43 ^a	1.35 ^a
TPR-CTW	1.42 ^a	1.43 ^a	1.35 ^a

*Means with different lowercase letters within a column are significantly different at $p < 0.05$ according to Tukey's HSD test

The MBR+ZTDSR-RR+ZTW-WR+ZTMB plots exhibited higher total organic carbon concentrations within coarse-particulate organic matter in macroaggregates (cPOM_M), light fractions in microaggregates inside macroaggregates (LF_{mM}), intra-aggregate particulate organic matter in microaggregates inside macroaggregates (iPOM_{mM}), and silt+clay in microaggregates inside macroaggregates (s+c_{mM}) fractions compared with TPR-CTW plots, indicating improved carbon retention and stabilization in CA soils (Table 91).

Table 91: Effect of long-term conservation agriculture on soil density fractions (%) in the 0-5 cm soil depth under a rice-wheat cropping system in an Inceptisol

Treatment s*	Soil density fractions (%)								
	cPOM _M	s+c _M	LF _{mM}	iPOM _{mM}	s+c _{mM}	LF _m	iPOM _m	s+c _m	s+c _B
ZT ₁	5.81 ^b	9.65 ^a	5.29 ^{bc}	20.9 ^b	6.41 ^{ab}	5.32 ^a	22.6 ^c	10.8 ^b _c	13.10 ^{ab}
CA ₁	8.22 ^a	8.21 ^{bc}	5.76 ^{ab}	22.3 ^{ab}	7.30 ^a	5.36 ^a	22.7 ^c	8.85 ^d	11.30 ^b
CA ₂	8.14 ^a	9.13 ^{ab}	5.30 ^{bc}	22.2 ^{ab}	6.09 ^{ab}	5.29 ^a	22.3 ^c	9.66 ^c _d	11.90 ^b
ZT ₂	6.18 ^b	9.81 ^a	4.97 ^{bc}	21.2 ^b	6.94 ^a	5.31 ^a	21.9 ^c	11.2 ^b	12.45 ^b
CA ₃	8.40 ^a	7.28 ^c	6.86 ^a	23.7 ^a	6.64 ^a	5.41 ^a	23.2 ^{bc}	7.33 ^c	11.21 ^b
AT	3.96 ^c	9.82 ^a	4.11 ^{cd}	18.9 ^c	6.53 ^{ab}	5.03 ^a	24.7 ^{ab}	12.1 ^a _b	14.80 ^a
CT	3.21 ^c	10.3 ^a	3.02 ^d	18.3 ^c	5.22 ^b	4.95 ^a	26.2 ^a	13.4 ^a	15.40 ^a

*Means with different lowercase letters within a column are significantly different at $p < 0.05$ according to Tukey's HSD test. * Zero tilled direct seeded rice (ZTDSR)- zero tilled wheat (ZTW), denoted as ZT₁, Wheat residue (WR) + ZTDSR - rice residue (RR) + ZTW, denoted as CA₁, WR + ZTDSR + brown manuring (BM) - RR + ZTW, denoted as CA₂, ZTDSR - ZTW - ZT mungbean (MB), denoted as ZT₂, Mungbean residue (MBR) + ZTDSR - RR + ZTW - WR + ZTMB, denoted as CA₃, Puddled transplanted rice (TPR) - ZTW, denoted as AT (alternate tillage), TPR - conventionally tilled wheat (CTW), denoted as CT (conventional tillage), Coarse particulate organic matter within macroaggregates (cPOM_M), silt+clay within macroaggregates (s + c_M), light fraction within microaggregates inside macroaggregates (LF_{mM}), intra-aggregate particulate organic matter within microaggregates inside macroaggregates (iPOM_{mM}), silt+clay within microaggregates inside macroaggregates (s + c_{mM}), light fraction inside microaggregates (LF_m), intra-aggregate particulate organic matter within microaggregates (iPOM_m), silt+clay within microaggregates (s + c_m), silt+clay of bulk soil (s+c_B).

The MBR+ZTDSR-RR+ZTW-WR+ZTMB plots showed maximum C stabilization (2.42 g C/1000 g bulk soil) within iPOM_{mM} which was 95% higher than TPR-CTW plots in top soil (Table 92).

Table 92: Effect of long-term conservation agriculture on SOC concentrations within density fractions (g kg⁻¹) in the 0-5 cm soil depth under a rice-wheat cropping system in an Inceptisol

Treatments*	cPOM _M	s+c _M	LF _{mM}	iPOM _{mM}	s+c _{mM}	LF _m	iPOM _m	s+c _m	s+c _B
ZT ₁	10.12 ^{bc}	9.53 ^{abc}	11.05 ^{ab}	7.02 ^b	8.72 ^{bc}	9.85 ^{ab}	7.29 ^{bc}	7.58 ^{bc}	4.45 ^b _c

CA ₁	12.47 ^{ab}	12.01 ^a	13.24 ^a	9.03 ^{ab}	9.96 ^{ab}	11.64 ^a	8.96 ^{ab}	9.01 ^{ab}	4.72 ^a bc
CA ₂	12.68 ^{ab}	12.16 ^a	13.52 ^a	9.21 ^{ab}	10.2 ^{ab}	11.85 ^a	9.34 ^a	9.18 ^{ab}	4.91 ^a b
ZT ₂	11.06 ^{ab}	10.27 ^{ab}	11.88 ^{ab}	7.11 ^b	8.84 ^{bc}	10.14 ^{ab}	7.82 ^{abc}	8.24 ^{abc}	4.53 ^b c
CA ₃	12.78 ^a	12.96 ^a	13.86 ^a	10.23 ^a	10.8 ^a	12.04 ^a	9.56 ^a	9.54 ^a	5.12 ^a
AT	7.92 ^{cd}	8.35 ^{bc}	9.53 ^b	7.56 ^b	8.06 ^c	9.08 ^b	7.21 ^{bc}	7.21 ^c	4.31 ^c
CT	6.82 ^d	6.12 ^c	8.91 ^b	6.75 ^b	7.92 ^c	8.49 ^b	7.06 ^c	7.02 ^c	4.22 ^c

*Means with different lowercase letters within a column are significantly different at $p < 0.05$ according to Tukey's HSD test

Table 93: Effect of long-term conservation agriculture on carbon stabilization (g C kg⁻¹ bulk soil) within density fractions in the 0-5 cm soil depth under a rice-wheat cropping system in an Inceptisol

Treatment _{s*}	cPOM_M	s+c_M	LF_mM	iPOM_m	s+c_mM	LF_m	iPOM_m	s+c_m	s+c_B
ZT ₁	0.59 ^b	0.92 ^{ab}	0.58 ^{bc}	1.47 ^{cd}	0.56 ^{abc}	0.52 ^{abc}	1.65 ^b	0.82 ^a	0.58 ^a
CA ₁	1.03 ^a	0.99 ^{ab}	0.76 ^{ab}	2.01 ^{abc}	0.73 ^a	0.62 ^{ab}	2.04 ^{ab}	0.80 ^{ab}	0.53 ^a
CA ₂	1.03 ^a	1.11 ^a	0.72 ^{ab}	2.04 ^{ab}	0.62 ^{ab}	0.63 ^{ab}	2.08 ^{ab}	0.89 ^a	0.58 ^a
ZT ₂	0.68 ^b	1.01 ^{ab}	0.59 ^{bc}	1.51 ^{bcd}	0.61 ^{ab}	0.54 ^{abc}	1.71 ^b	0.93 ^a	0.56 ^a
CA ₃	1.07 ^a	0.94 ^{ab}	0.95 ^a	2.42 ^a	0.72 ^a	0.65 ^a	2.21 ^a	0.70 ^b	0.57 ^a
AT	0.31 ^c	0.82 ^{ab}	0.39 ^{cd}	1.43 ^d	0.53 ^{bc}	0.46 ^{bc}	1.78 ^{ab}	0.88 ^a	0.64 ^a
CT	0.22 ^c	0.63 ^b	0.27 ^d	1.24 ^d	0.41 ^c	0.42 ^c	1.85 ^{ab}	0.94 ^a	0.65 ^a

*Means with different lowercase letters within a column are significantly different at $p < 0.05$ according to Tukey's HSD test

About 0.183 Mg C ha⁻¹ yr⁻¹ was stabilized inside microaggregates within macroaggregates in the MBR+ZTDSR-RR+ZTW-WR+ZTMB over control. These findings revealed that under long-term CA, the physical stabilization of SOC in microaggregates within macroaggregates was the major mechanism of carbon sequestration in rice-wheat cropping system in an Inceptisol of the Indo-Gangetic plains. Thus MBR+ZTDSR-RR+ZTW-WR+ZTMB (ZT plot with rice, wheat and mungbean residue retention) can be a viable option for rice-wheat cultivation in the Indo-Gangetic plains that can enhance carbon sequestration and carbon stabilization in soils by mitigating climate change.

Conservation agriculture effects on soil organic carbon sequestration in pigeon pea-wheat system

Carbon accumulation rate (CAR), sequestration rate (CSR) and TOC stock were studied in pigeon pea-wheat system after 14 years. It revealed that the CAR, CSR and TOC stock were significantly improved under CA based treatments than CT at 0-5, 5-15 & 15-30 cm depths of soil (Figures 104, 105 & 106). The CAR were 8, 29, 30 times and CSR were 6, 9 and 13 times higher under CA-PFB than CT at these depths of soil.

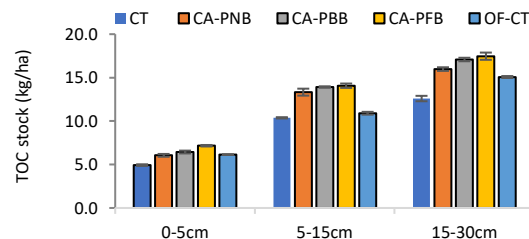


Fig 104. TOC stock were significantly improved under CA based pigeon pea-wheat system

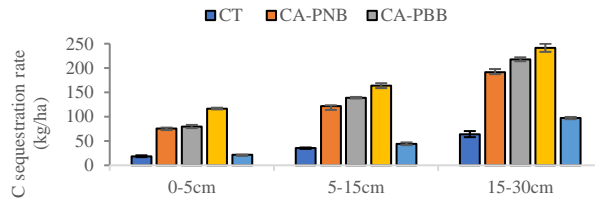


Fig 105 C-sequestration rate at different depths of soil

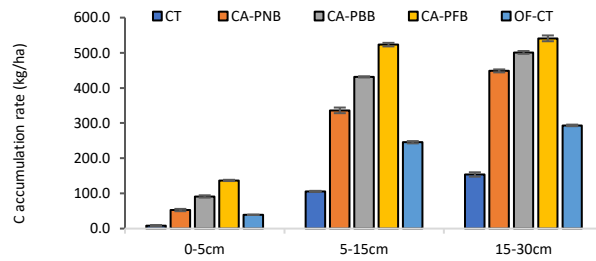


Fig 106. C-accumulation rate were 8, 29, 30 times higher under CA-PFB than CT at different depths of soil.

Carbon Sequestration

IIFSR

Soil samples were analyzed for various carbon fractions, C stock, C accumulation and C sequestration in the diverse cropping systems under CA based management practices. Data depicted in fig 107. showed that CA based management practices in R-W, R-W-GG, M-M-GG and Sr+GG-Rt+GG-W cropping system recorded 28.5%, 52.8%, 69.4% and 39.4% higher labile carbon (C_{VL} and C_L) over the R-W (CP) system. Similarly, 10%, 44.5%, 63% and 37.5% increase in recalcitrant pools (C_{LL} and C_{NL}) in these cropping systems over the R-W (CP) system.

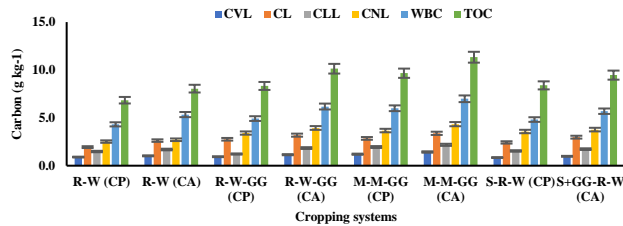


Fig 107. Influence of crop diversification and CA based management practices on various carbon fractions

Over a period of 10 years of CA based management practices in diverse cropping systems significantly influenced the total organic carbon in soil. Incorporation of maize-mustard and greengram residue significantly increase the soil TOC content. Over the conventional R-W system, 16.1%, 54.0%, 61.7% and 39.7% higher soil TOC content was recorded in R-W, R-W-GG, M-M-

GG and Sr+GG-Rt+GG-W systems under CA based management practices as compared to conventional R-W system.

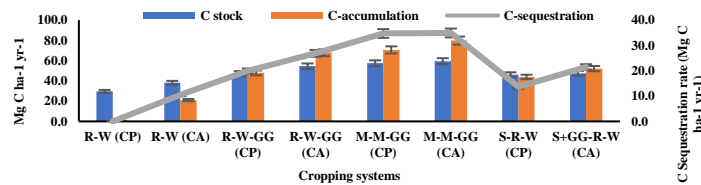


Fig 108. Soil C stock, C accumulation and C sequestration as influenced by crop diversification

Measurement of soil carbon stock (C stock) and carbon accumulation (C accumulation) is an important parameter for baseline carbon accounting, impact of land use planning and carbon credits and trading. The data related to soil C stock and C accumulation calculated for diverse cropping systems and CA based management practices are presented in fig 108. showed significant improvement in C stock and C accumulation in long-term CA based management practices. Significantly, 13.0%, 55.4%, 78.9% and 12.1% higher C stock was recorded in R-W, R-W-GG, M-M-GG and Sr+GG-Rt+GG-W systems under CA based management practices over the conventional R-W system. Likewise, these treatments were 11.2%, 35.8%, 36.8% and 22.3% superior for C accumulation over the conventional R-W systems after 10 years of CA based management practices (Fig. 108).

Soil C sequestration leads to C accumulation in soil, which increases the C stock. Significant improvement in C sequestration was recorded among the different treatments. Among the different cropping systems, M-M-GG (CA) system recorded 27.5% higher C sequestration over the conventional R-W systems.

CRIDA

Temperature sensitivity of soil carbon mineralization under maize-mustard system

The impact of long-term conservation agricultural practices on temperature sensitivity of carbon mineralization was assessed in an Inceptisol under maize-mustard system. The treatments details are three double-cropping zero-till systems, two triple-cropping zero-till systems with or without crop residue retention, and two conventional till systems [T1: ZTMz(-R)-ZTM(-R); T2: ZTMz+R-ZTM+R; T3: ZTMz+R+BM-ZTM+R; T4: ZTMz(-R)-ZTM(-R)-ZTMB(-R); T5: ZTMz+R-ZTM+R-ZTMB+R; T6: CTMz(-R)-ZTM(-R); T7: CTMz-CTM]. At 27°C, highest cumulative carbon mineralization (Ct) was found in T7 (CTMz-CTM) i.e., Day 2, 4, 6, 8 16 and 32 (Fig 109). On Day 2 and 4, there was no significant difference among treatments. On Day 6, T7 treatment had 66.7 % higher Ct (10.7 mg C 100 g⁻¹) than T5 (ZTMz+R-ZTM+R-ZTMB+R), which was at par with T6 (CTMz(-R)-ZTM(-R)) treatment. Similarly, on Day 8, T7 had 31.5 %, 39.04 % and 101.37 % higher Ct than T2, T4 and T5, respectively, in the 0-5 cm soil depth at 27 °C. Similarly, on 16th and 32nd day, the highest Ct (22.1 and 25.6 mg C 100 g⁻¹) was recorded in T7 (Table 94). At higher temperature (37°C), cumulative carbon mineralization in bulk soil (0-5 cm) was higher in all the treatments than that at 27°C, irrespective of treatments. At 37°C, highest cumulative carbon mineralization (Ct) was found in T7 i.e., Day 2, 4, 6, 8 16 and 32 (Fig 110). On Day 2, 4 and 16 there was no significant difference among treatments. On Day 6, T7 treatment had 104.1 % higher Ct (7.20 mg C 100 g⁻¹) than T5, which was at par with T6 treatment. Similarly, on Day 8, T7 had 42.9 %, and 83.5 % higher Ct than T2 and T5, respectively, in the 0-5 cm soil depth at 37 °C. Similarly, on 32nd day, the highest Ct (32.7 mg C 100 g⁻¹) was recorded in T7. The T6 treatment

had similar Ct to T7 treatment on 32nd Day. The decay rates (Kc) of SOC in bulk soils significantly varied according to tillage and residue management under conservation agriculture practices. At 27 °C, T7 treatment had highest Kc value which was 94.5 % higher than Kc of T5 treatment (Table 94). While at higher temperature (37 °C), decay rate was higher than 27 °C temperature. CTMz–CTM had highest decay rate at 37 °C, which was 110 and 134 % higher than T4 and T5 treatments, respectively. The T6 treatment had similar Kc to T7 treatment at 27 and 37 °C temperatures. The conventional tillage plots always had higher values of Kc compared with the zero tillage plots. The temperature sensitivity (Q10) values which denote the increase of reaction rate for raising 10°C temperature can also be used as an alternative measure of temperature sensitivity. These Q10 values of soil C mineralization were significantly affected by tillage and residue management in bulk soils. Highest temperature sensitivity (Q10-1.495) was observed in case of T7 among all other tillage and residue treatments, which was 1.28 and 1.39 times more than T3 and T5, respectively. Therefore, it can be said that temperature had a positive effect on SOC mineralization, with higher CO₂ evolution at higher temperatures regardless of treatment. Having higher rate of SOC mineralization, T7 treatment was highly temperature sensitive (with highest Q10 value), indicating more CO₂ evolution and less C stabilization. In contrast, ZT with and without residue retention treatments provided better SOC protection under CA practices. Considering the above said points, treatment with ZTMz+R–ZTM+R–ZTMB+R (T5) is so far the most effective treatment in carbon sequestration point of view.

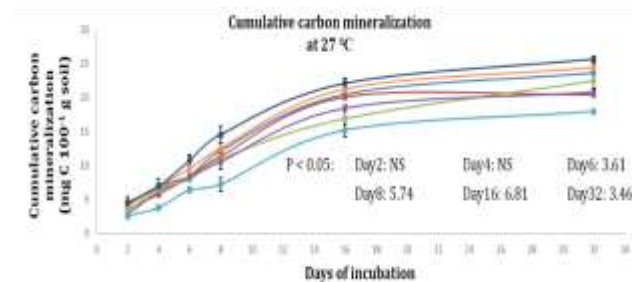


Fig 109. Cumulative carbon mineralization at 27⁰ C as affected by conservation agriculture under a maize-mustard system in an Inceptisol in soil layer

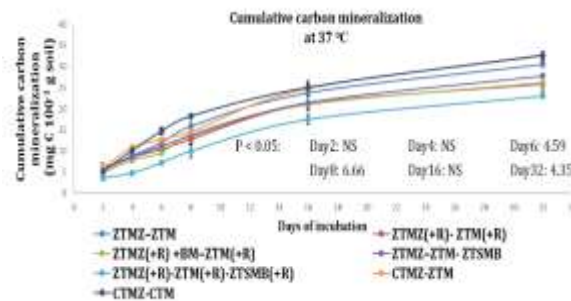


Fig 110. Cumulative carbon mineralization at 37⁰ C as affected by conservation agriculture under a maize-mustard system in an Inceptisol in the 0-5 cm soil layer

Table 94: Cumulative carbon mineralization, rate of carbon mineralization and temperature sensitivity as affected conservation agriculture under maize-mustard system in an Inceptisol soil layer

Treatment	Cumulative carbon mineralization (mg C 100 g ⁻¹ soil)		Rate of carbon mineralization (Kc*10 ⁻³ day ⁻¹)		Q ₁₀
	27 ° C	37 ° C	27 °C	37 °C	
	T1: ZTMZ-ZTM	23.7 ^{ab}	30.6 ^{ab}	1.11 ^b	
T2: ZTMZ(+R)- ZTM(+R)	20.5 ^{bc}	25.8 ^{cd}	1.05 ^b	1.40 ^b	1.33 ^c
T3:ZTMZ(+R) +BM-ZTM(+R)	22.5 ^{ab}	26.1 ^{cd}	1.13 ^b	1.31 ^b	1.17 ^e
T4:ZTMZ-ZTM- ZTSMB	20.8 ^{bc}	27.9 ^{bc}	0.85 ^c	1.01 ^c	1.25 ^d
T5:ZTMZ(+R)-ZTM(+R)-ZTSMB(+R)	18.0 ^c	23.0 ^d	0.73 ^c	0.91 ^c	1.07 ^f
T6:CTMZ-ZTM	24.4 ^a	32.5 ^a	1.42 ^a	2.03 ^a	1.43 ^b
T7:CTMZ-CTM	25.6 ^a	32.7 ^a	1.42 ^a	2.13 ^a	1.50 ^a
LSD (<0.05)	3.46	4.35	0.13	0.18	0.05

14.5 GHGs Emission and Global Warming Potential (GWP)

Greenhouse gases emissions rice and wheat crops

For estimation of GHG emission from different scenarios of tillage and residue management practices Tier II methodology of IPCC was employed. The GHG emission in system perspective was calculated considering both direct and indirect emission from rice and wheat crops using the modified emission factors (EFs). To compute GHG emissions, primary data from the 17 cropping seasons on various farm inputs and agricultural operations were considered and multiplied/processed with their respective EFs. Overall GHG emissions were considered from four sources: 1) GHG emissions from use of various farm inputs (herbicides, fertilizers and diesel fuel etc.) and farm operations (pumping irrigation water), 2) Soil derived direct and indirect N₂O emission (from nitrogenous fertilizer application); 3) CH₄ emissions from soils; and 4) GHG emissions from rice residue burning in farmer's practice (Lal, 2004). The resultant GHG emissions (CH₄, N₂O, CO₂) were then multiplied by their corresponding Global Warming Potential (GWP100) factors, 273, 28, and 1, respectively, to obtain the CO₂ equivalent GHG emissions (IPCC, 2021).

The total GHG emissions from rice wheat system under different scenarios ranged from 6507.86 to 11172.60 kg CO₂ eq ha⁻¹ (Table 8). Under different treatments, N₂O emissions constitutes majority of total GHG emissions and least contribution was from herbicide applications. The contribution of various sources to total GHG emission in different scenarios followed the trend: Total N₂O (33.90-62.99 %) > Irrigation (23.62-32.37 %) > Residue burning (30.32 %) > CH₄ emission from puddled transplanted rice (6.65 %) > Diesel (2.67-5.80 %) > Seeds (0.68-1.31 %) > Herbicide (0.20-0.79 %) (Fig 111). Sc-1 (farmers' practice) was the only scenario where rice residue burning (30.32%) and methane emissions (6.65%) PTR contributed to total GHG emissions. This CH₄ emissions were caused by anaerobic decomposition of organic matter in the flooded soil, result of the water used to cultivate the PTR. Ball et al. (1999) and Oorts et al. (2007) also reported higher N₂O fluxes under zero tillage. Tillage and residue management practices decreased the total GHG emissions by 38.84 to 41.75 % in comparison to conventional tillage practices. GHG emission from diesel consumption reduced by 25.30% in Sc-2 and Sc-3, and by

65.57% in Sc-4 and Sc-5 in comparison to Sc-1. The contribution by electricity used for pumping irrigation water showed a reduction by 21.22% (Sc-2), 20.62% (Sc-3), 20.18% (Sc-4), and 18.29% (Sc-5) in comparison to Sc-1. It was found that retaining or incorporating crop residue under reduced and zero tillage (Sc-3 and Sc-5) increased GHG emissions by 2.43-2.60%, primarily due to higher N₂O emissions as compared to without residue plots (Sc-2 and Sc-4). Unlike other GHG, N₂O emissions was significantly lower in Sc-1 compared to other treatments. Additionally, treatments with residue retention or incorporation recorded higher N₂O emissions than those without residue application, contributing to the overall increase in GHG emissions. The decomposition of crop residue provided carbon and nitrogen substrates for nitrifying and denitrifying bacteria, which accelerated N₂O production in the soil (Chen et al., 2013). The highest net GHG emission was recorded under Sc-1, whereas the lowest was recorded in Sc-5, showing an 84.07% reduction compared to Sc-1. This decrease was mainly due to reduction in emissions from diesel consumption (65.57%), irrigation water (18.29%) and avoiding residue burning and puddling in DSR. Net GHG emission reduced significantly in other treatments also i.e., by 66.34, 71.70, 78.37 and 84.07 % in Sc-2, Sc-3, Sc-4 and Sc-5, respectively, in comparison to Sc-1 due to higher carbon sequestration potential of soil under tillage and residue management practices.

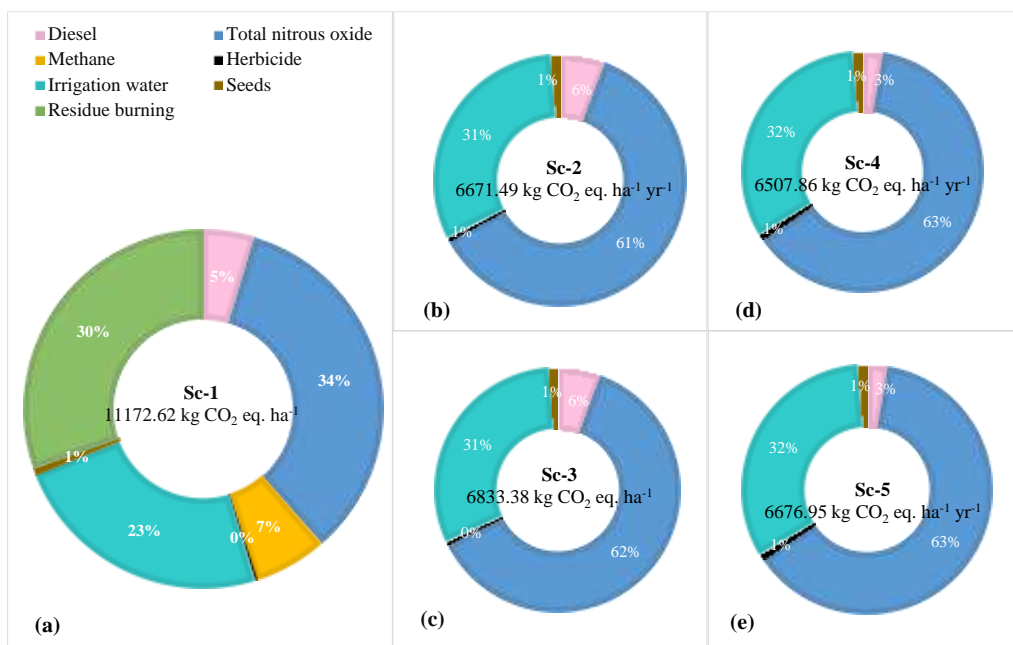


Fig 111: Effect of tillage, crop establishment and residue management practices on input-wise percent contribution to total GHG emission under different scenarios in rice-wheat system (data pooled-average for 17 years).

Where, Sc-1: Puddle transplanted rice - conventional tilled wheat, Sc-2: Reduce tilled direct seeded rice (RTDSR) - reduce tilled wheat (RTW); Sc-3: RTDSR-RTW + 1/3rd residue incorporation; Sc-4: Zero tilled direct seeded rice (ZTDSR)-zero tilled wheat (ZTW); and Sc-5: ZTDSR-ZTW + 1/3rd residue retention (RR)

Table 95: Effect of tillage, crop establishment and residue management practices on total GHG emission, carbon sequestration, and carbon footprint in rice wheat system (data pooled-averaged for 17-years).

Scenarios/ treatments	GHG emission (kg CO ₂ eq ha ⁻¹)								Carbon sequestration potential (kg CO ₂ eq ha ⁻¹ yr ⁻¹)	Net GHG emission	Carbon footprint (kg CO ₂ Mg ⁻¹)
	Diesel	Total N ₂ O	Methane	Herbicide	Irrigation Water	Seeds	Residue burning	Total			
Sc-1	518.10 ^a	3787.04 ^d	742.56	21.95 ^c	2639.27 ^a	76.50 ^b	3387.20	11172.60 ^a	2868.89 ^d	8303.73 ^a	703.93 ^a
Sc-2	387.04 ^b	4091.87 ^c	-	28.30 ^b	2079.27 ^c	85.00 ^a	-	6671.49 ^{bc}	3876.65 ^c	2794.84 ^b	244.57 ^b
Sc-3	387.04 ^b	4238.08 ^a	-	28.30 ^b	2094.95 ^c	85.00 ^a	-	6833.38 ^b	4483.86 ^b	2349.51 ^b	199.97 ^c
Sc-4	178.39 ^c	4086.40 ^c	-	51.40 ^a	2106.67 ^{bc}	85.00 ^a	-	6507.86 ^c	4711.69 ^b	1796.18 ^c	163.78 ^{cd}
Sc-5	178.39 ^c	4205.49 ^b	-	51.40 ^a	2156.68 ^b	85.00 ^a	-	6676.95 ^{bc}	5354.24 ^a	1322.70 ^c	123.36 ^d
Trt	***	***		***	***	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. Where, Sc-1: Puddle transplanted rice - conventional tilled wheat, Sc-2: Reduce tilled direct seeded rice (RTDSR) - reduce tilled wheat (RTW); Sc-3: RTDSR-RTW + 1/3rd residue incorporation; Sc-4: Zero tilled direct seeded rice (ZTDST)-zero tilled wheat (ZTW); and Sc-5: ZTDSR-ZTW + 1/3rd residue retention (RR)

Net ecosystem carbon balance (NECB) in CA-based rice-wheat system

Among the different tillage and residue treatments in rice wheat system, net ecosystem carbon balance (NECB) was estimated using closed chamber measurement technique by the following equation:

$$\text{NECB} = \text{NPP} - R_h - H - \text{CH}_4 + \text{SC} + \text{CR} + U$$

where NPP is the net primary production of the crop (wheat, rice and green gram and *Sesbania*); R_h is the heterotrophic respiration (soil CO_2 -C flux), measured by closed chamber method; CH_4 is soil CH_4 -C flux measured by chamber technique. H is the harvested straw and grain carbon removed from the field at the harvesting stage; SC is seed carbon; CR is crop biomass carbon incorporation rate (Mg ha^{-1}) and U is carbon added in the form of urea.

The carbon contents of rice straw, wheat straw, rice grain and wheat grain and rice and wheat roots were considered. The NPP was calculated by adding the above ground dry biomass yield of grain and straw, and belowground dry biomass yield (root biomass). A positive value of the NECB represents an ecosystem carbon gain after crop harvest on a seasonal scale. The net ecosystem carbon balance (NECB) was the highest in ZT R-W-GG system with GGR+RS retention (T6). The NECB ranged from $1129 \text{ kg C ha}^{-1}$ under conventional rice wheat system with no residue (T1) to $3523 \text{ kg C ha}^{-1}$ with residue retention in both crops (GGR+RS). The NECB of T6 was 261% higher than conventional treatment. The maximum portion of carbon was lost in the form of harvested biomass (74.6-79.1%), and heterotrophic respiration as CO_2 (20.7-25.4 %), whereas percentage of CH_4 emission was very low (0.03-0.24%) (**Figure 28**). There was significant impact of tillage ($p = 0.01$) and crop residue retention ($p < 0.01$) on NECB. Crop residue retention in single crop enhanced NECB by 55-99%, while residue retention in both the crops enhanced NECB by 192-212% compared to ZT without crop residue retention.

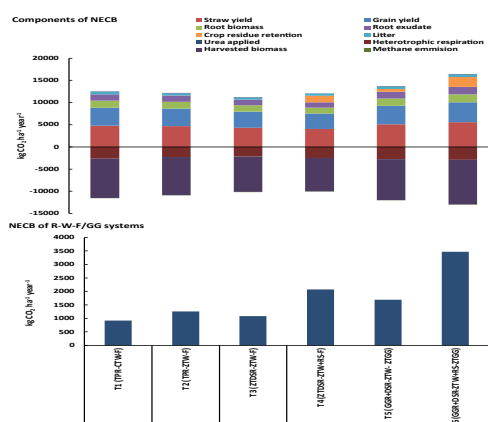


Fig 112. NECB and its components under R-W-F/GG system. Column with same alphabet is not significantly different

IIFSR

The global warming potential (GWP) and carbon equivalent emission (CEE) of the treatments for rice and wheat crops are presented in Table 96. It was observed that the GWP varied between $509.0 \text{ kg CO}_2\text{-eq ha}^{-1}/\text{season}$ (R-W-GG-CA) to $1072.4 \text{ kg CO}_2\text{-eq ha}^{-1}/\text{season}$ (R-W-CP) in rice and $344.8 \text{ kg CO}_2\text{-eq ha}^{-1}/\text{season}$ (R-W-GG-CA) to $730.1 \text{ kg CO}_2\text{-eq ha}^{-1}/\text{season}$ (R-W-CP) in wheat crop, respectively. The GWP was 40.7% and 32.9% lower in CA than under CT for rice crop, respectively. While the magnitude of GWP in wheat crop was 43.5% and 28.9% lower in CA treatments than CT, respectively (Table 96). The CEE, the amount of kg C ha^{-1} emitted in different treatments was highest ($285.6 \text{ kg C ha}^{-1}$ and $199.1 \text{ kg C ha}^{-1}$) in R-W (CP) both under rice and

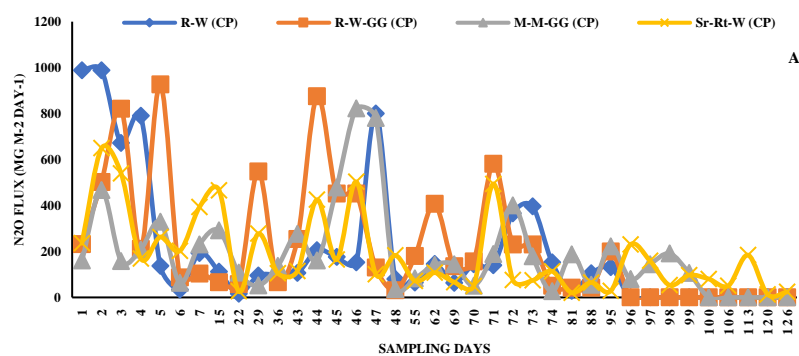
wheat crops. Lowest CEE was observed in R-W-GG (CA) for both the crops as these treatments had the largest CO₂ emissions and smaller amount of C fixed.

Table 96: Seasonal GHG emission, GWP and CEE in rice and wheat as affected by tillage, residue management and cropping systems

Cropping Systems	Rice		wheat	GWP-rice	GWP-wheat	CEE-rice (kg C ha ⁻¹)	CEE-wheat (kg C ha ⁻¹)
	CH ₄ (kg ha ⁻¹ /season)	N ₂ O-N (kg-N ha ⁻¹ /season)	N ₂ O-N (kg-N ha ⁻¹ /season)	(kg CO ₂ -eq ha ⁻¹ /season)	(kg CO ₂ -eq ha ⁻¹ /season)		
R-W (CA)	10.6	1.23	1.33	635.7	412.5	225.2	112.5
R-W (CP)	26.6	1.40	2.36	1072.4	730.1	285.6	199.1
R-W-GG (CA)	7.0	1.10	1.11	509.0	344.8	165.2	94.0
R-W-GG (CP)	15.7	1.18	1.57	759.1	485.2	147.8	132.3
SE(±)	2.76	0.010	0.489	25.68	51.59	7.00	14.07
C.D. (P<0.05)	7.97	0.027	1.416	73.36	148.98	20.21	40.63

* GHG=greenhouse gas emission; GWP=global warming potential (CH₄=24; N₂O=310); CEE=carbon equivalent emission

The temporal variation of nitrous oxide (N₂O) was measured in rice, maize and sugarcane crops both in conventional and conservation agriculture practices (fig 113 a & b). the temporal variation of N₂O in rice-wheat system varied from 28.5-988.6 µg m⁻² day⁻¹ in R-W (CT) and 24.4- 1779.5 µg m⁻² day⁻¹ in R-W (CA). at the same time, it ranged from 41.6-926.9 µg m⁻² day⁻¹ and 49.5-2437.5 µg m⁻² day⁻¹ in R-W-GG (CT) and R-W-GG (CA) treatments, respectively. In maize based cropping systems, the N₂O fluxed varied from 36.0-780.9 µg m⁻² day⁻¹ and 50.1-871.3 µg m⁻² day⁻¹ in M-M-GG (CT) and M-M-GG (CA) systems during maize growing period. Likewise, in the sugarcane based cropping systems, the range of N₂O flux was 28.5-649.3 µg m⁻² day⁻¹ and 44.5-1142.7 µg m⁻² day⁻¹ in Sr-Rt-W (CT) and Sr+GG-Rt+GG-W (CA) systems during the sugarcane growing period



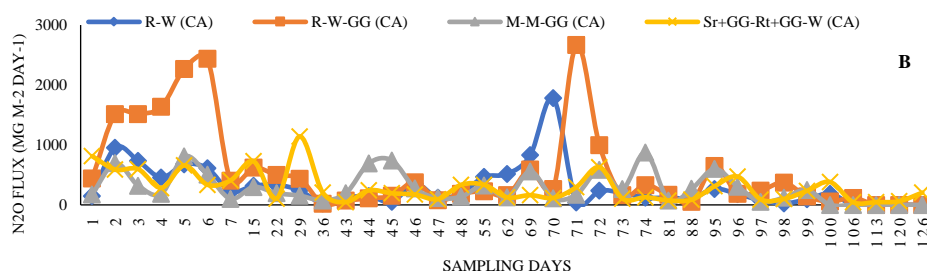


Fig 113. Temporal variation in N₂O flux during the kharif/summer season crops in conventional (a) and conservation agriculture (b) as affected by tillage, residue management and cropping systems

Greenhouse gas intensity (GHGi) and GWP in pigeon pea-wheat system

The global warming potential (GWP) in the pigeon pea–wheat (PW) system was significantly lower under conservation agriculture (CA) treatments, with CA-PNB (3085.5 kg CO₂ eq/ha) showing a 17.2% reduction compared to the highest-emitting treatment, OF-CT (3675.0 kg CO₂ eq/ha). Among CA practices, CA-PNB had the lowest GWP, while CA-PFB had the highest (3322.0 kg CO₂ eq/ha), indicating that nutrient and residue management within CA systems significantly affects emissions. In Table 97, the GWP values for individual crops and the overall PW system demonstrate notable variation across tillage and nutrient management practices. For pigeon pea, GWP ranged from 1150.5 kg CO₂ eq/ha under CT to 1414.0 kg CO₂ eq/ha under OF-CT. Among CA treatments, CA-PNB recorded the lowest emissions (1155.0 kg CO₂ eq/ha), whereas CA-PFB registered the highest (1215.0 kg CO₂ eq/ha), suggesting that even within CA frameworks, input management substantially influences emission levels. In wheat, a similar pattern was observed, with emissions lowest under CA-PNB (1930.5 kg CO₂ eq/ha) and highest under OF-CT (2261.0 kg CO₂ eq/ha). Notably, CA-PFB recorded the highest GWP (2107.0 kg CO₂ eq/ha) among CA treatments, underscoring the influence of residue and fertilizer application strategies on GHG outputs. These findings emphasize the efficacy of conservation agriculture, particularly CA-PNB, in mitigating greenhouse gas emissions in legume-cereal cropping systems

Table 97: Global warming potential (kg CO₂ eq/ha)

Global warming potential (kg CO ₂ eq/ha)			
Treatments	Pigeon pea	Wheat	PW system
CT	1150.5	2043.5	3193.5
CA-PNB	1155.0	1930.5	3085.5
CA-PBB	1190.5	2036.0	3226.5
CA-PFB	1215.0	2107.0	3322.0
OF-CT	1414.0	2261.0	3675.0
LSD (P=0.05)	65.8	109.2	177.3

The GHGI of the system productivity was in the order: OF>CT>CA. The GHG emissions per kg of productivity were (emission/kg) 0.30 kg CO₂ eq/kg under CA, 0.36 kg CO₂ eq/kg under CT, and 0.45 kg CO₂ eq/kg under OF.

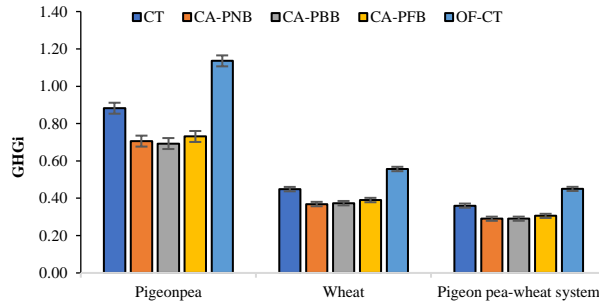
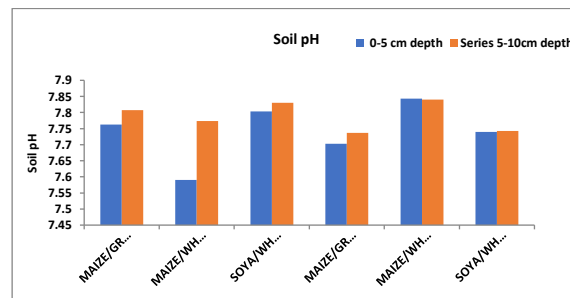


Fig 114. Greenhouse gas intensity (GHGi) in pigeon pea, wheat and pigeon pea-wheat system

Soil pH

There was no statistically significant variation observed in soil pH at 0-5cm soil depth among various treatments of cropping systems under different tillage practices. In the similar way at soil depth 5-10cm all treatments observed at par in Soil pH values. In other words, various combinations of cropping systems with tillage had not any significant effect on soil pH at 0-5 and 5-10 cm soil depth. However, soil pH values ranged from 7.59 ± 0.215 to 7.843 ± 0.014 in at 0-5 cm depth and it was 7.737 ± 0.058 to 7.84 ± 0.02 at 5-10 cm depth.



M-CP+CT: Maize-Chickpea + Conventional tillage * M-W+CT: Maize-Wheat+ Conventional tillage

Fig 115: Effect of various cropping systems on soil pH under different tillage practices

Soil Electrical conductivity

The value of electrical conductivity among various cropping systems in combination with tillage treatments were observed statistically at par. However, the minimum value $236.667 \pm 9.447 \mu\text{s/cm}$ was associated with maize-wheat +NT and maximum value $261.033 \pm 5.825 \mu\text{s/cm}$ with maize-chickpea +NT at 0-5 cm soil depth. At 5-10 cm soil depth the values of electrical conductivity again observed without any significant difference other among various treatments. At 5-10 cm soil depth minimum value was $216.8 \pm 34.156 \mu\text{s/cm}$ under maize-wheat +NT and maximum is $268.4 \pm 31.844 \mu\text{s/cm}$ in maize-wheat + CT.

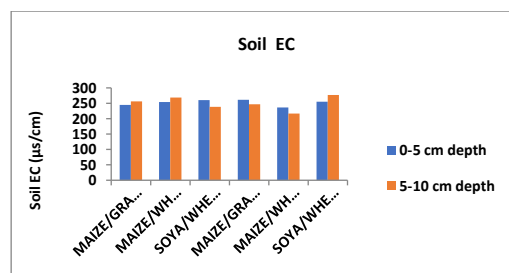


Fig 116. Effect of various cropping systems on soil EC under different tillage practices

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

IIFSR

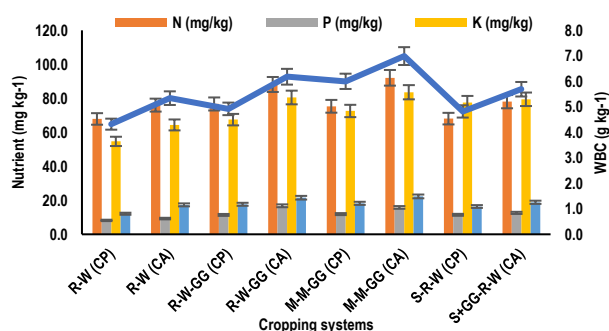


Fig 117. Impact of crop diversification and CA based practices on various soil chemical attributes

Due to incorporation of summer green gram along with CA practices 29.9% and 35.7% higher N were recorded in R-W-GG and M-M-GG cropping systems as compared to business-as-usual practices. P availability increased by 43.1%, 61.8% and 31.7% in CA based R-W-GG, M-M-GG and Sr+GG-Rt+GG-W systems. CA practices improved K availability in sugarcane by 45.8% over the farmers practices.

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Available Nitrogen in Soil

At both the soil depth i.e. 0-5 and 5-10 cm the values of available nitrogen under both tillage practices in combination with different cropping system were found with non-significant variation under wheat and chickpea crop. Although variation in available nitrogen value varied from 142.16 ± 4.18 to 150.52 ± 6.27 kg/ha at 0-5cm soil depth and 133.80 ± 12.71 to 142.16 ± 2.09 kg/ha at 5-10 cm of soil depth. It was observed that values of available nitrogen content (kg/ha) more at upper layer (0-5 cm) of the soil than deeper layer of soil (5-10cm), it means that availability of nitrogen reduced with soil depth.

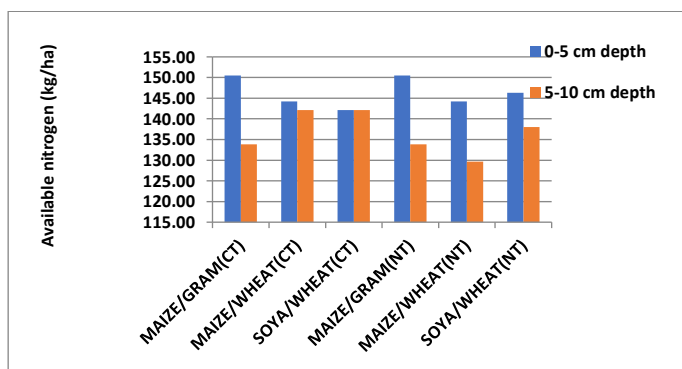


Fig 118. Effect of various cropping systems on Available Nitrogen under different tillage practices

Available Phosphorus

The average value of available phosphorus in soil ranged from 31.447 ± 0.76 to 33.993 ± 1.493 in 0-5cm soil depth 19.67 ± 2.139 to 25.833 ± 1.01 kg/ha in 5-10cm depth both minimum and maximum values were observed with different crop. However, in case of chickpea the values followed increasing trend with various tillage practices along with different levels of cropping system. However, tillage practices in combination with different cropping system, available phosphorus of the soil in wheat and chickpea crop was observed non-significant.

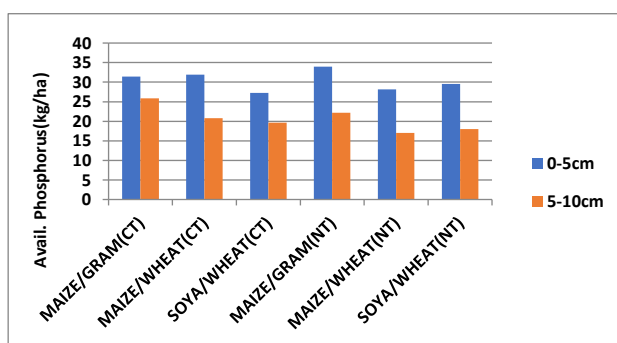


Fig 119. Effect of various cropping systems on Available Phosphorus under different tillage practices

Available Potassium

The effect of tillage and various cropping system on available potassium (kg/ha) was observed with statically non-significant variation in Chickpea and wheat crop. The value ranged 513.893 ± 16.605 to 706.833 ± 63.333 kg/ha at 0-5cm soil depth in various cropping system and 5-10cm depth ranged 360.043 ± 4.839 to 458.973 ± 36.578 kg/ha and both soil depth available potassium was observed non-significant.

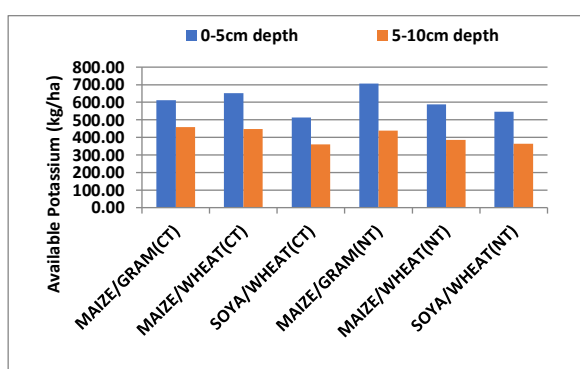


Fig 120. Effect of various cropping systems on Available Potassium under different tillage practices

Maize-Wheat System

Conservation agriculture on potassium availability and use efficiency

A study was conducted at ICAR-IARI, New Delhi, to assess the effects of different crop residue retention levels and potassium (K) fertilization strategies on soil properties, K fractions, crop

yield, and K use efficiency in a maize–wheat system under conservation agriculture. The experiment, laid out in a split-plot design, included four crop residue levels (0 to 6 t ha⁻¹) and five K fertilization treatments, including combinations with K-solubilizing bacteria (KSB). Results showed that 4 t ha⁻¹ crop residue retention (CR4) significantly increased soil organic carbon (by 20%) and cation exchange capacity (by 12%) compared to no residue (CR0). Available K content was notably higher (145 mg kg⁻¹) under CR4 with RDK50+KSB than under CR0 with full recommended K dose. Non-exchangeable K also slightly increased with higher residue levels. The study recommends adopting CR4 combined with RDK50+KSB to enhance K availability and use efficiency, while mitigating potassium mining risks in the intensively farmed maize–wheat systems of the Indo-Gangetic Plains

Pigeonpea- Castor System

CRIDA

In maize-pigeonpea cropping system integration of in situ moisture conservation and weed management along with CA practices influenced the available nutrients. Permanent conservation furrow and permanent bed and furrow and Zero tillage recorded higher available nitrogen, phosphorus and potassium as compared to conventional tillage (Table 98).

Table 98: Soil chemical properties as influenced by conservation agriculture in maize-pigeonpea cropping system

	N	P	K	OC
Main plots				
CT	186.16	52.26	313.14	0.65
ZTF	240.51	57.55	317.76	0.78
ZTPB	199.91	82.74	330.58	0.80
ZTS	214.45	58.07	405.33	1.07
LSD	6.99	14.69	35.36	0.17
Subplots				
control	206.91	58.53	389.83	0.83
pre+intercultivation	206.95	61.25	277.55	0.82
pre+post emerg	223.18	63.78	373.39	0.77
pre+post+intercultivation	204.00	67.05	326.05	0.88
LSD	19.15	5.97	24.04	0.09
Interactions				
CT-control	198.33	63.17	370.33	0.73
CT-pre+intercultivation	190.33	51.02	164.66	0.68
CT-pre+post emerg	205.00	50.67	406.24	0.59
CT-pre+post+intercultivation	151.00	44.17	311.33	0.61

ZTF-control	239.00	56.89	376.00	0.99
ZTF-pre+intercultivation	227.33	48.00	360.86	0.74
ZTF-pre+post emerg	249.06	61.32	299.00	0.62
ZTF-pre+post+intercultivation	246.66	64.00	325.18	0.78
ZTPB-control	156.00	64.86	376.33	0.88
ZTPB-pre+intercultivation	187.00	91.80	292.00	0.80
ZTPB-pre+post emerg	236.66	77.66	361.00	0.73
ZTPB-pre+post+intercultivation	220.00	96.64	293.00	0.81
ZTS-control	234.33	49.21	436.66	0.73
ZTS-pre+intercultivation	223.16	54.18	292.66	1.05
ZTS-pre+post emerg	202.00	65.48	427.33	1.17
ZTS-pre+post+intercultivation	198.33	63.41	464.66	1.33
CV	10.81	11.31	8.35	13.60

In Sorghum-Blackgram cropping system, soil samples were collected after harvest of horsegram from 0-7.5, 7.5-15 and 15-30 cm depths and analyzed for available N, P, K. The available NPK was not significantly influenced by tillage or residue management practices at all the depths. Available K at 7.5 cm depth, was significantly higher in conventional tillage without crop residue (Fig 121, 122, 123).

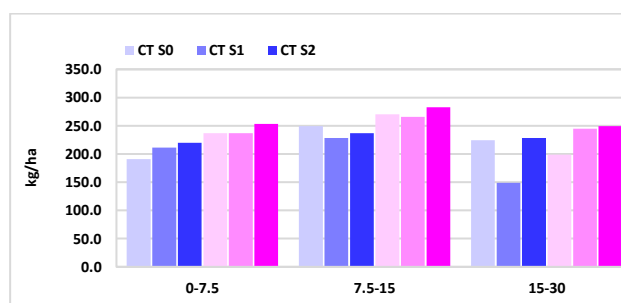


Fig 121. Effect of tillage and residue management on soil available

N

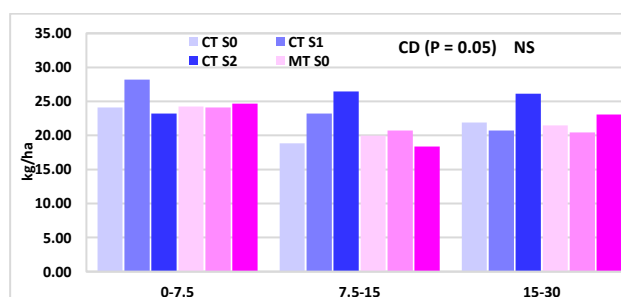


Fig 122. Effect of tillage and residue management on soil available P

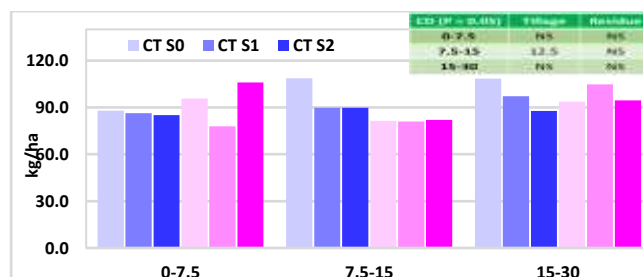


Fig 123. Effect of tillage and residue management on soil available K

In pigeonpea- finger millet sequence cropping system, soil samples from three depths 0-7.5, 7.5-15 cm and 15-30 cm were analysed for various chemical properties (Table 5, 6).

Among different tillage practices significantly higher available nitrogen (287.23, 257.43 and 210.11 kg ha⁻¹), phosphorus (107.74, 99.61 and 83.44 kg ha⁻¹) and potassium (185.57, 176.51 and 169.43 kg ha⁻¹) was observed with reduced tillage at 0-7.5 cm, 7.5-15 cm and 15-30 cm depth, respectively. Among two cover crops significantly higher available nitrogen (286.82, 257.87 and 214.62 kg ha⁻¹) and phosphorus (105.44, 100.17 and 82.15 kg ha⁻¹) was recorded with horse gram as cover crop in all three depths while significantly higher available potassium was recorded with sunhemp (195.09, 181.25 and 170.38 kg ha⁻¹) as a cover crop in all the three depths of 0-7.5 cm, 7.5-15 cm and 15-30 cm, respectively and was on par with horse gram in all the three depths (182.34, 173.00 and 162.45 kg ha⁻¹). Interaction effect was significant. Higher available nitrogen (323.54, 303.45 and 238.34 kg ha⁻¹) and phosphorous (118.38, 109.43 and 95.64 kg ha⁻¹) was observed in reduced tillage with horse gram at all the three depths while significantly higher availability of potassium (216.50, 201.84 and 191.04 kg ha⁻¹) was recorded in reduced tillage with sun hemp as cover crop in all the three depths and was on par with reduced tillage with horse gram (195.22, 192.30 and 182.76 kg ha⁻¹) (Table 99).

Table 99: Available nitrogen, phosphorus and potassium in soil as influenced by conservation agriculture practices in finger millet under pigeonpea-finger millet sequence cropping system

Treatments	Nitrogen (kg ha ⁻¹)			Phosphorus (kg ha ⁻¹)			Potassium (kg ha ⁻¹)		
	0-7.5 cm	7.5-15 cm	15-30 cm	0-7.5 cm	7.5-15 cm	15-30 cm	0-7.5 cm	7.5-15 cm	15-30 cm
Tillage practice									
M ₁ : Conventional tillage	192.96	165.13	148.74	66.07	60.88	50.32	158.15	146.67	140.02
M ₂ : Reduced tillage	287.23	257.43	210.11	107.74	99.61	83.44	185.57	176.51	169.43
M ₃ : Zero tillage	239.61	199.25	188.16	93.48	83.95	66.74	182.95	171.27	161.26
S. Em. ±	5.19	1.35	1.26	0.63	0.86	0.46	1.32	1.22	1.19
CD (p=0.05)	20.36	5.32	4.96	2.48	3.38	1.82	5.18	4.81	4.69
Cover crops									
C ₁ : Control	201.61	172.83	162.82	69.79	61.51	55.32	149.23	140.20	137.88
C ₂ : Sunhemp	231.36	191.11	169.57	92.06	82.75	63.03	195.09	181.25	170.38

C ₃ : Horsegram	286.82	257.87	214.62	105.44	100.17	82.15	182.34	173.00	162.45
S. Em. ±	10.52	4.66	4.11	2.02	1.99	1.53	3.72	3.49	3.32
CD (p=0.05)	32.42	14.35	12.65	6.22	6.14	4.73	11.46	10.77	10.23
Interaction									
M ₁ C ₁	161.82	156.40	143.50	51.30	44.73	43.20	131.40	131.30	126.50
M ₁ C ₂	185.53	143.40	132.40	59.40	55.40	41.30	178.54	165.40	155.16
M ₁ C ₃	231.52	195.60	170.32	87.50	82.50	66.47	164.50	143.30	138.40
M ₂ C ₁	261.74	213.40	188.16	92.68	90.10	75.26	145.00	135.40	134.50
M ₂ C ₂	276.40	255.43	203.84	112.17	99.29	79.41	216.50	201.84	191.04
M ₂ C ₃	323.54	303.45	238.34	118.38	109.43	95.64	195.22	192.30	182.76
M ₃ C ₁	181.28	148.70	156.80	65.40	49.70	47.50	171.30	153.90	152.64
M ₃ C ₂	232.15	174.50	172.48	104.60	93.58	68.38	190.24	176.50	164.94
M ₃ C ₃	305.40	274.56	235.20	110.43	108.59	84.34	187.30	183.40	166.20
S. Em. ±	18.23	8.07	7.11	3.50	3.45	2.66	6.44	6.05	5.75
CD (p=0.05)	NS	24.86	21.92	10.78	10.64	8.19	19.84	18.65	17.72

M₁: Conventional tillage
C₁: Control

M₂: Reduced tillage
C₂: Sunhemp

M₃: Zero tillage
C₃: Horse gram

Cotton-Pigeonpea System

In cotton-pigeonpea system, buildup of available P (13.16 kg ha⁻¹) in top 0-15 cm soil depth was observed in ZT. Higher water soluble and exchangeable K was observed in ZT and MT as compared to CT.

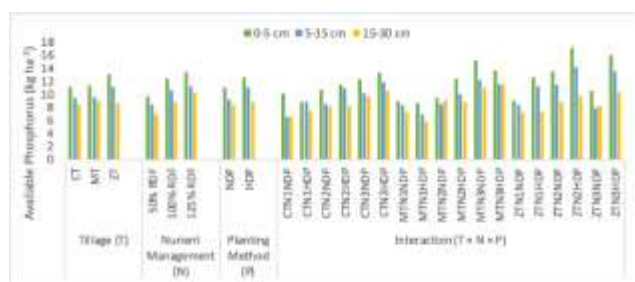




Fig 124. available N, P, K and S in Cotton-Pigeonpea System

Cotton-wheat System

IARI

Nitrogen, P, and K accumulation in soil after 14 years in cotton-wheat system

All CA systems had significantly higher available N, P &K than CT, but the PBBR100N led to highest increase by 75%, 91% and 99%, resp. over initial values (Table 100). Root biomass was calculated from shoot: root of cotton (6.2:1) (Rosolem et al., 1998, 1999) and wheat (7.4:1) (Bolinder et al., 2007)]

Table 100: Effect of CA and N on soil available N, P, and K (after 14 years)

Treatments	Available N (kg/ha)			Available P (kg/ha)			Available K (kg/ha)		
	Initial (2010-11)	2023	Increase (%)	Initial (2010-11)	2023	Increase (%)	Initial (2010-11)	2023	Increase (%)
CT	182.3	243.4	33.5	52.2	75.2	44.1	300.6	411.6	36.9
PNBR	182.3	303.2	66.3	52.2	92.6	77.4	300.6	564.2	87.7
PBBR	182.3	319.5	75.3	52.2	99.7	91.0	300.6	596.8	98.5
ZTFBR	182.3	298.7	63.9	52.2	90.4	73.2	300.6	576.2	91.7
LSD (P=0.05)	-	22.6	-	-	8.4	-	-	32.7	-

Foxtail Millet- Greengram System

Post-harvest soils of rice-mustard-cow pea system of Chene, Jharkhand

pH in post-harvest soil of rice-mustard-cow pea varied from 4.66 to 5.03 and pH was highest in ZTTR (5.03). Organic carbon content was the highest in CA practices (0.61 and 0.62% in ZTDSR and ZTTR, respectively). Both CA practices of ZT-DSR & ZTTR treatments showed higher value of available-N content compared to other treatments. Further, available-P content was also higher in both CA treatments. Available K content was significantly the highest under ZTTR treatment (192.6 kg/ha). The soil microbial biomass carbon was significantly higher in ZTTR (268 mg C/kg soil) and was non-significant with ZTDSR (Table 101).

Table 101: Effect of CA practices on changes of soil properties in post-harvest soils of rice-mustard-cow pea system

Treatment	pH	Organic carbon (%)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	SMBC (mg/kg soil)
Rice establishment methods						
Rice-fallow	4.66	0.47	166.8	14.25	162.1	139.2
ZTDSR	4.98	0.61	184.5	21.35	189.6	257.2
CTDSR	4.71	0.56	174.3	17.15	174.7	166.1
ZTTR	5.03	0.62	188.3	20.75	192.6	268.0
FPTR	4.87	0.58	176.3	18.95	182.2	158.4
LSD (p≤0.05)	0.28	0.046	10.14	2.20	8.91	26.93

Post-harvest soils of rice-linseed-green gram cropping system

SOC content in ZTDSR and ZTTR showed (0.58 and 0.59%) significantly higher over rice-fallow, but when compared among themselves, showed non-significant. Available-N content was significantly highest of 201.2 kg/ha in ZTTR treatment & significantly higher over treatment. Available-P content was highest of 20.45 kg/ha in ZTTR treatment & found significantly higher over CTDSR & rice-fallow. Available-K content showed significantly highest of 186.8 kg/ha in ZTTR over rice-fallow treatments. The soil microbial biomass carbon was significantly highest of 276 mg C/kg soil in ZTTR compared to rice-fallow, CTDSR and FPTR, while it showed non-significant with ZTDSR (Table 102).

Table 102: Effect of CA practices on changes of soil properties in post-harvest soils of rice-linseed-green gram system

Treatment	pH	Organic carbon (%)	Available-N (kg/ha)	Available-P (kg/ha)	Available-K (kg/ha)	SMBC, mg/kg soil
Rice establishment methods						
Rice-fallow	4.78	0.43	173.2	15.45	160.0	174.6
ZTDSR	4.98	0.58	191.2	19.33	184.7	266.6
CTDSR	4.84	0.52	180.1	17.18	172.7	181.2
ZTTR	5.05	0.59	201.2	20.45	186.8	276.1
FPTR	4.92	0.55	191.4	18.60	179.5	188.0
LSD (p≤0.05)	NS	0.055	9.49	2.76	11.06	35.74

F. Micronutrients in Conservation Agriculture

CRIDA

At 0 -7.5 cm, 7.5-15 cm and 15- 30 cm available micronutrient content Zn (1.11, 0.84 and 0.71 mg kg⁻¹), Mn (13.00, 8.70 and 6.72 mg kg⁻¹) and Cu (1.46, 0.93 and 0.82 mg kg⁻¹) in soil varied significantly with respect to different tillage practices and highest value was recorded in reduced tillage followed by zero tillage practice (Table 103). Available micronutrient content Fe (19.39, 16.80 and 14.77 mg kg⁻¹) was significantly higher at all the three depths in reduced

tillage and was found on par with zero tillage at 0-7.5 cm depth. Boron content (0.76, 0.47 and 0.33 ppm) was significantly higher in reduced tillage and was found on par with zero tillage at 15-30 cm depth. Among the cover crops significantly higher micronutrient content of Zn (1.11, 0.85 and 0.70 mg kg⁻¹), Mn (10.66, 8.34 and 6.16 mg kg⁻¹), Fe (19.72, 16.86 and 14.41 mg kg⁻¹) and Cu (1.21, 0.94 and 0.82 mg kg⁻¹) was recorded with horse gram as cover crop followed by sun hemp in all the three depths of 0-7.5 cm, 7.5-15 cm and 15-30 cm. Interaction effects of reduced tillage and cover crops was non-significant.

Table 103: Soil micro nutrient status as influenced by conservation agriculture in finger millet under pigeonpea-finger millet sequence cropping system

Treatments	Zinc (mg kg ⁻¹)			Manganese (mg kg ⁻¹)			Iron (mg kg ⁻¹)			Copper (mg kg ⁻¹)			Boron (ppm)		
	0-7.5 cm	7.5-15cm	15-30 cm	0-7.5 cm	7.5-15cm	15-30 cm	0-7.5 cm	7.5-15 cm	15-30 cm	0-7.5 cm	7.5-15cm	15-30 cm	0-7.5 cm	7.5-15cm	15-30 cm
Tillage practice															
M ₁ : Conventional tillage	0.99	0.81	0.61	9.13	7.76	5.37	18.35	15.52	13.19	1.06	0.89	0.75	0.73	0.46	0.32
M ₂ : Reduced tillage	1.11	0.84	0.71	13.00	8.70	6.72	19.39	16.80	14.77	1.46	0.93	0.82	0.76	0.47	0.33
M ₃ : Zero tillage	1.04	0.82	0.64	9.45	8.06	5.67	19.16	16.62	14.70	1.05	0.93	0.81	0.65	0.43	0.26
S. Em. ±	0.01	0.01	0.01	0.08	0.07	0.05	0.16	0.14	0.12	0.01	0.01	0.01	0.00	0.00	0.00
CD (p=0.05)	0.03	NS	0.02	0.32	0.28	0.18	0.63	0.54	0.48	0.04	NS	0.03	0.02	0.01	0.01
Cover crops															
C ₁ : Control	0.97	0.81	0.61	10.06	7.87	5.43	18.42	15.65	13.92	1.02	0.89	0.74	0.61	0.39	0.25
C ₂ : Sunhemp	1.06	0.82	0.65	10.87	8.31	6.18	18.76	16.43	14.32	1.35	0.92	0.82	0.67	0.42	0.29
C ₃ : Horsegram	1.11	0.85	0.70	10.66	8.34	6.16	19.72	16.86	14.41	1.21	0.94	0.82	0.85	0.54	0.36
S. Em. ±	0.02	0.02	0.01	0.23	0.18	0.13	0.41	0.35	0.31	0.02	0.02	0.02	0.02	0.01	0.01
CD (p=0.05)	0.07	NS	0.04	NS	NS	0.40	NS	NS	NS	0.07	NS	0.05	0.05	0.03	0.02
Interaction															
M ₁ C ₁	0.92	0.80	0.57	9.00	7.56	4.80	17.97	15.26	12.91	1.00	0.86	0.65	0.61	0.40	0.29
M ₁ C ₂	1.00	0.82	0.59	9.16	7.68	5.60	18.61	15.75	13.47	1.02	0.88	0.80	0.76	0.44	0.31
M ₁ C ₃	1.06	0.82	0.67	9.22	8.04	5.72	18.48	15.54	13.18	1.18	0.95	0.82	0.82	0.54	0.35
M ₂ C ₁	1.07	0.82	0.68	12.16	8.49	6.49	18.64	15.75	14.34	1.00	0.86	0.78	0.66	0.41	0.31
M ₂ C ₂	1.12	0.83	0.72	13.94	8.98	7.10	18.94	16.88	14.92	1.98	0.97	0.86	0.67	0.43	0.31
M ₂ C ₃	1.15	0.87	0.73	12.90	8.62	6.58	20.59	17.78	15.05	1.40	0.95	0.84	0.96	0.58	0.37
M ₃ C ₁	0.94	0.80	0.58	9.01	7.56	5.00	18.65	15.95	14.51	1.06	0.95	0.81	0.58	0.37	0.17
M ₃ C ₂	1.05	0.82	0.63	9.50	8.27	5.84	18.73	16.67	14.58	1.05	0.92	0.81	0.60	0.40	0.26
M ₃ C ₃	1.13	0.85	0.72	9.85	8.35	6.18	20.11	17.25	15.00	1.04	0.92	0.80	0.78	0.51	0.35

S. Em. ±	0.04	0.03	0.02	0.40	0.31	0.23	0.71	0.61	0.54	0.04	0.03	0.03	0.03	0.02	0.01
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.13	NS	NS	0.08	NS	0.04

3. Soil Biological Properties

Rice-Wheat System

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Biological soil health and resilience

Soil samples were collected from conservation agriculture experiment. The treatments comprised of: T1- Zero-till direct-seeded rice (ZTDSR) - zero till wheat (ZTW), T2- ZTDSR+wheat residue (WR)-ZTW+rice residue (RR), T3-ZTDSR + wheat residue (WR) + (SBM) -ZTW + RR, T4- ZTDSR - ZTW - ZTMB, T5- ZTDSR + MR- ZTW + RR - ZTMB + WR, T6-Transplanted puddled rice (TPR) - conventional till wheat (CTW)- conventional till mung-bean (CTMB)] at 0-15 cm soil depth. Biological soil health index (BSHI) (Figure 125) and soil resilience index (SRI) (Figure 126) were developed to find out the best management practices for improving soil health and resilience under rice-wheat cropping system. Six PCs were extracted on the basis of eigen value >1. The key indicators of soil health under CA based rice-wheat system were β -glucosidase, bacterial amoA 16S rRNA, archaeal 16SrRNA, bacterioidetes 16SrRNA, bacterial 16SrRNA and mineralizable C of soil. The highest value of BSHI was found in ZTDSR+MR-ZTW+RR- ZTMB+WR treatment and lowest was with TPR-CTW-CTMB treatment. The value of soil resilience index (SRI) was varied from 0.69 to 0.77. The highest value of SRI was found in ZTDSR+MR-ZTW+RR- ZTMB+WR treatment and lowest was with TPR-CTW-CTMB treatment. The triple zero tillage with residues retention improve better soil resilience under CA based rice-wheat cropping system in IGP.

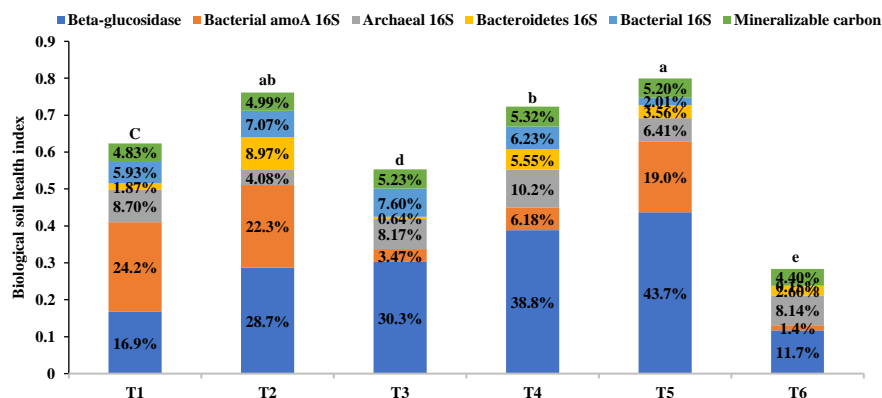


Fig 125. Biological soil health under rice-wheat system

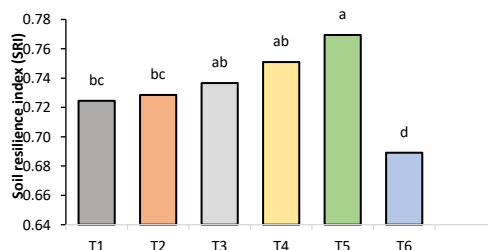


Fig 126. Biological soil health and resilience under rice-wheat system

Beta- glucosidase activity in soil at flowering and harvest of rice

Two parameters which pertains for the soil carbon transformations mediated by soil microorganisms were studied to gain insights related to the impact of the CA technologies. Beta-glucosidase activity (Table 104) was significantly higher (19.66 ± 1.74 $\mu\text{mole/g}$ of soil) in ZT+CR+BM-ZT+CR than ZT and CT (31.06% higher than ZT and 170.79% higher than CT). ZT +CR had significantly higher value (18.73%) beta - glucosidase than without CR. ZT +MB had significantly lower (3.66%). Beta - glucosidase had significantly higher value at flowering than at harvest. Zero tilled soils receiving the combined input of brown manure and crop residues exhibited the highest activity of beta – glucosidase while individual addition of either the brown manure or crop residues recorded significantly lower enzyme activity at the two soil depths, both at flowering and harvest stages of crop growth. Observations comparing the Zero tilled soils, receiving crop residues with or without the inclusion of legume mungbean crop revealed that legume was effective in the carbon mineralization as evident with higher activity of beta-glucosidase.

Table 104: Beta-glucosidase activity at flowering and harvest of rice across soil depth

Treatments	Beta - glucosidase ($\mu\text{mole/g}$ of soil) in rice			
	Soil depth (cm)			
	Beta - glucosidase at flowering		Beta - glucosidase at harvest	
	0-15	15-30	0 -15	15-30
ZT-ZT	10.85 ± 0.96^f	15.00 ± 1.43^d	3.29 ± 0.37^e	0.95 ± 0.12^s
ZT+BM-ZT	7.26 ± 0.81^h	9.07 ± 0.99^g	7.51 ± 0.84^c	6.83 ± 0.72^d
ZT+CR-ZT+CR	13.54 ± 1.39^e	17.81 ± 1.97^{bc}	11.09 ± 0.99^b	8.81 ± 0.90^c
ZT+CR+BM-ZT+CR	18.20 ± 1.88^a	19.66 ± 1.74^a	14.74 ± 1.55^a	14.35 ± 1.48^a
ZT-ZT-ZT	14.47 ± 1.77^d	12.75 ± 1.21^e	4.47 ± 0.49^{de}	4.23 ± 0.52^f
ZT+MB-ZT+RR-ZT+WR	$16.98 \pm 1.74_b$	18.16 ± 2.02^b	8.22 ± 0.89^c	6.34 ± 0.69^d
CTR – ZTW	8.55 ± 0.96^s	12.00 ± 1.23^f	5.65 ± 0.61^d	5.48 ± 0.63^e
CTR-CTW (CT)	15.51 ± 1.58^c	17.17 ± 1.69^c	10.70 ± 0.84^b	9.60 ± 1.35^b
CD (0.01)	1.053	0.939	1.996	1.084

IIFSR

Various Cropping Systems

Addition of summer greengram in R-W, M-M and Sr-Rt-W systems significantly improved dehydrogenase (DHA) enzyme activity in these cropping systems, as DHA was 25.7%, 97.4%, 122.6% and 8.3% higher in these cropping systems over the conventional R-W systems (Table 105). At the same time, alkaline phosphatases enzyme (ALP) was also 67.3%, 81.8%, 105.9% and 74.9% superior in R-W, R-W-GG, M-M-GG and Sr+GG-Rt+GG-W systems under CA based management practices over the conventional R-W system. Soil FDA was also improved significantly due long-term CA based management practices in diverse cropping systems as it was 9.3%, 15.5%, 59.1% and 20.7% superior in R-W, R-W-GG, M-M-GG and Sr+GG-Rt+GG-W systems under CA based management practices over the conventional R-W system.

Table 105: Effect of crop diversification and conservation agriculture practices on soil carbon, nitrogen and phosphorus cycling enzymes

	DHA ($\mu\text{g TPF g}^{-1}$ soil 24 h^{-1})	ACP ($\mu\text{g pNP g}^{-1}$ soil h^{-1})	ALP ($\mu\text{g pNP g}^{-1}$ soil h^{-1})	MBC (mg kg^{-1})	β - Glucosidase ($\mu\text{g pNPG g}^{-1}$ soil h^{-1})	FDA ($\mu\text{g F g}^{-1}$ dry soil h^{-1})
Cropping Systems (CS)						

R-W (CP)	239.8	65.87	111.0	206.7	147.6	221.5
R-W (CA)	301.4	69.30	185.7	309.6	154.9	242.1
R-W-GG (CP)	376.5	65.26	191.6	248.9	148.7	227.6
R-W-GG (CA)	473.3	69.70	201.8	328.2	156.3	255.8
M-M-GG (CP)	274.7	77.26	193.6	258.8	151.4	306.5
M-M-GG (CA)	533.9	107.6	228.6	440.5	161.8	352.3
S-R-W (CP)	160.1	51.92	95.5	225.4	144.5	266.1
S+GG-R-W (CA)	259.8	65.27	194.1	239.3	145.3	267.4
Sem (±)	35.00	7.89	6.38	17.41	1.889	10.72
C.D. (P<0.05)	99.20	22.35	18.10	49.33	5.325	30.37
Soil Depth						
0-15 cm	437.5	78.16	159.2	396.4	152.5	383.1
15-30 cm	313.0	72.09	109.8	305.6	149.0	328.5
30-45 cm	279.4	61.65	85.0	196.7	76.07	174.3
45-60 cm	229.6	60.68	59.4	149.3	68.03	83.72
Sem (±)	24.75	5.57	12.78	12.21	1.343	7.58
C.D. (P<0.05)	70.14	NS	36.21	34.60	3.805	21.47

Soil microbial population

Earthworm abundance in CA-based cotton-wheat system

The earthworm population was enumerated by counting the number of earthworms per m³ area during different stages of crop growth such as tillering, flowering and maturity stages of wheat and branching, squaring and maturity stages of cotton. The study revealed that the highest populations 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 (Figure 127). In both wheat and cotton crop during all the stages of crop growth, the highest count of earthworm was recorded by PBB+R+100N followed by ZTFB+R+100N, PNB+R+100N and the lowest were recorded in the conventional tillage plot. PBBR resulted in higher earthworm population and biomass, which were 283% and 198% higher compared to CT.

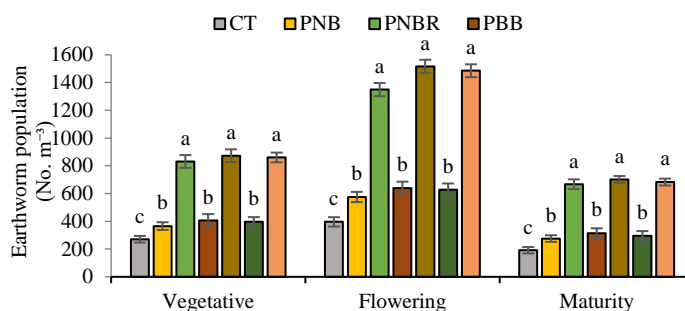


Fig 127. Earthworm biomass in cotton- wheat system under different crop establishment methods

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Soil microbial diversity was assessed in samples collected from the conservation agriculture (CA) field experiment conducted on Vertisols in central India. The study evaluated two cropping systems: maize–chickpea (MC) and wheat–soybean (WS), under various tillage and residue management treatments. The treatments included

- No-tillage with 90% crop residue retention (NT-90%),
- Conventional tillage (CT) with residue incorporation, and
- No residue retention with No - tillage (0% residue).

Each treatment was applied to both cropping systems: NT-90%-MC, NT-90%-WS, CT-MC, CT-WS, 0-MC, and 0-WS. Soil samples were collected from each treatment plot, and total genomic DNA was extracted using standard protocols. The bacterial 16S rRNA gene was amplified via polymerase chain reaction (PCR). PCR amplicons were sequenced using the Illumina platform, following standard high-throughput sequencing methodologies to analyze the eubacterial community composition.

Soil microbial diversity was evaluated using the Shannon diversity index, Simpson index, and Operational Taxonomic Unit (OTU) richness (Fig. 128). These metrics collectively reflect the richness, evenness, and community composition of soil microbes across different crop management systems. The Shannon index ranged from 3.948 to 5.834 across treatments, indicating substantial variation in soil microbial diversity under different CA practices. The diversity followed the trend of NT-90%-MC (5.834) > NT-90%-WS (5.484) > CT-MC (4.695) > CT-WS (4.438) > 0-MC (3.958) > and 0-WS (3.948). These results emphasize the positive impact of conservation practices and crop choice on microbial diversity. The Simpson index data ranged from 0.9745 to 0.9963, reflecting variations in species dominance and evenness. The highest value of 0.9963 in NT90%MC indicated that the microbial community was highly even, with no single species dominating, suggesting a well-balanced, diverse ecosystem. The lowest values, such as 0.9745 for CTWS. The OTU (Operational Taxonomic Unit) richness varied significantly across treatments. It ranged from 75 OTUs in CTWS to 519 OTUs in NT90MC. The highest OTU richness observed in NT90MC suggested that no-till and residue retention practices leads to more diverse and abundant microbial community. The lowest OTU richness in CTWS indicated that conventional tillage, especially with wheat-soybean rotations, leads to reduced microbial diversity and richness.

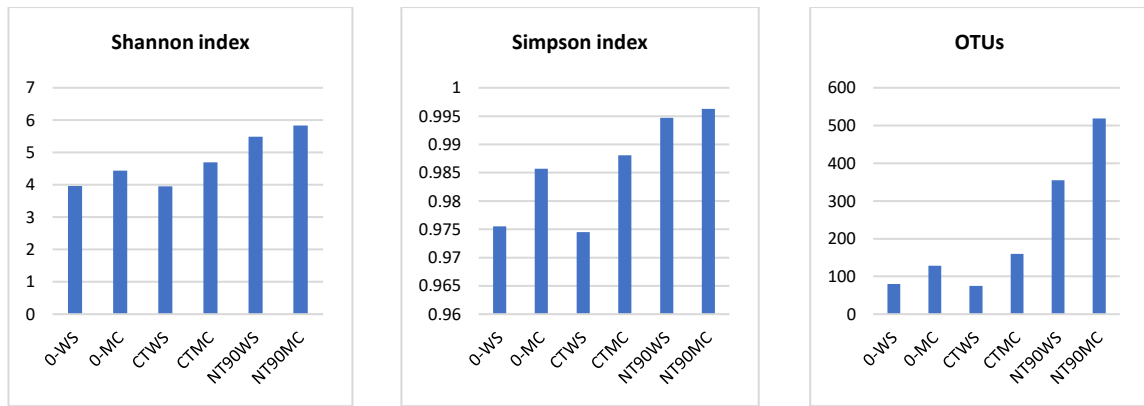


Fig 128. Microbial diversity in soil samples collected from different management of CA practices.

The stacked bar chart (Fig 2) illustrates the relative abundance of microbial genera across different CA treatments. Among the classified genera, Acidobacteria emerges as the most dominant, contributing approximately 20–25% of the total identified community. This was followed by Sphingomonas (10–15%), Microvirga (8–12%), Flavisolibacter (6–10%), and Rubrobacter (5–8%). Other genera such as Steroidobacter, Ramlibacter, Dongia, contribute smaller proportions, generally ranging from 2–5%. NT90MC recorded the highest OTU richness (519 OTUs), indicating a highly diverse and abundant microbial community. NT90WS followed with 355 OTUs, while 0-MC and 0-WS exhibited 160 and 128 OTUs, respectively. The lowest OTU count was observed in CTWS at 75 OTUs, demonstrating a significant reduction in microbial diversity under conventional tillage, especially in wheat–soybean rotations. The NT-90-MC, treatment supports a microbial structure similar to CT-MC, with Acidobacteria (~24%), Sphingomonas (~14%), and Microvirga (~11%) as dominant genera. In NT-90-WS, Acidobacteria (~22%) and Microvirga (~13%) continue to dominate, while Sphingomonas and Flavisolibacter are slightly lower than in the maize-chickpea system. Overall, the data clearly show that conservation agriculture practices—particularly no-till systems with high residue retention—greatly enhance soil microbial diversity, richness, and community balance. In contrast, conventional tillage systems, especially in wheat–soybean rotations, are associated with reduced microbial diversity and richness. These findings underscore the critical role of conservation practices in promoting sustainable soil health and ecosystem function.

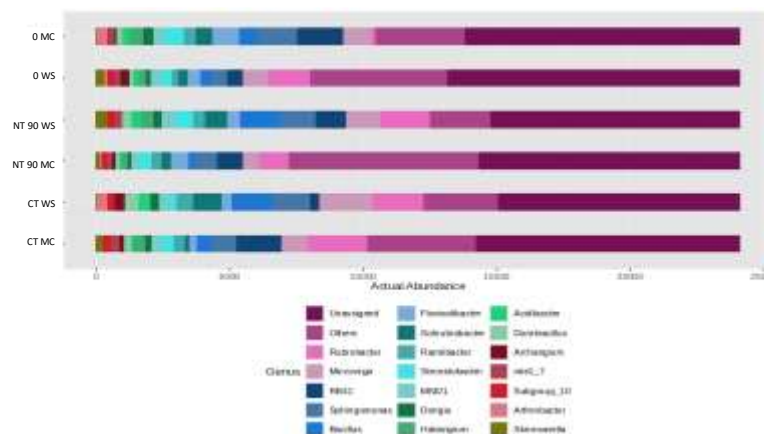


Fig 11. Abundance of major microbial species in different treatments under CA practices.

CRIDA

In Sorghum-Blackgram cropping system, soil biological properties, viz., microbial biomass carbon and dehydrogenase activity 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 and dehydrogenase activity with tillage and residue management (Fig 129, 130, 131, 132).

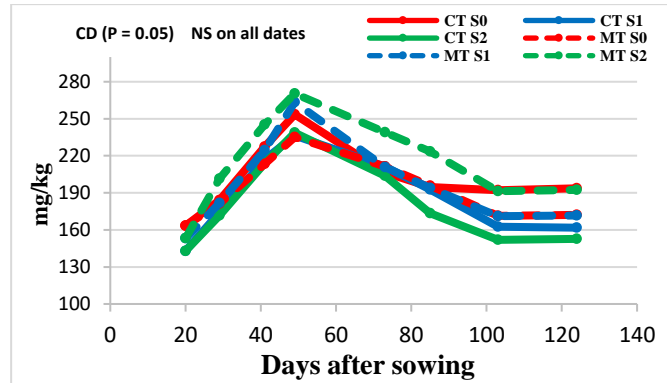


Fig 129. Effect of tillage and residue management on soil microbial biomass carbon (SMBC) in 0-7.5 cm soil layer

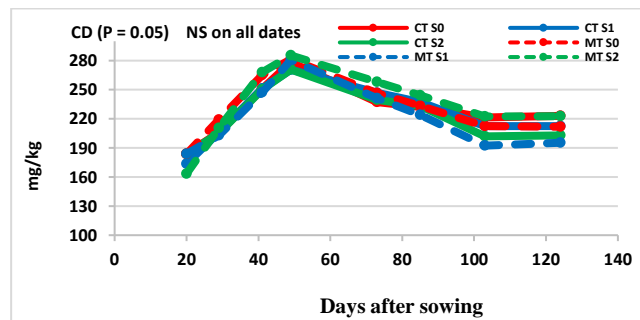


Fig 130. Effect of tillage and residue management on soil microbial biomass carbon (SMBC) in 7.5-15 cm soil layer

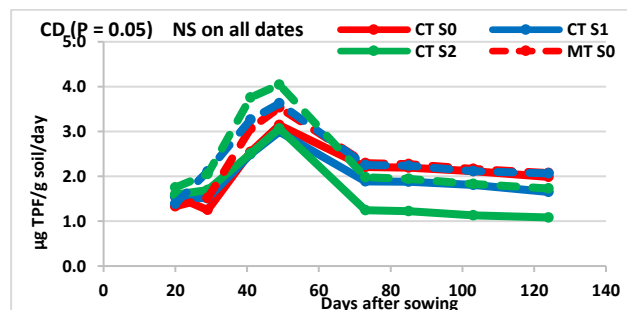


Fig 131. Effect of tillage and residue management on soil dehydrogenase activity in 0-7.5 cm soil layer

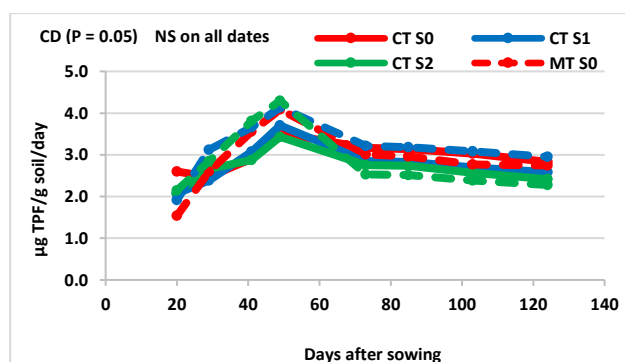


Fig 132. Effect of tillage and residue management on soil dehydrogenase activity in 7.5-15 cm soil layer

In maize-pigeonpea cropping system integration of in situ moisture conservation and weed management along with CA practices influenced the biological properties. Permanent conservation furrow and permanent bed and furrow and Zero tillage recorded higher dehydrogenase, urease, MBC and MBN as compared to conventional tillage (Table 106).

Table 106: Soil biological properties as influenced by conservation agriculture in maize-pigeonpea cropping system

	Dehydrogenase	Urease	MBC	MBN
Main plots				
CT	3.02	149.62	185.21	130.77
ZTF	3.04	150.50	190.03	137.28
ZTPB	3.35	164.50	215.25	129.39
ZTS	2.97	149.62	186.86	138.18
LSD	0.11	6.61	17.43	14.81
Subplots				
control	3.65	151.37	198.96	126.22
pre+intercultivation	2.78	144.37	190.88	140.40
pre+post emerg	3.19	161.00	190.05	132.81
pre+post+intercultivation	2.77	157.50	197.46	136.19
LSD	0.26	14.28	15.69	8.69
Interactions				
CT-control	3.28	161.00	191.11	129.43
CT-pre+intercultivation	3.03	140.00	179.37	148.54
CT-pre+post emerg	3.30	161.00	176.97	132.34
CT-pre+post+intercultivation	2.48	136.50	193.38	112.78
ZTF-control	3.29	140.00	194.09	121.01

ZTF-pre+intercultivation	2.83	143.50	200.30	151.29
ZTF-pre+post emerg	2.98	143.50	184.84	131.02
ZTF-pre+post+intercultivation	3.06	175.00	180.89	145.79
ZTPB-control	4.20	168.00	215.33	145.93
ZTPB-pre+intercultivation	2.88	147.00	201.95	134.93
ZTPB-pre+post emerg	3.53	175.00	224.01	104.53
ZTPB-pre+post+intercultivation	2.80	168.00	219.70	132.18
ZTS-control	3.81	136.50	195.31	108.51
ZTS-pre+intercultivation	2.39	147.00	181.93	126.84
ZTS-pre+post emerg	2.95	164.50	174.36	163.35
ZTS-pre+post+intercultivation	2.74	150.50	195.86	154.01
CV	10.00	11.03	9.58	7.70

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 conservation agriculture (CA) based rice-wheat system was demonstrated on farmers' fields in two districts of the north-western Indo-Gangetic plain *viz.* Bareilly and Karnal. Fields of ten farmers (five from each district) were planted with direct seeding rice (DSR), transplanted rice (TPR), zero-till wheat (ZTW), and conventional tillage wheat (CTW), and their crop yields and net returns were compared. In Karnal, DSR had slightly lower yield but higher net returns than TPR (Tables 107 & 108). Rice yields under DSR ranged from 4.80 - 5.50 t/ha, and TPR from 5.30-5.80 t/ha. However, the ZTW yield was always higher ranging from 5.20-5.80 t/ha. As a result, the system productivity (WEY) was comparable between DSR-ZTW (11.02 t/ha) and TPR-CTW (11.00 t/ha) systems, but the net returns (NR) and net benefit:cost (NB:C) was higher under DSR-ZTW system than in TPR-CTW system. Higher NB:C in DSR-ZTW system indicated higher economic efficiency under CA system compared to traditional methods.

Table 107: Rice yield, wheat yield and system productivity in farmer fields Karnal, Haryana 2024-25

Farmer's Name	Village	DSR yield (t/ha)	TPR yield (t/ha)	ZTW yield (t/ha)	CTW yield (t/ha)	DSR-ZTW system WEY (t/ha)	TPR-CTW system WEY (t/ha)
Hardeep Singh	Jalmana	5.10	5.60	5.70	5.20	10.54	10.51
Mandeep Singh	Jalmana	4.80	5.30	5.60	5.30	10.15	10.33
Hari Mohan	Kurlan	5.20	5.60	5.20	5.10	10.13	10.41
Sadanand Sharma	Kurlan	5.0	5.50	5.50	5.20	10.24	10.42
Krishan Sharma	Kurlan	5.50	5.80	5.80	5.50	11.02	11.00

Table 108: Net returns (NR) in rice, wheat and rice-wheat system in farmer fields Karnal, Haryana 2024-25

Farmer's Name	Village	NR in DSR (Rs/ha)	NR in TPR (Rs/ha)	NR in ZTW (Rs/ha)	NR in CTW (Rs/ha)	NR in DSR-ZTW system (Rs/ha)	NR in TPR-CTW system (Rs/ha)	NB:C in DSR-ZTW system	NB:C in TPR-CTW system
Hardeep Singh	Jalmana	93304	84303	142379	124164	235683	208467	2.96	1.97
Mandeep Singh	Jalmana	84654	76003	135154	119629	219808	195632	2.76	1.85
Hari Mohan	Kurlan	92104	82903	126654	118779	218758	201682	2.75	1.90
Sadanand Sharma	Kurlan	87504	80603	135129	121204	222633	201807	2.79	1.90
Krishan Sharma	Kurlan	102504	88903	140004	126479	242508	215382	3.04	2.03

Similarly, in Bareilly, DSR yields ranged from 4.00 t/ha to 4.70 t/ha, and TPR yields highest at 5.60 t/ha. The highest ZTW yield was 5.60 t/ha, while CTW was maximum at 5.40 t/ha (Tables 109 & 110).

System productivity (WEY) was slightly higher in TPR-CTW (10.33 t/ha) than in DSR-ZTW (9.77 t/ha), but, the net returns under DSR-ZTW system was higher than in TPR-CTW system. The NB:C was also maximum in the DSR-ZTW system (2.64). Overall, the DSR-ZT wheat-based system outperformed the other systems in both districts, demonstrating higher economic returns. These field demonstrations confirmed the superiority of CA-based systems, highlighting their potential as a sustainable and economically viable alternative to conventional farming.

Table 109: Rice yield, wheat yield and system productivity in farmer fields Bareilly, Uttar Pradesh, 2024-25

Farmer's Name	Village	DSR yield (t/ha)	TPR yield (t/ha)	ZTW yield (t/ha)	CTW yield (t/ha)	DSR-ZTW system WEY(t/ha)	TPR-CTW system WEY (t/ha)
Om Prakash	Rajpura	4.30	5.20	5.50	5.10	9.58	10.03
Chatarpal	Rajpura	4.00	5.20	5.60	5.40	9.39	10.33
Bhagwandas	Rajpura	4.20	5.00	5.50	5.20	9.48	9.94
Dheeraj Kumar	Manehra	4.70	5.60	5.00	4.80	9.46	10.11
Rajender Kumar	Manehra	4.50	5.30	5.50	5.20	9.77	10.23

Table 110: Net returns (NR) in rice, wheat and rice-wheat system in farmer fields Bareilly, Uttar Pradesh, 2024-25

Farmer's Name	Village	NR in DSR (Rs/h)	NR in TPR (Rs/ha)	NR in ZTW (Rs/ha)	NR in CTW (Rs/ha)	NR in DSR-ZTW system (Rs/ha)	NR in TPR-CTW system (Rs/ha)	NB:C in DSR-ZTW system	NB:C in TPR-CTW system
Om Prakash	Rajpura	73854	74753	131129	114779	204983	189532	2.57	1.79
Chatarpal	Rajpura	64504	73703	136354	124054	200858	197757	2.52	1.87
Bhagwandas	Rajpura	68054	68403	132729	117204	200783	185607	2.52	1.75
Dheeraj Kumar	Manehra	81304	82903	116604	105504	197908	188407	2.48	1.78
Rajender Kumar	Manehra	79504	77403	131129	117204	210633	194607	2.64	1.84

CRIDA, Hyderabad

Adapting and mainstreaming available best bet location Specific conservation agriculture practices

Experiments were conducted in different cropping systems on both KVK farm as well as farmers' fields to demonstrate the advantage of reducing tillage practices and residue retention.

Proposed cropping Systems:

- ❖ Pigeon pea +Foxtail millet (Suryanandi) Inter cropping– Chick pea (NBeG-49) with minimum tillage
- ❖ Foxtail millet (Suryanandi)– Chick pea (NBeG-49) with minimum tillage
- ❖ Soyabean- Bengalgram cropping sequence with minimum Tillage
- ❖ Pigeon pea +Foxtail millet (Suryanandi) Inter cropping) with conservation furrow at every 3.6mts

Demonstration on minimum tillage Bengalgram in Setaria + Redgram Intercropping:

The results indicated that highest Redgram equivalent yield (2790 kg/ha) and net returns was obtained with minimum tillage Bengalgram in Korra+ Redgram intercropping (Rs 109187/ha) than Korra+ Redgram intercropping (2173kg/ha) (Rs. 82710 ha). The additional net income of the farmers was also increased in minimum tillage Bengalgram in Korra+ Redgram intercropping which is calculated as Rs. 26,477/- more than the in Setaria+ Redgram Intercropping.

Table 111: Demonstration on minimum tillage Bengalgram in Setaria + Redgram Intercropping

Treatments	Locations (No)	Farmers visited (Nos)	Yield (q/ha)*	Net returns (Rs /ha)	B:C Ratio
Redgram+Setaria- Bengal gram	10	39	2790	109187	3.13
Redgram+Setaria	10	25	2173	82710	2.95



Demonstration Setaria- Bengalgram cropping sequence with minimum Tillage

The results indicated that highest net returns were obtained with Korra-bengalgram sequence (Rs. 90290 /ha) than fallow –Bengalgram (Rs. 59452 /ha). The additional net income of the farmers was also increased in Korra- Bengalgram sequence which is calculated as Rs. 30838/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. In order to increase net returns Rs/ha and cropping intensity.

Table 112: Demonstration 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	2623-1461	77653	167943	90290	30452	2915
Bengalgram	1947	52500	111952	59452		1947



Demonstration on Soyabean- Bengalgram cropping sequence with minimum Tillage

The results indicated that highest net returns was obtained with Soyabean- Bengalgram sequence (Rs. 104947 /ha) than fallow –Bengalgram (Rs. 55850 /ha). The additional net income of the farmers was also increased in Soyabean- Bengalgram sequence which is calculated as Rs. 49097 more than the Fallow- Bengalgram

Table 113: Demonstration on Soyabean- Bengalgram cropping sequence with minimum Tillage

Treatments	Locations (No)	Farmers visited (Nos)	Yield (q/ha)*	Netreturns (Rs./ha)	B:C Ratio
Soybean-Bengalgram	10	28	33.10	104947	2.22
Bengalgram	10	10	19.00	55850	2.00



Demonstration on conservation furrow in Setaria + Redgram Intercropping:

The results indicated that highest Redgram equivalent yield (1844 kg/ha) and net returns was obtained with conservation furrow in Korra+ Redgram intercropping (Rs 63621/ha) than Redgram sole crop without conservation furrow (1613kg/ha) (Rs 50021ha). The additional net income of the farmers was also increased with conservation furrow in Korra+ Redgram intercropping which is calculated as Rs. Rs 13600 more than sole crop of Redgram.

Table 114: Demonstration on 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	18.44	63621	4.48	10
Redgram without conservation furrow(FP)	10	10	16.13	50021	3.35	10



IIWBR, Karnal

Field demonstrations on *in-situ* rice residue management in wheat under rice-wheat system were conducted at farmers’ field in Taroari, Kunjpura and Johrmajra village 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 with THS machines with a lesser time and energy requirement compared to conventional system. The wheat yield was similar under CA (61.6 q/ha) and CT (60.9 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.



Fig.133. 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, Kartarpur and Barsalu for 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 222 was sown using a seed rate of 150 kg/ha during the month of January. The new version of RDD was used for seeding in full trash of sugarcane. The wheat yield obtained ranged from 29.93 to 48.9 q/ha when sown using RDD. Whereas, 1000 grains weight ranged 33-37 g due to delayed sowing. These results clearly showed that an additional crop of wheat can be taken in sugarcane ratoon using RDD.

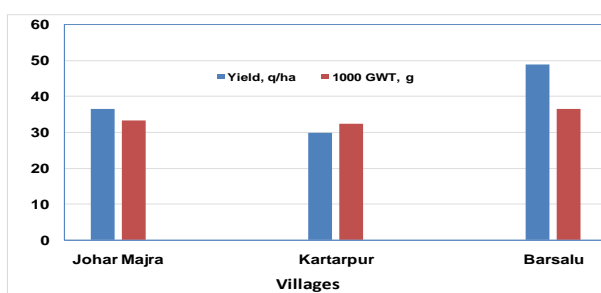


Fig.134. Performance of wheat seeded in sugarcane ratoon using Rotary Disc Drill



Testing of no-till disc drill for seeding in no-till conditions in the presence of loose crop residue

No-till strip drill received from ICAR-CIAE, Bhopal was tested under no till conditions in the presence of loose rice crop residue under rice-wheat system. This machine has powered cutting disc in front for cutting crop residue and rear side is aligned tynes for drilling seed and fertilizers. The cutting action of the disc was not satisfactory and moreover, there was dragging of crop residue along with the tynes (See photos below). This machine is not suitable for seeding in loose crop residue.

DWR, Jabalpur

Farmers Scientist interaction under SCSP

ICAR - Directorate of Weed Research, Maharajpur, Jabalpur organized a *Kisan Mela*-cum-Exhibition on 18 February 2025. The event witnessed enthusiastic participation from around 1000 farmers and 300 students from the Jabalpur division. Welcoming the attendees, Dr. J.S. Mishra, Director, ICAR-Directorate of Weed Research, highlighted the pressing challenges posed by weeds in modern agriculture. He noted that intensive farming practices and labour shortages are worsening weed problems, which cause an estimated annual loss of Rs 70,000 crore in ten major crops. He emphasized

the significance of such fairs in disseminating weed management technologies and advocated for an integrated approach to weed control.

Hon'ble Shri Jagat Bahadur Singh Annu, Mayor of Jabalpur, underscored the importance of adopting new agricultural technologies to ensure higher productivity on limited land, especially in light of the growing population. He further emphasized reducing pesticide use to protect both soil and human health. The Mayor also visited various stalls, interacted with participants, and congratulated the organizers and exhibitors.

Chief Guest, Hon'ble Mrs. Sumitra Valmik, Member of Parliament (Rajya Sabha), commended the event and expressed concern about the hardships faced by farmers due to natural disasters. She assured that the government is addressing these challenges through various relief schemes.

Several distinguished guests shared valuable insights:

- Dr. Arun Kumar Joshi, Managing Director of BISA, highlighted the importance of agricultural diversity and promoted the concept of *Tikau* (sustainable) farming, which improves soil and environmental health without stubble burning.
- Dr. K.R.S. Sambasiva Rao, Vice Chancellor of Mangalayatan University, spoke on the potential of modern technologies to boost food production.
- Dr. R.C. Mishra, Vice Chancellor of Mahakaushal University, emphasized the need to enhance agribusiness skills alongside traditional farming.
- Dr. S.R.K. Singh, Director of ATARI, Jabalpur, stressed the role of crop diversification and vertical farming in promoting natural and organic practices to improve soil health.
- Dr. A.K. Vishwakarma, Project Coordinator for Sesame and Niger at JNKVV, Jabalpur, discussed strategies for improving yields of oilseed crops.

During the Mela, participating farmers visited the Directorate's demonstration fields to learn about the latest weed management practices. The exhibition also showcased a wide range of topics including agriculture, pesticides, seed varieties/hybrids, medicinal and aromatic plants, forest species, agricultural machinery, animal husbandry, fisheries, poultry, etc. Several leading banks provided information on their latest schemes and services for farmers.

A *Kisan Gosthi* (farmers' seminar) was organized as part of the event, where agricultural scientists addressed farmers' queries and provided expert guidance. Progressive farmers were also recognized and felicitated for their contributions.





RCER, Patna

CA-based practices was evaluated during 2024-25 at the farmer's field at 2-locations viz. Chene, Ranchi, Jharkhand & Kandora, Jashpur, Chhattisgarh. CA-based management practices comprised of zero-till transplanted rice (ZTTR), zero-till-direct seeded rice (ZT- DSR), conventional till-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 on residual soil moisture and fertility status.

Another, CA practices was evaluated during 2024-25 in farmer's field at Chene, Ranchi, Jharkhand. CA-practices comprised of ZTTR, ZTDSR, CTDSR, FPTR & rice fallow were evaluated on winter crops *i.e.*, mustard (Pusa-26) and linseed (BAU 06-03) after harvesting of rice. Rice grain yield was significantly higher (4.65 t/ha) under ZTDSR system compared to other CA & farmer's management practices (Table 115). Farmer's practice registered grain yield of 4.25 t/ha.

Table 115: Yields of kharif & rabi season crops at Jharkhand and Chhattisgarh experimental 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	4.39 ^{bc}	-	-	4.55 ^b	-	-	-
ZTDSR	4.65 ^a	6.35 ^a	3.56 ^a	5.28 ^a	2.51 ^a	6.67 ^a	3.57 ^a
CTDSR	4.40 ^{bc}	5.51 ^{bc}	3.30 ^{ab}	4.51 ^b	2.17 ^{bc}	6.04 ^b	3.10 ^{bc}
ZTTR	4.59 ^{ab}	5.84 ^b	3.42 ^{ab}	5.16 ^a	2.38 ^{ab}	6.51 ^a	3.39 ^{ab}
FPTR	4.25 ^c	5.29 ^c	3.02 ^b	4.71 ^b	2.02 ^c	5.41 ^c	2.89 ^c

Values in column having different superscripts significantly different from each other (DMRT, P<0.05). Winter crops of mustard & linseed were grown in rice-fallow under different CA practices. Significantly highest mustard seed yield was recorded (6.35 q/ha) under ZTDSR followed by ZTTR (5.84 q/ha). CA-practices of ZTDSR were recorded highest grain yield over ZTTR & FPTR (Table 115). Grain yield of linseed varied from 3.02 to 3.56 q/ha among different CA-based management practices. The CA-based practices (ZTDSR) registered the highest grain yield (3.56 q/ha) followed by ZTTR. Rice equivalent yield (REY) was obtained under winter crops ranged between 0.98 to 1.90 t/ha. Among the different treatments, REY was found higher under CA and noted higher in ZTDSR treatment (Fig 135).

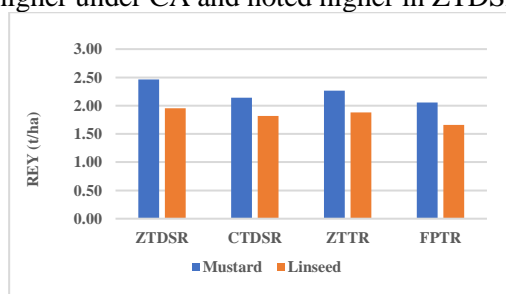


Fig.135. Rice equivalent yields of different crops and cropping systems at Jharkhand

System REY of cropping sequences were also evaluated under different CA-based management practices. It was observed that REY of rice-mustard cropping sequences (7.12 t/ha) under ZTDSR was significantly better over other cropping system of rice-linseed and rice-fallow system alone. Higher REY of these sequences were observed under CA practices (ZTDSR & ZTTR) as depicted in Fig. 136.

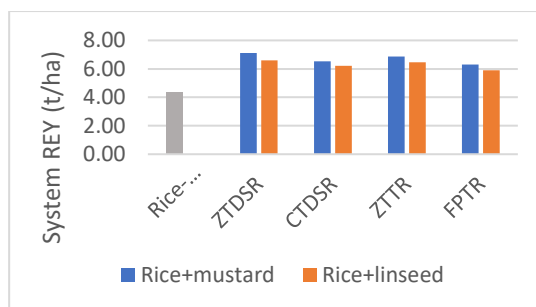


Fig 136. Rice equivalent yields of different crops and cropping systems at Jharkhand

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

The maximum rice grain yield (5.28 t/ha) was recorded under ZTDSR and followed by ZTTR (5.16 t/ha) production system. CTDSR production system was recorded the lowest grain yield (4.51 t/ha) during the study.

Training

03 days training program conducted on "Rice fallow management by CA technology" under SCSP Fund at Kumekela, Pathalgaon, Jashpur, Chhattisgarh *w.e.f.* 17-19th Oct. 2024. A total of 50 SC farmers of Kumekela participated. Farmers were trained with CA-technology for rice- fallow management and how to increase cropping intensity & acquainted with good agricultural practices for cereal, pulses, oilseed crops, cucurbitaceous crops, leguminous vegetables. The farmers were given seeds of chickpea 90kg, lentil 80kg, linseed 80kg, mustard 80kg and bitter gourd seeds 1kg among 50 farmers for demonstration purpose for rice fallow management.



Press and Media Coverage



Workshop

- Organized National Workshop as Organizing Secretary on “Strategies and Approaches for Greening Rice Fallow Areas’ at ICAR-RCER, Patna, Bihar, from 3-4thJan. 2025.



Inauguration of National Workshop on “Strategies and Approaches for Greening Rice Fallow Areas’ by the Hon. DDG-NRM, Dr SK Chaudhari and release of publications at ICAR-RCER, Patna, Bihar, from 3-4thJan. 2025

- 3-Days Training Programme-cum-Exposure-Visit on “Greening rice fallow areas through conservation agricultural management practices” during 17-19 March 2025 at KVK Mandu, Ramgarh, Jharkhand:** ICAR-RCER, Patna, organized 3-Days Training Programme-cum-Exposure Visit on Greening Rice fallow areas through CA management practices during 17-19 March 2025 under Consortia Research Platform on conservation agriculture (CRP on CA). Training-cum-exposure visit programme was focused on sustainable management of rice-fallows system by educating the SC participants on how to manage rice-fallows areas through integrated crop management and conservation agricultural management practices. More than 35 farmers from Guleriyachak village, Tekari Block under Gaya district of Bihar including 10-women and 25 men, participated in program along with team of scientists from Institute. Sessions provided valuable insights into the sustainable crop management, soil moisture management during cropping periods, livestock integration in existing production system, insect-pest management and crop production and economic benefits of rice-fallow community. Event was formally inaugurated by Dr. Anup Das, Director, ICAR RCER, Dr Ujjwal Kumar, Head, DSEE, Dr Abhay Kumar, PS, DSEE, Dr. Sudhanshu Shekar, Head, KVK, Ramgarh, Dr. PK Sundaram, Sr. Scientist, DLWM, and Dr. Pawan Jeet, Scientist, DLWM, ICAR RCER Patna. This program was designed by Dr Rakesh Kumar, Senior Scientist (Agronomy) & Principal Investigator of CRP on CA Project. Training-cum-exposure-visit was funded from the SCSP components under CRP on CA project under guidance of Dr AK Biswas, LCPC, Dr. AK Biswas, IISS Bhopal. in the agriculture.



NIASM, Baramati

Workshop and frontline demonstration organized:

1. Organized a one-day frontline demonstration of the multifunctional ratoon drill (MRD) at a farmer's field in Khandaj Village, Baramati, on December 13, 2024. The primary objective of the demonstration was to raise awareness among sugarcane farmers about the benefits of conservation agriculture (CA) practices, such as chickpea intercropping in trash-retained fields with minimal soil disturbance in ratoon crops. About 25 progressive farmers and officials from the Malegaon BK sugar mill participated.



2. Organized a one-day workshop-cum-frontline demonstration on 'Enhancing Sugarcane Productivity using Conservation Agricultural Practices and Engineering Interventions' for sugarcane farmers on 27 January 2025 at ICAR- NIASM, Baramati. A total of 50 sugarcane farmers from the nearby villages of Malegaon Kh, Malegaon BK, Khandaj, and Pandhare participated.

3. SCSP Activities:

Organized a one-day demonstration-cum-awareness program on CRPCA research activities, along with the distribution of SCSP inputs (Kitchen Utensil kits and dairy cans) to scheduled caste beneficiaries and farmers, on 27 March 2025 at ICAR-NIASM, Baramati. About 60 beneficiaries and farmers participated in the event.



i. Development of a self-propelled earthing-up cum fertilizer drill machine for band placement in sugarcane

Performing intercultural operations such as earthing-up and fertilizer band placement in standing sugarcane crops is a major challenge. To address this, a self-propelled machine has been developed for earthing-up and drilling fertilizer in bands. The machine comprises a 3.5 hp engine, gearbox, L-channel iron wheels, main ridger and furrow openers, fertilizer box, and an application mechanism. Testing and performance evaluation of the machine are in progress.



IISS

Demonstration of Best-Bet Conservation Agriculture Practices on Farmers' Fields in Vertisols of Central India

Objectives

- To evaluate conservation agriculture practices for crop productivity and profitability in farmer's field.
- To identify the best conservation agriculture practices.
- To create awareness about conservation agriculture practices, among farming community.

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 20-30 farmers field during *kharif* and *rabi* season of 2024-25. 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.



Plate 9: General view of farmers' field during sowing operation Crop – Soybean

Growth and yield parameters of soybean

Farmers field experiments were conducted in a participatory mode in adopted villages viz., Khamkheda, Raslakhedi, Raipur and Karodkhurd using soybean (JS 2029) as test crop to evaluate the different crop establishment techniques such as zero tillage (ZT), reduced tillage (RT) and conventional tillage (CT) at 30 farmers field during *kharif* season of 2024. All the recommended agronomic practices were followed as per technical details. Plant growth and yield parameters were observed at different growth stages of soybean under different farmer's field as per treatments.

Table 116: Impact of different tillage practices on plant height of soybean at different growth stages under participatory mode under CRP on CA.

Plant of soybean at 30, 60 and 90 days after sowing										
	Name of Farmer's	ZT			RT			CT		
		30	60	90	30	60	90	30	60	90
1	Shri Parvat Yadav	23.00	32.33	39.00	23.67	27.67	38.33	21.00	27.67	40.67
2	Shri Nandlal Yadav	20.00	33.00	35.33	25.00	29.67	40.67	24.00	32.33	39.67
3	Shri Karan Singh Yadav	16.00	28.67	39.33	21.00	29.00	38.00	20.00	30.67	35.00
4	Shri Hemraj Yadav	21.67	30.67	38.67	20.67	28.67	39.33	19.33	30.33	38.00

5	Shri Naval Singh Yadav	23.00	37.00	40.67	21.67	30.33	34.33	21.00	32.00	35.33
6	Shri Deepak Yadav	20.67	34.67	41.67	22.33	32.33	34.33	22.00	32.67	41.33
7	Shri Raj Narayan Yadav	22.00	27.33	40.33	27.33	28.33	31.00	22.67	28.33	41.67
8	Shri Jagjeevan Ahirwar	18.67	28.33	42.33	18.00	32.33	41.67	19.00	30.00	41.00
9	Shri Ram Singh Lodhi	20.67	30.33	43.00	19.33	30.00	42.67	17.33	29.00	39.00
10	Shri Himmat Singh Lodhi	20.67	30.00	46.33	19.00	28.67	40.00	20.33	30.33	39.67
11	Shri Naval Singh Lodhi	18.33	32.00	44.00	18.33	30.00	43.67	18.67	29.33	41.00
12	Shri Azad Singh	18.00	31.00	40.00	19.33	28.33	40.00	18.33	29.00	39.00
13	Shri Santosh Yadav	26.00	35.00	39.33	21.00	32.33	37.33	21.67	32.33	37.67
14	Shri Chain Singh Jat	21.00	30.00	35.33	19.67	31.00	43.67	22.00	31.00	40.00
15	Shri Jeevan Singh Jat	18.33	32.00	42.33	20.00	29.67	38.33	20.00	27.67	41.67
16	Shri Badam Singh Jat	19.67	32.00	37.00	21.33	30.00	38.00	20.00	29.00	39.67
17	Shri Ram Singh Jat	20.33	27.33	44.00	19.67	28.33	37.33	19.00	27.67	38.67
18	Shri Vijay Malviya	20.00	31.00	43.67	18.33	30.00	42.67	20.00	29.00	41.67
19	Shri Phul Singh	17.33	29.67	42.67	20.67	31.00	41.33	18.00	30.33	40.33
20	Shri Goverdhan	20.33	31.00	40.00	20.00	27.00	40.67	18.00	29.33	39.33
21	Shri Bhagwan Singh	17.00	31.00	44.67	21.67	30.67	41.00	19.67	29.00	40.33
22	Shri Mohan Babu Meena	22.33	33.00	41.00	21.33	33.33	42.67	19.67	37.00	42.00
23	Shri Kamod Singh Meena	21.33	32.33	41.33	19.33	32.00	40.67	20.00	35.33	40.00
24	Shri Raju meena	20.67	32.67	44.67	19.33	33.00	41.33	18.67	30.00	39.33
25	Shri Naresh Meena	22.00	33.33	44.67	20.33	33.33	38.33	18.33	32.33	40.00
26	Shri Narvda Prashad	20.67	35.33	43.33	20.00	34.33	41.33	20.33	34.33	40.33
27	Shri Prahlad Malviye	20.33	35.00	44.67	20.33	31.33	44.00	22.00	30.33	39.00
28	Shri Munna Lal Ahirwar	22.33	35.33	39.33	20.00	22.33	41.67	22.00	31.67	40.33
29	Shri Tulshi Ram Ahirwar	20.33	30.00	40.33	20.33	29.00	38.67	20.33	27.67	38.67
30	Shri Madho Singh Ahirwar	22.00	34.00	44.67	19.00	31.00	40.33	20.00	20.00	39.67
	Mean	20.49	31.84	41.46	20.60	30.17	39.78	20.11	30.19	39.67

The plant height of soybean was recorded at 30, 60, and 90 days after sowing (DAS) at farmers' fields and the mean data revealed that there was no-significant difference among the between different tillage practices (Table 117). Furthermore, results showed that the higher plant height was observed under zero-tillage followed by conventional tillage and reduced tillage. Although the differences among the tillage practices were modest, zero tillage consistently showed superior plant growth across most of the farmers' fields. Similarly, the average data (Table 117) on yield attributes of soybean indicated that zero tillage recorded the highest number of pods per plant (36.6) and seeds per plant (77.63), followed

by reduced tillage (35.07 pods/plant and 74.53 seeds/plant), and conventional tillage (34.47 pods/plant and 72.47 seeds/plant).

Table 117: Yield attributes of soybean at farmer's field demonstrations under zero tillage, reduce tillage and conventional tillage practices.

	Name of Farmer's	ZT		RT		CT	
		No. of Pods/plant	No. of Seed/plant	No. of Pods/plant	No. Seed/plant	No. of Pods/plant	No. of Seed/plant
1	Shri Parvat Yadav	40	80.00	37	81	28	56
2	Shri Nandlal Yadav	50	90.00	48	95	39	82
3	Shri Karan Singh Yadav	38	82.00	37	76	36	79
4	Shri Hemraj Yadav	25	59.00	28	59	42	86
5	Shri Naval Singh Yadav	31	65.00	29	62	35	76
6	Shri Deepak Yadav	36	79.00	38	76	36	79
7	Shri Raj Narayan Yadav	37	75.00	29	60	41	83
8	Shri Jagjeevan Ahirwar	26	56.00	37	78	35	75
9	Shri Ram Singh Lodhi	28	60.00	37	78	38	80
10	Shri Himmat Singh Lodhi	36	75.00	35	77	32	65
11	Shri Naval Singh Lodhi	41	90.00	37	72	35	73
12	Shri Azad Singh	38	79.00	36	76	35	75
13	Shri Santosh Yadav	41	86.00	39	83	38	81
14	Shri Chain Singh Jat	42	89.00	38	85	34	71
15	Shri Jeevan Singh Jat	37	83.00	36	78	36	75
16	Shri Badam Singh Jat	41	89.00	37	84	35	76
17	Shri Ram Singh Jat	36	78.00	38	87	40	89
18	Shri Vijay Malviya	40	85.00	35	72	36	76
19	Shri Phul Singh	41	88.00	29	65	25	56
20	Shri Goverdhan	25	56.00	28	59	38	76
21	Shri Bhagwan Singh	27	58.00	35	78	28	52
22	Shri Mohan Babu Meena	42	87.00	35	72	38	80
23	Shri Kamod Singh Meeena	38	80.00	39	81	20	45
24	Shri Raju meena	40	89.00	38	80	40	82
25	Shri Naresh Meena	45	95.00	32	66	36	74
26	Shri Narvda Prashad	32	69.00	33	70	26	55
27	Shri Prahlad Malviye	42	87.00	35	78	40	83
28	Shri Munna Lal Ahirwar	28	60.00	25	55	32	68
29	Shri Tulshi Ram Ahirwar	35	75.00	36	75	32	66
30	Shri Madho Singh Ahirwar	40	85.00	36	78	28	60
	Average	36.6	77.63	35.07	74.53	34.47	72.47

Soybean yield

Thirteen farmers field demonstrations (Table 118) under zero, reduced and conventional tillage were conducted during kharif season 2024 as soybean test crop under CRP on CA. Average data revealed that zero tillage recorded higher grain and biological yield of soybean at most of 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 farmer's field as compared to zero till farming.

Table 118: Farmers field demonstrations under zero tillage, reduced tillage and conventional tillage were conducted during kharif season 2024 as soybean test crop under CRP on CA

Name of Farmer's		ZT		RT		CT	
		Biological yield (kg/ha)	Grain yield (kg/ha)	Biological yield (kg/ha)	Grain yield (kg/ha)	Biological Yield (kg/ha)	Grain yield (kg/ha)
1	Shri Parvat Yadav	2237.5	1212.5	2225.0	1025.0	2150.0	1037.5
2	Shri Nand lal Yadav	2750.0	1437.5	3000.0	1525.0	2325.0	1150.0
3	Shri Karan Singh Yadav	2062.5	1287.5	2025.0	1225.0	1950.0	1212.5
4	Shri Hemraj Yadav	2750.0	1325.0	2325.0	1237.5	1975.0	1062.5
5	Shri Naval Singh Yadav	2025.0	1025.0	1450.0	1037.5	1950.0	1575.0
6	Shri Deepak Yadav	2875.0	1425.0	2750.0	1312.5	2300.0	1025.0
7	Shri Raj Narayan Yadav	3000.0	1350.0	2150.0	1275.0	2250.0	1125.0
8	Shri Jagjeevan Ahirwar	2914.0	1225.0	2975.0	1325.0	2325.0	1062.5
9	Shri Ram Singh Lodhi	1550.0	912.5	1475.0	1100.0	2000.0	1125.0
10	Shri Himmat Singh Lodhi	2800.0	1425.0	2425.0	1412.5	2025.0	1112.5
11	Shri Naval Singh Lodhi	2050.0	1100.0	2000.0	912.5	1775.0	1300.0
12	Shri Azad Singh	1950.0	1325.0	2650.0	1300.0	2450.0	1212.5
13	Shri Santosh Yadav	2300.0	1337.5	2237.5	1225.0	2225.0	1025.0
14	Shri Chain Singh Jat	2325.0	1212.5	2275.0	1050.0	2175.0	912.5
15	Shri Jeevan Singh Jat	2025.0	1025.0	1387.5	1200.0	1975.0	1112.5
16	Shri Badam Singh Jat	2450.0	1200.0	2300.0	1200.0	2287.5	1025.0
17	Shri Ram Singh Jat	2325.0	1212.5	2175.0	1025.0	2300.0	1112.5
18	Shri Vijay Malviya	2087.5	1225.0	2412.5	1362.5	1875.0	1350.0
19	Shri Phul Singh	3000.0	1400.0	2475.0	1362.5	2200.0	1275.0
20	Shri Goverdhan	2325.0	1200.0	2250.0	1025.0	2275.0	1112.5
21	Shri Bhagwan Singh	2000.0	1025.0	2050.0	1175.0	1975.0	1112.5
22	Shri Mohan Babu Meena	3110.0	1312.5	2450.0	1100.0	2150.0	1500.0
23	Shri Kamod Singh Meeena	3125.0	1312.5	2400.0	1112.5	2187.5	1014.5
24	Shri Raju meena	2100.0	1200.0	2025.0	1025.0	1812.5	1112.5
25	Shri Naresh Meena	2750.0	1375.0	3000.0	1250.0	2450.0	1200.0
26	Shri Narvda Prashad	1975.0	1100.0	2050.0	1200.0	2600.0	1025.0

27	Shri Prahlad Malviye	2975.0	1525.0	2925.0	1337.5	3000.0	1600.0
28	Shri Munna Lal Ahirwar	1800.0	1187.5	1750.0	1000.0	2225.0	1450.0
29	Shri Tulshi Ram Ahirwar	2050.0	1312.5	1850.0	1300.0	1800.0	1225.0
30	Shri Madho Singh Ahirwar	2300.0	1400.0	2037.5	1112.5	3075.0	1712.5
	Average	2399.6	1253.8	2250.0	1191.7	2202.1	1195.9



Plate 10: Farmers field demonstrations under zero tillage, reduced tillage and conventional tillage

Table 119: Weed population at soybean crop under farmers' fields

Weed Density/ m ²				
S.no.	Farmers Name	ZT	RT	CT
1	Shri Parvat Yadav	16	15	16
2	Shri Nand Lal Yadav	27	25	22
3	Shri Karan singh Yadav	17	16	15
4	Shri Hemraj Yadav	32	22	21
5	Shri Naval singh yadav	25	23	23
6	Shri Deepak Yadav	21	18	20
7	Shri Rajnarayan Yadav	18	15	14
8	Shri Santosh Yadav	31	28	25
9	Shri Chain Singh Jat	37	35	34
10	Shri Jeevan Singh Jat	31	29	25
11	Shri Badam Singh Jat	36	31	28
12	Shri Subham malviya	26	23	21
13	Shri Jagjeevan Ahirwar	21	21	20
14	Shri Vijay Malviya	30	27	23
15	Shri Ram Singh Lodhi	23	19	18
16	Shri Himmat Singh Lodhi	37	35	34
17	Shri Naval Singh Lodhi	34	31	28
18	Shri Azad Singh	41	34	29
19	Shri Phul Singh	34	32	30
20	Shri Goverdhan	31	27	24
21	Shri Bhagwan Singh Meena	33	27	22
22	Shri Mohan Babu meena	24	21	19
23	Shri Kamod Singh meena	39	35	30
24	Shri Raju meena	33	29	23
25	Shri Naresh meena	41	41	34
26	Shri Prahlad Malviya	41	37	30
27	Shri Narvada Prasad	34	28	23
28	Shri Munnalal Ahirwar	35	32	30

29	Shri Tulsiram Ahirvar	38	37	32
30	Shri Madhosingh Ahirvar	40	34	31
	Mean	30.87	27.57	24.80

Crop – Wheat

Wheat growth and yields

Wheat crop was raised in participatory mode under CRP on CA at different farmers' fields (12 demonstrations) in adopted villages. Growth and yield parameters were recorded in wheat crop in different farmer's field under different tillage practices.



Plate 11: Preparation of field for sowing of wheat crop in farmers field

Growth and yield parameters of wheat

The plant height of wheat was recorded at 30, 60, and 90 days after sowing (DAS) at farmers' fields and the mean data revealed that there was no- significant difference among the tillage practices (Table 120). Furthermore, results showed that the higher plant height was observed under zero-tillage followed by conventional and reduced tillage. Although the differences among the tillage practices were modest, zero tillage consistently showed superior plant growth across most of the farmers' fields. The average number of grains per spike also indicates that ZT recorded the highest value grains per spike as compared to other tillage practices.

Table 120: Impact of different tillage practices on plant height of wheat at different growth stages under participatory mode under CRP on CA.

S. No	Name of Farmer's	ZT				RT				CT			
		30	60	90	HR	30	60	90	HR	30	60	90	HR
1	Shri Nand Lal Yadav	14.7	44.7	87.0	87.7	13.3	44.0	82.3	82.0	14.7	42.3	83.0	82.0
2	Shri Parvat Yadav	17.0	52.3	82.7	88.3	14.0	45.7	82.0	82.3	15.3	48.0	77.7	82.3
3	Shri Hemraj Yadav	15.0	45.0	90.0	88.3	13.3	42.3	85.7	85.0	13.0	43.7	82.7	82.3
4	Shri Rajnarayan Yadav	13.7	44.7	85.7	87.0	12.0	43.3	85.3	85.7	14.0	42.3	82.7	87.3
5	Shri Karan Singh Yadav	17.0	45.7	88.3	88.3	16.3	43.3	85.7	86.7	13.7	43.3	83.0	82.0
6	Shri Deepak Yadav	12.3	43.3	89.0	88.0	12.7	42.7	86.0	84.7	13.7	42.3	86.3	83.0
7	Shri Naval Singh Yadav	16.7	45.3	89.0	89.7	14.7	44.3	86.0	85.0	13.7	42.3	84.0	85.3

8	Shri Jagjeevan Ahirwar	14.7	44.7	86.3	86.3	14.0	42.7	84.0	84.0	13.0	40.3	84.7	84.7
9	Shri Himmat Singh Lodhi	17.3	17.0	44.7	84.7	14.7	15.3	41.3	83.0	14.7	14.3	42.7	82.0
10	Shri Naval Singh Lodhi	17.0	41.0	86.0	89.0	15.3	40.7	86.7	86.7	14.3	42.3	84.7	83.7
11	Shri Ram Singh Lodhi	17.0	45.0	86.7	89.0	12.3	40.0	84.7	84.7	13.0	39.0	84.3	83.0
12	Shri Azad Singh	17.0	45.0	88.3	86.7	19.0	42.3	85.3	84.7	14.7	42.7	85.7	85.0
	Average	15.8	42.8	83.6	87.8	14.3	40.6	81.3	84.5	14.0	40.3	80.1	83.6

*HR: Harvesting Stage

Table 121: Number of grains/ears of wheat influenced under the different tillage practices under conservation agriculture at farmer's fields

S.No.	Name of Farmer's	Number of grains/ spikes		
		ZT	RT	CT
1	Shri Nandlal Yadav	47	48	42
2	Shri Parvat Yadav	56	52	50
3	Shri Hemraj Yadav	35	40	39
4	Shri Jagjeevan Ahirwar	45	48	55
5	Shri Rajnarayan Yadav	50	51	45
6	Shri Karan singh Yadav	50	58	52
7	Shri Deepak Yadav	51	52	50
8	Shri Himmat Singh Lodhi	46	25	39
9	Shri Naval Singh Lodhi	37	35	40
10	Shri Ram Singh Lodhi	48	40	30
11	Shri Naval singh yadav	46	38	56
12	Shri Azad Singh	46	32	41
	Average	46.42	43.25	44.92

Grain yield and harvest index of wheat crop

Grain yield of wheat was recorded under different tillage practices at participatory and results revealed that the higher grain yield was observed under zero tillage at most of the farmer's field. However, some farmers recorded higher yield under reduced and conventional tillage as compared to zero tillage. Furthermore, the mean data of wheat revealed that zero tillage recorded higher grain yield (4850 kg/ha.) of wheat as compared to reduce tillage and conventional tillage. The higher harvest index was recorded under reduced tillage (47.1) at most of farmer's field as compared to zero tillage (44.32) and conventional tillage (44.51).

Weed Density under wheat fields

In general, weed density at 30 and 60 days after sowing was recorded under different farmers' fields and observed that (Table 122) higher weed density was noticed under the zero tillage practices as compared to reduced and conventional tillage.

S.No.	Name of Farmer's	Grain yield/ha			Harvest Index		
		ZT	RT	CT	ZT	RT	CT
1	Shri Nand lal Yadav	5250	5130	4880	49.4	47.7	47.6
2	Shri Parvat Yadav	4630	4610	4750	47.4	43.4	45.2
3	Shri Hemraj Yadav	5110	5000	5200	45.4	51.3	47.8
4	Shri Santosh Yadav	1550	1330	1130	37.6	37.9	37.5
5	Shri Karan Singh Yadav	5530	5000	4920	45.6	46.0	49.8
6	Shri Deepak Yadav	5250	4940	5060	45.2	48.2	40.5
7	Shri Naval Singh yadav	4750	4950	4800	48.1	50.1	46.8
8	Shri Jagjeevan Ahirwar	4800	5000	4500	44.7	44.9	45.0
9	Shri Himmat Singh Lodhi	5250	5400	4900	41.2	49.7	45.6
10	Shri Naval Singh Lodhi	5300	5000	5100	43.3	52.0	40.0
11	Shri Ram Singh Lodhi	5130	5100	4800	41.0	45.8	41.3
12	Shri Azad Singh	5600	5500	5000	43.1	48.4	47.1
	Average	4850	4750	4590	44.3	47.1	44.5

Table 122: Weed density under different tillage practices under conservation agriculture at farmer's fields.

Weeds density /m ²						
Farmers name	ZT		RT		CT	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Shri Nand Lal Yadav	44.0	7.00	38.0	4.00	6.09	11.00
Shri Parvaat Yadav	41.0	16.00	46.0	10.00	4.36	7.00
Shri Hemraj Yadav	49.0	9.00	36.0	7.00	4.55	7.00
Shri Deepak Yadav	25.0	5.00	50.0	6.00	3.27	12.00
Shri Karan Singh Yadav	43.0	10.00	38.0	12.00	3.64	8.00
Shri Santosh Yadav	36.0	13.00	40.0	23.00	3.64	7.00
Shri Naval Singh Yadav	41.0	22.00	57.0	14.00	4.73	8.00
Shri Chain Singh Jat	40.0	14.00	50.0	12.00	3.18	12.00
Shri Raj Narayan Yadav	30.0	10.00	26.0	10.00	0.91	7.00
Mean	38.78	11.78	42.33	10.89	3.82	8.78

Crop – Chickpea

Under chickpea, eight (8) field demonstrations were conducted during rabi season at different farmers' fields in adopted villages viz., Khamkheda, Raslakhedi, Raipur and Karodkhurd using RVG 202 variety of chickpea under conservation agriculture in participatory mode.



Plate 12: Preparation of field for sowing of chickpea for demonstration

Growth and yield attributes of chickpea

The data on plant height at different growth stages (30, 60, and 90 DAS) revealed that the highest average plant height was noticed under zero tillage followed by reduced tillage and conventional tillage (Table 123). Furthermore, at harvest, results indicated that tallest plant was also observed under ZT which was at par with reduced and conventional tillage practices.

Table 123: Impact of different tillage practices on plant height of chickpea at different growth stages under participatory mode under CRP on CA

S.No	Name of Farmer's	ZT				RT				CT			
		30	60	90	HR	30	60	90	HR	30	60	90	HR
1	Shri Santosh Yadav	12.0	45.0	42.3	42.3	11.0	42.3	44.3	44.3	12.3	31.7	39.0	39.0
2	Shri Jeevan Singh Jat	12.0	32.0	39.7	42.3	12.7	29.3	39.0	41.7	11.0	29.7	37.3	39.7
3	Shri Badam Singh Jat	10.3	31.0	47.3	47.3	10.0	29.0	43.0	43.0	12.0	31.3	42.3	42.3
4	Shri Chain Singh Jat	12.3	28.3	45.0	43.3	12.0	27.0	43.3	44.3	14.0	30.0	45.0	42.3
5	Shri Ram Singh Jat	12.3	32.7	41.7	43.3	12.3	28.3	40.3	41.0	11.0	29.3	43.3	42.3
6	Shri Vijay Malviya	12.0	37.7	44.7	44.7	9.0	29.7	43.0	43.0	11.7	39.0	40.0	40.0
7	Shri Phul Singh	11.7	34.7	47.3	47.3	9.0	39.0	44.7	44.7	12.0	40.0	45.3	45.3
8	Shri Goverdhan	13.0	39.3	47.0	50.0	12.7	37.7	50.0	50.0	13.0	38.0	47.3	49.3
	Average	12.0	35.1	44.4	45.1	11.1	32.8	43.5	44.0	12.1	33.6	42.5	42.5

HR- Harvesting stage

This consistent superiority of zero tillage in maintaining plant height from early growth to harvest indicates better soil management and crop vigor under zero tillage conditions. The minimal disturbance to the soil likely improves root development, water retention, and nutrient availability, contributing to improved plant performance throughout the growing season. The comparative analysis of the number of pods per plant (Table 124) showed that zero tillage recorded a slightly higher pods per plant as compared to conventional tillage and reduced tillage.

Table 124: Yield attributes of chickpea influenced under the different tillage practices of under conservation agriculture at farmer’s fields

		ZT	RT	CT
S. No	Name of Farmer’s	No. of pods/plant	No. of pods/plant	No. of pods/plant
1	Shri Santosh Yadav	62	50	40
2	Shri Jeevan Singh Jat	71	58	58
3	Shri Badam Singh Jat	56	70	66
4	Shri Chain Singh Jat	60	71	63
5	Shri Ram Singh Jat	71	59	65
6	Shri Vijay Malviya	48	56	68
7	Shri Phul Singh	60	60	70
8	Shri Goverdhan	71	65	66
	Average	62	61	62



Plate 13: chickpea crops under the different tillage practices of under conservation agriculture at farmer’s fields

Grain yield and harvest index of chickpea crop

The chickpea yield was also recorded at different field experiments in participatory mode under CRP on CA (Table 125). The higher grain yield of chickpea was recorded under reduced tillage which is more or less similar to zero tillage, however, lower grain yield of chickpea was noticed under conventional tillage practices at farmers’ fields.

Table 125: chickpea yield and harvest index influenced by tillage practices under conservation agriculture at farmer's fields

Name of farmers		Yield (q/ha)			HI		
		ZT	RT	CT	ZT	RT	CT
1	Shri Rajnarayan Yadav	11.5	12.5	12.0	38.8	48.5	47.6
2	Shri Jeevan Singh Jat	11.1	14.0	12.3	39.2	37.3	34.0
3	Shri Badam Singh Jat	12.0	13.0	9.8	35.6	38.5	35.5
4	Shri Chain Singh Jat	13.5	12.0	9.0	38.1	38.4	38.5
5	Shri Ram Singh Jat	14.0	15.3	13.1	34.9	43.5	38.6
6	Shri Vijay Malviya	15.0	12.0	14.0	44.8	35.5	40.0
7	Shri Phul Singh	13.5	14.0	13.0	37.1	41.4	34.8
8	Shri Goverdhan	14.0	15.0	12.0	36.9	41.3	38.6
	Mean	13.1	13.5	11.9	38.1	40.5	38.4

Table 126: List of students under the project in the reporting period 2024-25

S.N.	Name	Degree	University/Institute	Chairperson
1.	Sourabh Raghuwanshi	Ph.D. (Completed)	RVSKVV, Gwalior	Dr. R. S. Choudhry
2.	Sourab Mahar	M.Sc. (Completed)	BU BHOPAL	Dr. P. Tripathi
3.	Ms. Jyoti	M.Sc. (On Going)	IARI-Bhopal Hub	Dr Khushboo Rani
4.	Ms. Rosy Lakra	M.Sc. (On Going)	Barkatullah University, Bhopal	Dr. B.P. Meena
5.	Mr. Parth Gautam	M.Sc. (On Going)	Barkatullah University, Bhopal	Dr. B.P. Meena
6.	Mr. Jayesh Goutam	M.Sc. (On Going)	RVSKVV, Gwalior, Bhopal	Dr. R.H. Wanjari
7.	Ms. Sakshi Tiwari	M.Sc. (On Going)	RVSKVV, Gwalior, Bhopal	Dr. P. Tripathi
8.	Mrs. Uma	M.Sc. (On Going)	Barkatullah University, Bhopal	Dr. P. Tripathi
9.	Ms. Mnisha Ranwa	Ph.D. (On Going)	IARI-Bhopal hub	Dr. N.K. Lenka
10.	Mr. Ankit patidar	M.Sc. (On Going)	RVSKVV, Gwalior, Bhopal	Dr. R.K. Singh

CIAE, Bhopal

Capacity building of the stakeholders through various skill development programs for promoting CA machinery.

Evaluation of slit till drill at Farmers field

To popularize the suitable CA machinery among the stakeholders through various skill development programs and to build the confidence of farmers for adoption of machinery, the institute developed technology (Slit till drill) was demonstrated in various villages (08 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. Farmer's name, their village, mobile number along with date of sowing is listed below:


Table 127: Evaluation of slit till drill at Farmers field



S. No.	Farmer name	Village	Mobile no.	Area in acre	Sowing date
1	Hemraj Yadav	Khamkheda	9098419959	1	08/12/2024
2	Bhagwan Singh	Binapur	9926761873	1	05/12/2024
3	Parvat Yadav	Khamkheda	9827614695	1.5	15/12/2024
4	Munnalal Ahirwal	Khajuri	8120928255	2.5	17/12/2024
5	Himmat Singh	Karondkhurd	9981113024	1	17/12/2024
6	Narvada Prasad	khajuri	9166612131	1	21/12/2024
7	Raju Meena	Binapur	9713521896	1	03/11/2024
8	Prahlad Malviya	Khajuri	8717937319	1	22/12/2024

Demonstration and distribution of improved resource conservation agricultural tools

Under the SCSP Programme, critical agricultural inputs, including fertilizers and hand tools, were provided to address resource gaps and support the economic development of Scheduled Castes (SCs) living below the poverty line, as outlined in Table 128. Additionally, awareness programs were conducted to promote institute-developed and conservation technologies. Hands-on training sessions were also organized to enhance knowledge and facilitate the effective use of improved tools for better crop production.

Table 128: Detail of demonstration and distribution of improved resource conservation agricultural tools among the farmers

Date	Village details and purpose	No. of farmers participated	Machine demonstration and distribution
13/02/2024	Field day-cum-demonstration and distribution of CIAE made hand tool Village- Jamoniya Hatesingh, in Sehore, Madhya Pradesh. Hand tools distributed 1. Manual hand ridger for women- 26 2. Manual twin wheel hoe- 10 3. Manual peg type dry land weeder- 20 4. Multi fuel cooking stove- 10	66	

16.02.2024	<p>Field day-cum-demonstration and distribution of CIAE made hand tool</p> <p>village- Ratanpur, in Bhopal, Madhya Pradesh</p> <p>Hand tools distributed</p> <p>Manual peg type dry land weeder and manual twin wheel hoe.</p>	41	
15.03.2024	<p>Field day-cum-demonstration and distribution of CIAE made hand tool village– Mubarak pur, Ashta, in Sehore, Madhya Pradesh.</p>	25	
20.03.2024	<p>Field day-cum-demonstration and distribution of CIAE made hand tool</p> <p>Village– Kheri, Icchawar, in Sehore, Madhya Pradesh</p>	60	