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INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Consortia Research Platform on Conservation Agriculture

ANNUAL REPORT 2022

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1. Background

Agriculture is the most important sector in India; accounting for 18-19 per cent of the country's GDP and employs more than 60 per cent of the labour force. Food grain production of the country has reached a record 329.68 million tonnes during 2022-23, under favourable weather conditions those prevailed throughout the year. The mission of increasing food grain production, though somehow realized at present, but under risk due to climatic aberrations and reduced availability of land, water, nutrients along with poor and continuous degradation of the resources to cope up with the demands of increasing population. Although the country had attained self-sufficiency in food grain production through intensification of agriculture with high yielding varieties and fertilizer application during the green revolution, productivity is still low and is stagnating. Conservation agriculture permits management of soils for sustainable agricultural production without excessively disturbing the soils, while protecting it from the processes of soil degradation like erosion, compaction, aggregate breakdown, loss of organic matter, leaching of nutrients, and processes that are accentuating by anthropogenic interactions in the presence of extremes of weather and management practices. The organic materials conserved through this practice are decomposed slowly, and much of it is incorporated into the surface layer, thus reduces the liberation rate of carbon into the atmosphere. In the total balance, carbon is sequestered in the soil, and turns the soil into a net sink of carbon. This could have profound consequences in our fight to reduce greenhouse gas emissions into the atmosphere from agricultural operations and thereby help to forestall the calamitous impacts of global warming.

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

1.1 Conservation Agriculture – Indian Scenario

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

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

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

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

1.2 Challenges in adoption of Conservation Agriculture:

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

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

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

Package of equipment and technology for residue-incorporation and bed planters have been developed for higher productivity with reduced irrigation water requirements. Recent development and performance of agricultural machinery have concentrated both on biological and mechanical parameters. Selection of most appropriate equipment for a specific situation is essential for maintaining soil physical environment. Besides the chosen equipment should be fuel efficient. Tractor operated/self-propelled machinery/technologies used in conservation agriculture (CA) have the potential to meet the challenges encountered in CA under field conditions. Zero tillage farming on 1.2 million ha Indo-Gangetic plains reportedly saved 360 million m^3 water. It also reduces the number of operating hours of the pumps, thus reducing CO2 emission and consumption of electrical energy.

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

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

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

1.3 Technological Gaps

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

1.4 Mission

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

1.5 Objectives

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

1.6 Thrust areas of Research

- Developing low cost, energy efficient and environment friendly CA technologies for major cropping systems both under rainfed and irrigated conditions.
- Validation and up-scaling location specific CA packages in farmers' participatory mode involving all stakeholders.
- Assessing the impact of CA practices on soil health, carbon sequestration, soil microbial biodiversity, resource use efficiency and mitigation of climate change.

1.7 Approach

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

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

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

Research Highlights of CRP on Conservation Agriculture (2022)

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

A. Tillage and Residue Management Practices

1. Rice-Wheat Cropping System

IARI

Wheat yield, system productivity, and net returns were superior for long-term (12 years) triple zero-till cropping system (TZT) involving ZT DSR with summer mungbean (SMB) residue (MBR)- ZT wheat (ZTW) with rice residue (RR)– ZT summer mungbean (ZTSMB) with wheat residue (WR) compared to other CA systems and puddled transplanted rice (PTR) - conventional till wheat (CTW) system (Fig. 1). Notably, CA resulted in ~16% higher wheat yield, ~34% higher system productivity and ~9% lower rice yield than TPR-CTW system. The triple ZT system could save almost 60 kg N/ha in rice-wheat system per year. Furthermore, TZT+R gave 35% and 7% higher net returns with and without mungbean, respectively. This led to sustainable intensification of the R-W system with a legume mungbean, which proved to be a superior alternative and an important adaptation and mitigation strategy to climate change.

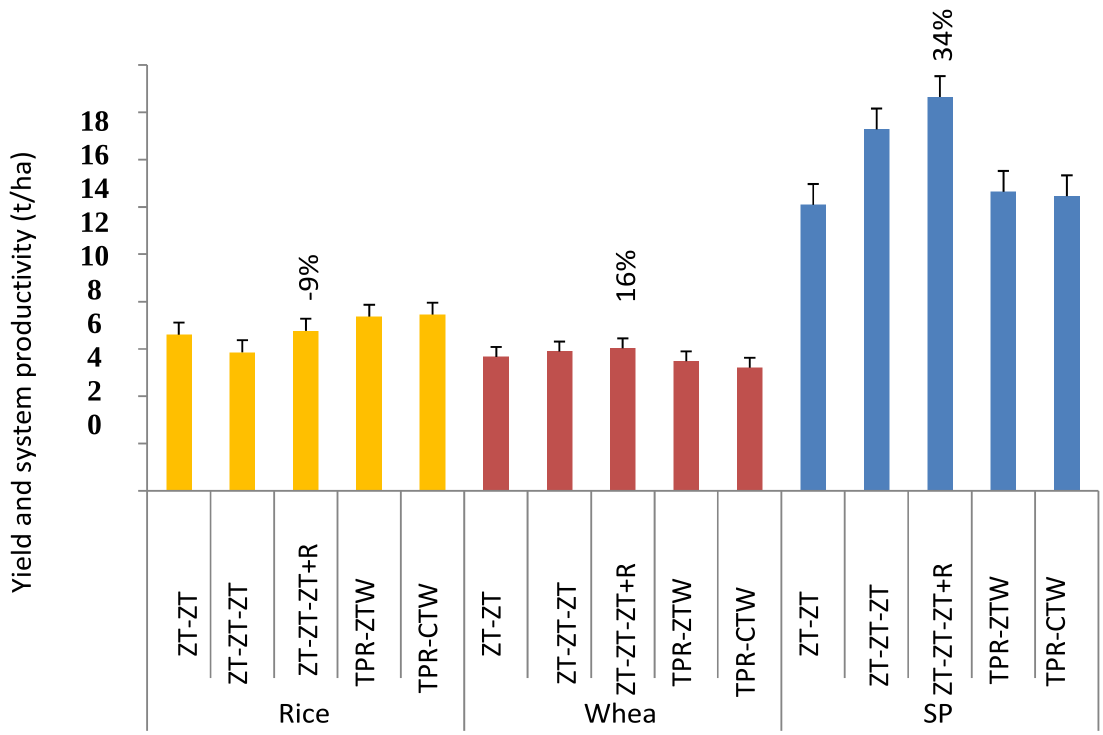


Fig 1. Effect of CA on rice yield, wheat yield, and system productivity under rice-wheat system

CSSRI

Rice crop during *kharif* 2022

a) Puddled transplanted rice (PTR)

Higher grain yield (6.02 t ha^{-1}) was recorded under conventional puddle transplanted rice with wheat residue incorporation (PTR+RI) than without residue incorporation (5.76 tha^{-1}). So, residue incorporation in conventional PTR rice increased the grain yield by 4.51 % (Fig. 2).

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

Plate 2. Experimental view of DSR in reduced tillage (residue incorporation, sowing and germination) and DSR in zero tillage with wheat residue, germination in anchored residue and rice performance

b) Direct seeded rice under reduced tillage with wheat residue

Direct seeded rice under reduced tillage with wheat residue (RTDSR+RI) produced grain yield of 5.20 tha^{-1}, which was 9.72% lower in comparison to PTR (5.76 tha^{-1}) and 2.07% lower in comparison to direct seeded rice under reduced tillage without wheat residue (RTDSR) (5.31t ha^{-1}), respectively.

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

Grain yield under zero tilled DSR with anchored wheat residue (ZTDSR+RR) was 4.82 t ha^{-1} which was 16.31% lower than the TPR (5.76 t ha^{-1}) and 1.43% lower than the direct seed rice in zero tillage without wheat residue incorporation (ZTDSR; 4.89 t ha^{-1}) (Fig. 2). The lower yield in the ZTDSR+RI was mainly because of the higher weed population, lower plant density as compared to the PTR.

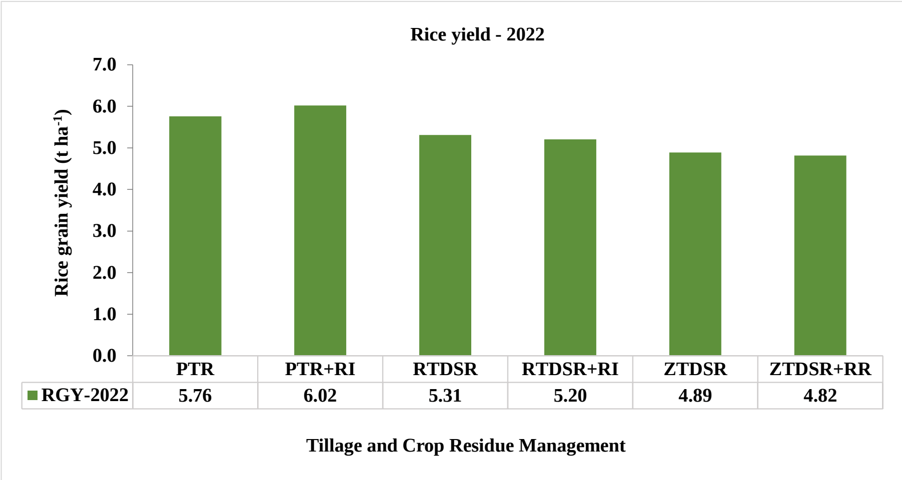


Fig 2. Effects of different tillage and residue management practices on rice grain yield, kharif 2022

(**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* 2021-22

a) Conventional tilled wheat (CTW)

Higher grain yield (5.22 t ha^{-1}) was recorded under conventional tilled wheat (CTW) than after residue incorporation (5.05 t ha^{-1}). So, residue incorporation in CTW decreased the grain yield by 3.25% (Fig. 3).

b) Reduced tilled wheat with rice residue

Reduced tilled wheat residue without rice residue (RTW) produced grain yield of 5.44 t ha^{-1}, which was 4.21and 3.62% higher in comparison to CTW (5.22 t ha^{-1}) and reduced tilled wheat residue with rice residue (RTW+RI) (5.25 t ha^{-1}), respectively (Fig. 3).

c) Zero tilled wheat with anchored rice residue

Grain yield under zero tilled wheat with anchored rice residue (ZTW+RR) was 5.12 t ha^{-1} which was 1.91% lower than the CTW (5.22 t ha^{-1}) and 7.41% lower than zero tilled wheat without rice residue incorporation (ZTW; 5.53 t ha^{-1}) (Fig. 3). The lower yield in the ZTW+RR was mainly because of the higher weed population, lower plant density as compared to the CTW. It is clear from the results that zero/reduced tillage plays an important role in increasing wheat grain yield, Minimum soil disturbance helps to protect soil organic carbon and saved from deformation of soil physical properties. However, the residue retention under both the conservation tillage treatments, i.e., reduced tillage and zero tillage leads to considerable lose in wheat yield.

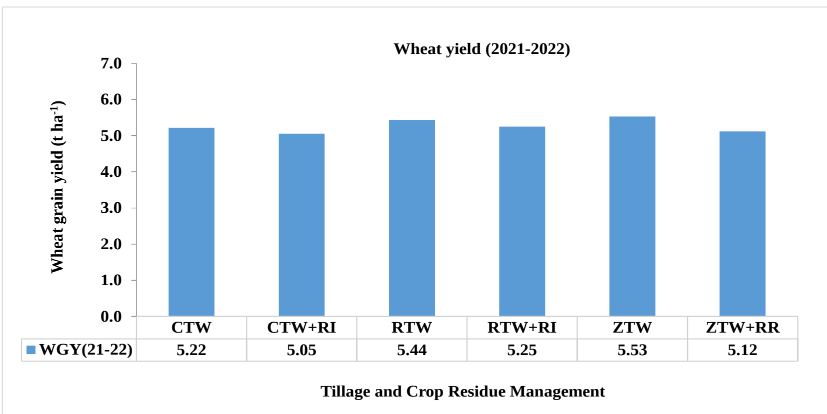


Fig 3: Effects of tillage and residue management practices on wheat grain yield during rabi 2021-22

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

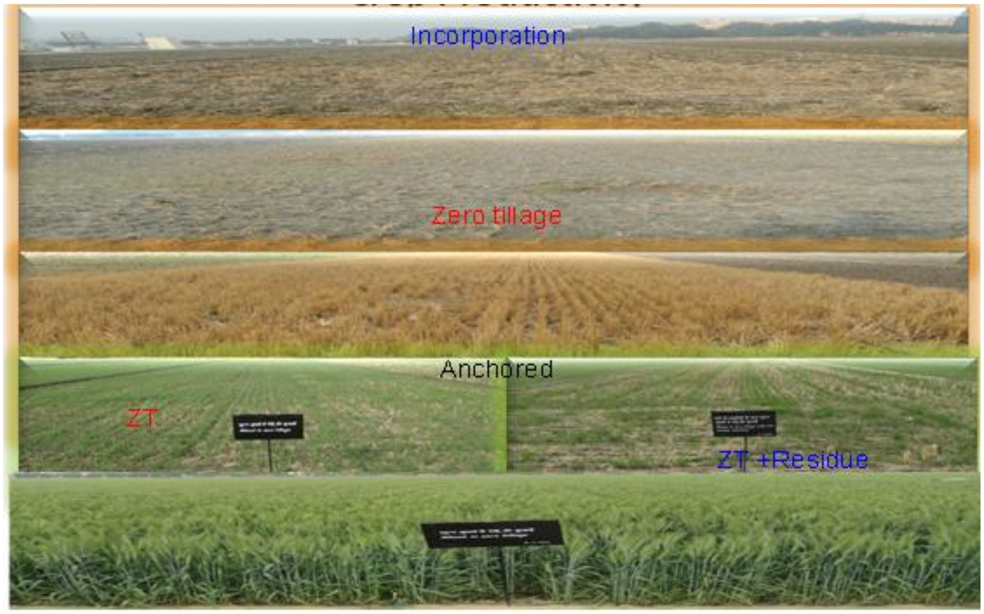


Plate 3. Experimental view of wheat germination under rice residue incorporation/anchored and zero tillage conditions

Rice-Wheat Cropping System during 2022-23

a) PTR/CTW

Higher grain yield (11.07 t ha^{-1}) was recorded under conventional puddle transplanted rice/ conventional tilled wheat with residue incorporation (PTR+RI/CTW+RI) than without residue incorporation (10.98 t ha^{-1}). So, residue incorporation in conventional PTR rice increased the grain yield by 0.82% (Fig. 4).

b) RTDSR+RI/RTW+RI

Direct seeded rice under reduced tillage/ reduced tilled wheat with residue (RTDSR+RI/RTW+RI) produced grain yield of 10.45 t ha^{-1}, which was 4.82 and 2.79 % lower in comparison to PTR/CTW (10.98 t ha^{-1}) and direct seeded rice under reduced tillage/ reduced tilled wheat without wheat residue (RTDSR/RTW) (10.75 t ha^{-1}), respectively (Fig.4).

c) ZTDSR+RR/ZTW+RR

Grain yield under zero tilled DSR/zero tilled wheat with anchored wheat residue (ZTDSR+RR/ZTW+RR) was 9.93 t ha^{-1} which was 9.56% lower than the PTR/CTW (10.98 t ha^{-1}) and 4.70% lower than the direct seed rice in zero tillage without wheat residue incorporation (ZTDSR/ZTW; 10.42 t ha^{-1}) (Fig. 4).

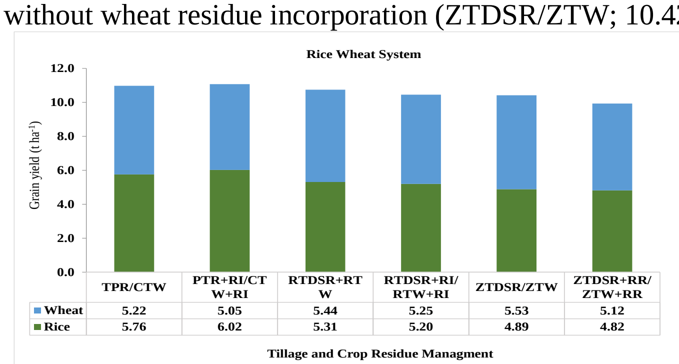


Fig 4: Effects of tillage and residue management practices on rice-wheat cropping system grain yield during 2022-23.

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

Long term impact for tillage and residue management

In a 14-year (2006-2020) field experiment, assessment of the effects of conservation (reduced/zero) tillage and residue management (incorporation/retention) (CsT+RM) practices on carbon input, carbon sequestration, yield and yield trends of rice-wheat system (RWS) was done. Experiment consisted one scenario of conventional tillage (Sc-1: Puddle transplanted rice - conventional tilled wheat); and four scenarios of CsT+RM that are, 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). Overall, 14-years mean DSR yield significantly ($P < 0.05$) lowered (9.0-22.0%), and wheat yield significantly increased (4.4-9.2%) in CsT+RM practices as compared to Sc-1. The mean RWS yield lowered by 1.0-3.8% in reduced tillage and 6.3-9.3% in zero tillage under CsT+RM practices. The sustainable yield index of DSR was lower (0.50-0.58), and wheat was higher (SYI; 0.65-0.69) in CsT+RM, indicating the low sustainability of DSR and better sustainability of wheat in CsT+RM. Significant ($p<0.0001$) changes in rice and wheat yields in were observed due to different tillage, crop establishment and residue management practices (Table 1). The fourteen years pooled data revealed highest rice yield of 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. Lowest yield of 5.28Mg ha^{-1} was attained in Sc-5 where the crop was grown as ZTDSR with surface retention of rice residues. 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}). 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}).

The time trend analysis of the rice, wheat and RWS yield showed positive trends in yield improvement over the experimental period under all the scenarios (Table 1 &Fig. 5). In rice, highest increment in slope was observed in Sc-3 (0.21 Mg ha^{-1} yr^{-1}) followed by Sc-5 (0.17 Mg ha^{-1} yr^{-1}) and the lowest was in Sc-4 (0.13 Mg ha^{-1} yr^{-1}) (Table 1& Fig. 5). However, in wheat, the highest increment in slope was attained in Sc-5 (0.12 Mg ha^{-1} yr^{-1}) followed by Sc-3 (0.09 Mg ha^{-1} yr^{-1}) and lowest was in Sc-1 (0.01 Mg ha^{-1} yr^{-1}). In system perspective, the yield enhancement was almost similar in Sc-3 and Sc-5, but was more than twice than in Sc-1 (0.14 Mg ha^{-1} yr^{-1}). Tillage, crop establishment and residue management practices had significant ($p<0.0001$) effect on yield sustainability of rice, wheat and RWS. In rice, Sc-1 (PTR) was found to be most sustainable one with SYI of 0.65 while Sc-5 (ZTDSR+RR) was reported least sustainable (SYI=0.50). For wheat, the SYI varied between 0.64 (Sc-1) to 0.69 (Sc-3). In system perspective, PTR/CTW had the highest SYI of 0.73 following the sequence of Sc-1 >Sc-2 = Sc-3 > Sc-4 >Sc-5.

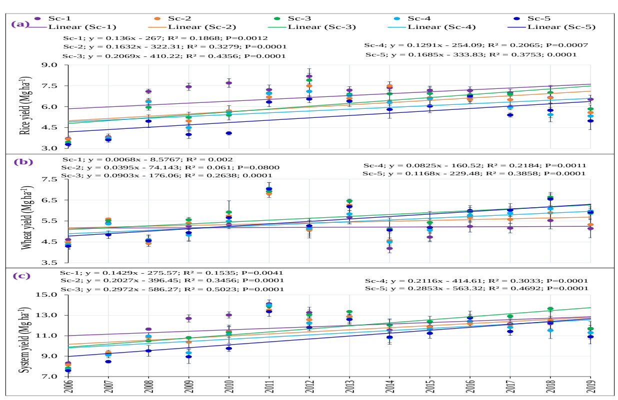


Fig 5: Trends in grain yield of (a) rice, (b) wheat and (c) rice-wheat system for long-term under different crop establishment, tillage and residue management practices.

Note: 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).

Table 1: Effect of tillage, crop establishment and residue management practices on grain yield, sustainable yield index and yield trend in rice-wheat system (2006-20).

Scenarios/ Treatment	Grain Yield (Mg ha^{-1})						Sustainable yield index (SYI)			Cumulative Yield gain		
	First Year (2006-07)			14 years								
	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 different letter (s) in a scenario/column are significantly different ($p < 0.05$; Tukey's HSD test).*Treatments effect was found to be non-significant.

Note: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).

Rotational System

A new experiment was started with sowing of rice in Kharif 2022 season with objective to examine the impact of the rotation-based (DSR)-ZTW-Moong/Green manure system on productivity, profitability and weed dynamics under rotation based (DSR/PTR) system in reclaimed sodic soils. The primary objectives were to investigate the productivity, profitability, and resource use efficiency of the rotation-based (DSR)-ZTW-Moong/Green manure system in partially reclaimed soils and to assess its influence on soil health. Furthermore, the study aimed to comprehend the weed flora dynamics in the rotation-based (DSR)-ZTW system. The research involved the evaluation of three combinations of rotation-based (DSR)-ZTW-Moong/Green manure systems in comparison to the conventional practice of rice/wheat (PTR/CTW), which is presented in Table 2.

Table 2: Detail of experiment of rotation based DSR-ZTW-Moong system at CSSRI, Karnal

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

Detail of rice crop during *kharif* 2022

Data are given in Fig.6 for the comparison of different rotational (DSR-PTR) systems in rice crop during Kharif 2022. Results of rotation cropping systems are discussed below as:

a) One-year rotation

The one-year rotation i.e., DSR-PTR-DSR (Sc 2) produced a grain yield of 6.14 t ha^{-1}, which was 8.63 % lower in comparison to the convention tilled rice (Sc 1; 6.72t ha^{-1}).

b) Two-year rotation

Grain yield under two-year rotation i.e., DSR-DSR-PTR (Sc 3) was 5.86t ha^{-1} which was 4.56% lower than the one-year rotation i.e., DSR-PTR-DSR (Sc 2; 6.14 t ha^{-1}) and 12.79 % lower than convention tilled rice (Sc 1; 6.72t ha^{-1}).

c) Three-year rotation

Grain yield under three-year rotation i.e., DSR-DSR-DSR-PTR (Sc 4) was 6.01 t ha^{-1} during the *kharif* 2022. During 2022, 2.11 and 10.56 % lower yield was reported in Sc 4 in comparison to DSR-PTR-DSR (Sc 2; 6.14 t ha^{-1}) and convention tilled rice (Sc 1; 6.72t ha^{-1}), respectively. However, the grain yield produced in Sc 4 was 2.55 % higher than the DSR-DSR-PTR (Sc 3; 5.86t ha^{-1}).

12.3.2 Detail of wheat crop during *rabi* 2021-22

Data are given in Fig.7 for the comparison of different rotational systems in wheat crop during *rabi*2021-22. Results of rotation cropping systems are discussed below as:

a) One-year rotation

The one-year rotation wheat with zero tillage (Sc 2) produced a grain yield of 5.20 t ha^{-1}, which was 5.41 % lower in comparison to the convention tilled wheat (Sc 1; 5.45t ha^{-1}).

b) Two-year rotation

Grain yield under two-year rotation with zero tillage (Sc 3) was 5.25t ha^{-1} which was 0.96 % higher than the one-year rotation with zero tillage (Sc 2; 5.20 t ha^{-1}) and 4.54 % lower than convention tilled rice (Sc 1; 5.50t ha^{-1}).

c) Three-year rotation

Grain yield under three-year rotation with zero tillage (Sc 4) was 5.18 t ha^{-1} during the *rabi* 2021-22 (Fig. 15). During 2021-22, 5.81, 0.38 and 1.33 % lower yield was reported in SC 4 in comparison to convention tilled wheat (Sc 1; 5.50t ha^{-1}), one-year rotation wheat with zero tillage (Sc 2; 5.20 t ha^{-1}) and two-year rotation with zero tillage (Sc 3; 5.25t ha^{-1}), respectively.

Rice-Wheat Cropping System during 2022-23

Data are given in Fig.8 for the comparison of different rotational systems in rice-wheat cropping system during 2022-23. Results of rotation cropping systems are discussed below as:

a) One-year rotation

The one-year rotation i.e., DSR-PTR-DSR with zero tillage wheat (Sc 2) produced a grain yield of 11.34 t ha^{-1}, which was 7.20 % lower in comparison to the convention tilled rice and wheat (Sc 1; 12.22t ha^{-1}) (Fig.8).

b) Two-year rotation

Grain yield under two-year rotation i.e., DSR-DSR-PTR with zero tillage wheat (Sc 3) was 11.11t ha^{-1} which was 2.02 % lower than the one-year rotation i.e., DSR-PTR-DSR with zero tillage wheat (Sc 2; 11.34 t ha^{-1}) and 9.08 % lower than convention tilled rice and wheat (Sc 1; 12.22t ha^{-1}) (Fig.8).

c) Three-year rotation

Grain yield under three-year rotation i.e., DSR-DSR-DSR-PTR with zero tillage wheat (Sc 4) was 11.19 t ha^{-1} during 2022-23 (Fig.8). During 2022-23, 8.42 and 1.32 % lower yield was reported in SC 4 in comparison to DSR-PTR-DSR with zero tillage wheat (Sc 2; 11.34 t ha^{-1}) and convention tilled rice and wheat (Sc 1; 12.22t ha^{-1}), respectively. However, the grain yield produced in Sc 4 was 0.72 % higher than the DSR-DSR-PTR with zero tillage wheat (Sc 3; 11.11t ha^{-1}).

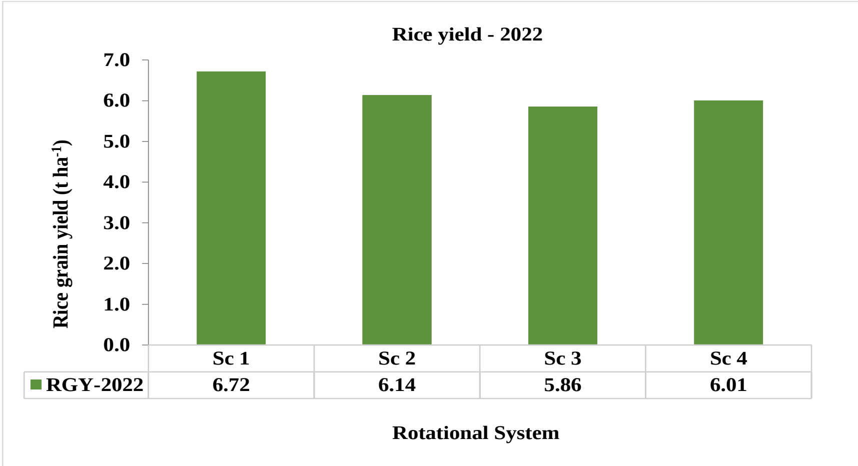


Fig 6: Effects of different rotation system on rice grain yield during kharif 2022.

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

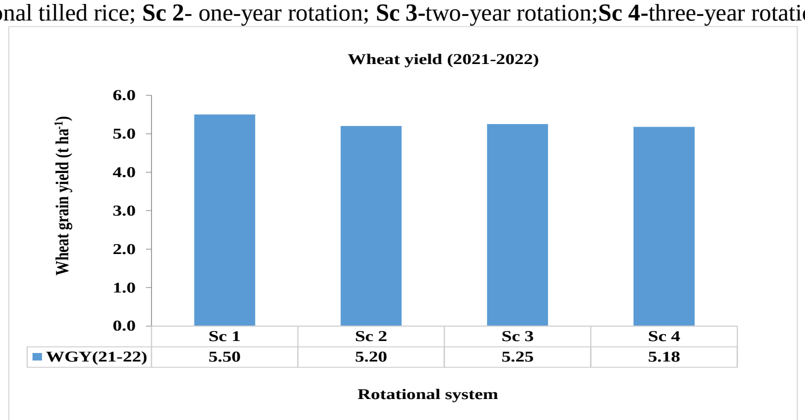


Fig 7: Effects of different rotation system on wheat grain yield during rabi 2021-22.

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

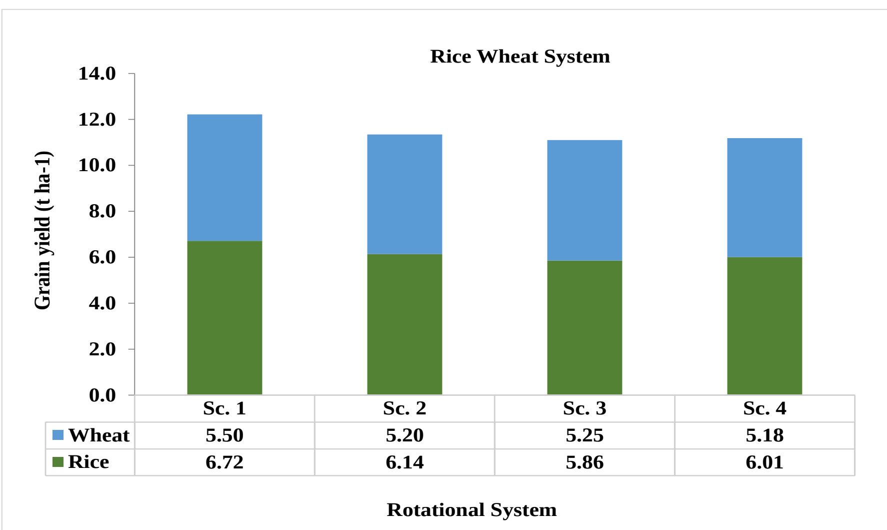


Fig 8: Effects of different rotation system on rice-wheat grain yield during 2022-23.

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

IIWBR

In rice-wheat system, wheat grain yield was slightly better under CT (51.53 q/ha) compared to CA system (48.44 q/ha) (Fig 9) due to higher population of some broadleaved weeds such as *Medicago denticulata* and

Rumex dentatus in CA system. The effect of manuring on wheat was not distinctly visible and long-term continuation may result some desirable effect on system productivity.

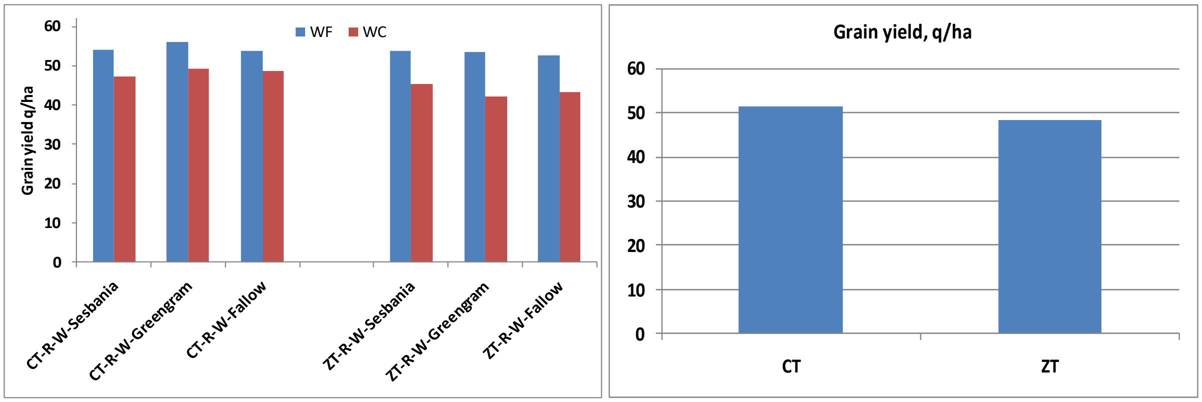


Fig 9: Effect of tillage and manuring on wheat yield in rice-wheat system

A long-term trial involving various rice residue levels (no residue, anchored, anchored + loose residue @3 t ha^{-1} and anchored + loose residue @6 t ha^{-1}) managed by different active type seeding machines (Rotary Disc Drill, Happy Seeder and Super Seeder) in wheat followed by direct seeding of rice in all plots was initiated in rice-wheat system during 2021-22. Wheat was sown during mid-November using DBW 222 variety while rice was directly seeded during first fortnight of June using hybrid seed (Arize Swift Gold). The results of *Rabi* season of 2021-22 and *Kharif* season of 2022 are presented in Fig 10. At various rice residue levels across all seeding machines, mean wheat yield was similar (50.2-51.3 q/ha). The maximum wheat yield (52.98 q/ha) was found under sowing with Happy Seeder which was slightly higher than wheat sown under conventional tillage. The power requirement was minimum in case of Rotary Disc Drill while Super Seeder required higher tractor power for its operation. The yield of direct seeded rice in plots with various residue levels in previous wheat crop varied 30.1-34.0 q/ha with being highest under residue-free conditions.

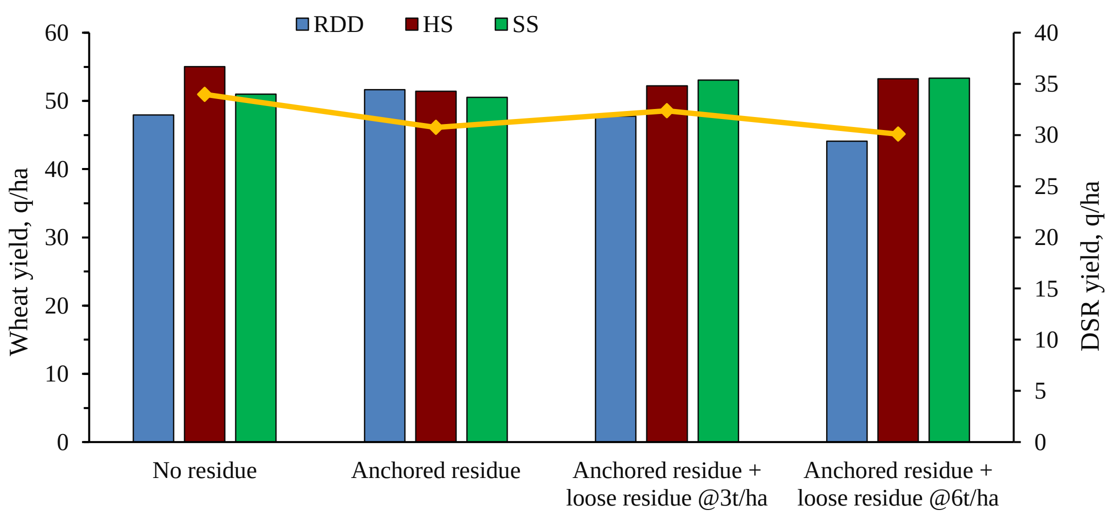


Fig 10: Effect of various treatments on crop productivity

2. Rice- Fellow cropping system

RCER

Rice-fallow, a monocropping production system, is gaining attention for cropping intensification in the South Asia for sustainable food production. There is huge scope for utilization of winter fallow lands for cultivation of short-duration and high-yielding pulses and oilseeds by utilizing residual soil moisture and adopting resource-efficient crop establishment-cum-residue management (CERM) method. Hence, in present investigation, impact of different CERM practices on overall system productivity, earthworm activity, pest/natural enemies dynamics, and soil health parameters were evaluated in rice-pulse/oilseed cropping system in rainfed lowland rice fallows ecosystem of eastern India for long-term sustainability. Three crop establishment methods viz. zero-till DSR (ZTDSR), conventional-till-direct seeded rice (CTDSR) and transplanted puddle rice (TPR) and along with residue management (with and without residue) were combined with five potential winter crops e.g., chickpea, lentil, safflower, linseed, and mustard. The results revealed that rice yield was significantly higher in TPR with retention of residue. TPR/conventional tillage was 28.9 and 15.4% more grain yield than ZTDSR (conservation agriculture, CA) and CTDSR (partial CA, pCA) management practices, respectively. However, TPR production system had a negative impact on overall performances of all winter crops. Increase in grain yield of post-rainy crops in CA-based system was 21.2, 89.7, 44.1, 44.4 and 25.3%, respectively over to TPR system. Diversification in rice-fallow with inclusion of the high-yielding short-duration rice varieties (Swarna Shreya) during rainy season and suitable potential pulses (chickpea, lentil)/ oilseeds (safflower, linseed, mustard) crop during winter resulted in an increase in overall system productivity from 5.44 to 9.54 Mg ha^{-1}. CA-based production systems had 35.6, 27.3, 91.9 and 73.4%, higher earthworm casting, burrowing events, total earthworm counts and biomass, respectively than TPR.

ICAR RCER Farming System Research Centre for Hill & Plateau Region, Plandu, Ranchi: Rice-fallow systems in South Asian countries play a pivotal role in increasing agricultural production. However, the productivity of this system is largely challenged by deteriorating soil health and limited residual soil moistures in dry periods, precluding possibility of winter and/or spring season crops after rice harvest. This investigation explores possibilities of including winter and/or spring crops through conservation agriculture (CA)-based management practices and evaluates its effect on soil carbon dynamic, system productivity, energy, and carbon budgeting. Field experiments were conducted at a farmer's field in participatory modes at Chene Village, Jharkhand, India, and had five treatments comprising (1) fallow-land [FL]; (2) transplanted puddle rice (TPR)-fallow (winter)-fallow (summer), a typical cultivation practice of this region [RF]; (3) TPR–conventional-till mustard–conventional-till blackgram [CP]; (4) CA with zero-till transplanted rice(ZTTR)-ZT mustard–ZT blackgram [CA1]; (5) CA with zero-till direct seeded rice (ZTDSR)- ZT mustard–ZT blackgram [CA2]. System rice equivalent yield in CA2 during initial four years was lower than CP but it was 23.7% higher over CP in fifth year.

3. Maize-Wheat cropping system (MWS)

IARI

Under the CA-based maize-wheat system (after 12 years), all the CA-based ZT permanent broad, narrow, and flat beds with residue resulted in significantly higher yields of maize, wheat and system productivity than conventional tillage (CT) system (Fig 11). In contrast to previous years, ZT permanent broad bed with 100% N had a higher maize yield by ~46%, wheat yield by ~10%, and system productivity by ~23% than CT system. However, 75% N was comparable with 100% N, this leads to saving of 25% N. This CA-based maize-wheat system could be a promising crop diversification option for rice-wheat system and an important adaptation and mitigation strategy to climate change.

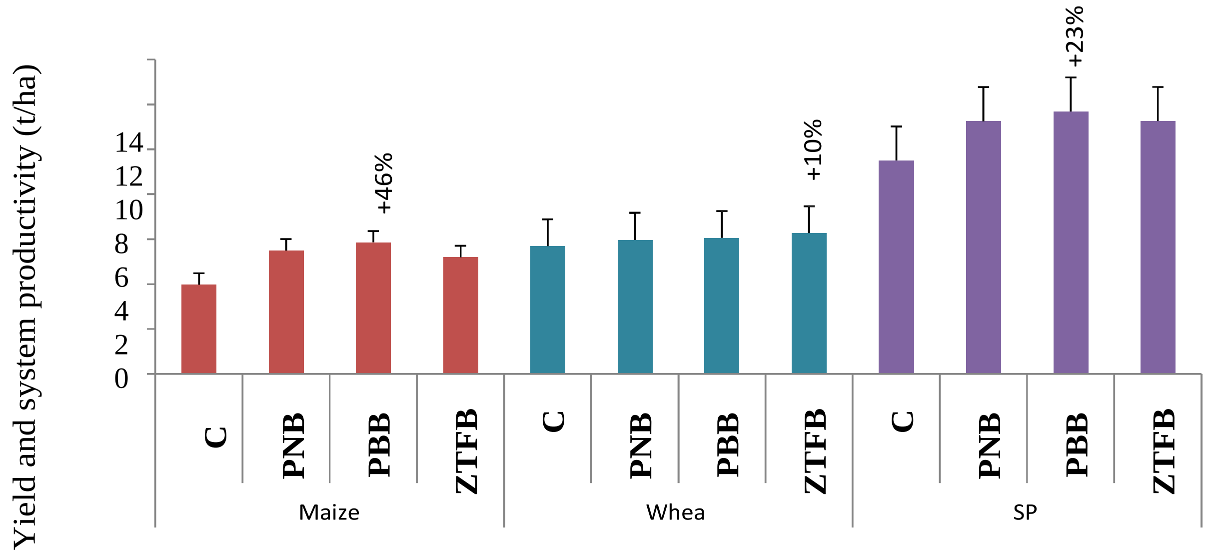


Fig 11: Effect of CA on maize yield, wheat yield, and system productivity under maize-wheat cropping system

IIWBR

4. Maize-Wheat-Green gram cropping system

At ICAR-IIWBR (29˚42'22"N; 85˚40'13"E), a long term experiment was initiated during Kharif 2015, to evaluate the "Long term effect of tillage, residue and nutrient management in maize-wheat-green gram system" in a systems' perspective. The experiment was conducted in split plot design with three replications. The main plot consisted of four treatments involving the combination of tillage and residue management {ZT (Zero tillage); ZT with residue retention (CA); CT (Conventional tillage) and CT + residue incorporation} and sub plots were having the four nutrient management options (Control; Recommended N alone; Recommended NPK; and Rec. NPK + FYM 10 t/ha). Wheat cultivar DBW 222 (2021-22) was sown on November18, 2021 at row to row spacing of 20 cm using a seed rate of 125 kg/ha considering the 1000 grain weight as 38 g. The sowing was done using Turbo Happy Seeder. The full residue load of maize (175 q/ha) after removing the cobs was either removed, or retained or incorporated. The incorporation was done using rotary tiller. The irrigations were given as per the recommended practices. For control of weeds pinoxaden 50 g/ha fbmetsulfuron 4 g/ha were applied at 35 fb 40 DAS. The recommended dose of N:P_2O_5:K_2O consisted of 150:60:40 kg/ha. Full P and K were applied as basal before pre seeding irrigation. Whereas N was applied in two equal splits (half dose each just before first and second irrigation).

The perusal of data in Table 3 revealed that the effect of nutrient management was significant, whereas the effect of tillage and residue management and their interactions were non-significant except for grain yield. Among four nutrient management options minimum yield was recorded in unfertilized control plots having a mean yield of 11.73 q/ha. The poor yield in this treatment was due to lesser yield attributes mainly the effective tillers. The wheat grain yield was maximum (55.64 q/ha) when FYM @ 10t/ha was applied along with Rec. NPK. However, statistically this treatment was at par with Recommended NPK application. The unfertilized plots were having the lowest 1000 grains weight. Among tillage and residue management options, CT wheat had lowest 1000 grains weight.

Table 3: Effect of tillage, residue and nutrient management in wheat under Maize-wheat system during 2021-22

Tillage and residue management	**Plant height, cm**	**Earhead length, cm**	**Tillers/m^2**	**Yield q/ha**	**1000 grain weight, g**
ZT	89.6	9.3	393.0	36.46	32.94
ZT+R*	99.4	10.2	438.6	41.51	34.10
CT	95.6	9.7	403.2	38.86	32.85
CT+RI*	97.5	10.0	416.4	41.46	33.49
CD at 5%	4.94	NS	28.17	2.37	NS
Nutrient management					
Control	66.2	7.0	326.6	11.73	31.48
N Alone	94.4	10.1	385.9	37.01	34.81

Rec. NPK	110.0	11.1	466.7	53.92	33.48
Rec. NPK+ FYM 10t/ha	111.5	11.1	472.1	55.64	33.59
CD at 5%	5.37	0.71	23.39	2.82	0.73

*R=Residue Retention and RI= Residue incorporation

Residue incorporation

ZT-Wheat

CA-Wheat (Wheat in full maize residue)

Plate 4. Long term maize-wheat experiment's treatments

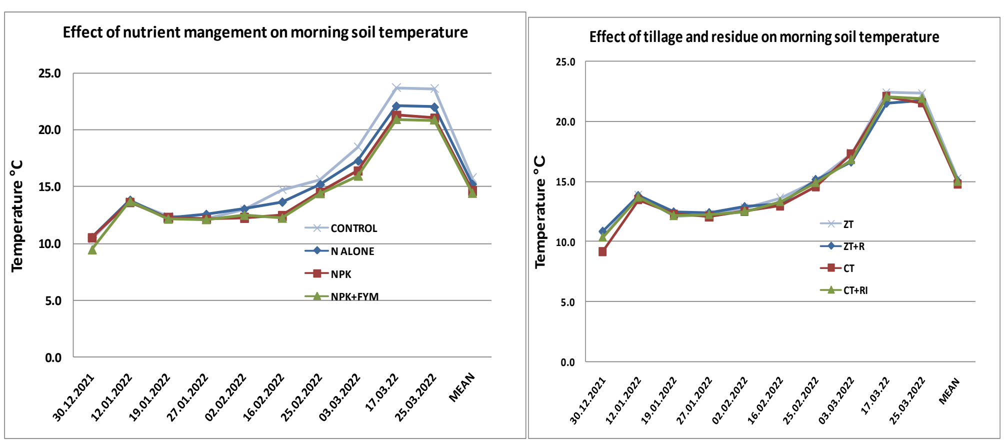


Fig 12: Effect of tillage, residue and nutrient management on morning soil temperature in long term maize-wheat-greengram experiment

Observations were also taken on soil temperature in the morning and noon on different dates (Fig 12 and 13). The morning temperatures were on slightly higher in CA system where as reverse in the noon, where the temperatures were on lower side. The noon temperatures in the control plots were higher than different nutrient management treatments.

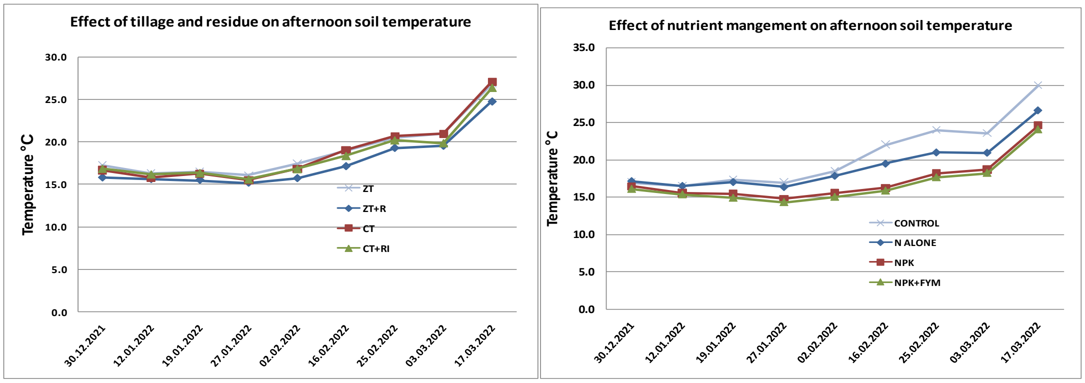


Fig 13: Effect of tillage, residue management and nutrient management on afternoon soil temperature during different crop seasons in long term maize-wheat-greengram experiment

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

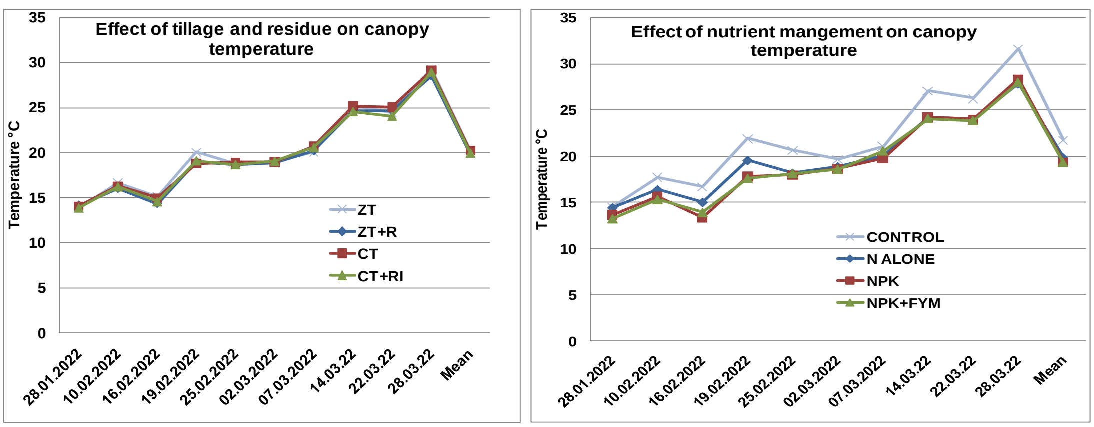


Fig 14: Effect of tillage, residue and nutrient management on canopy temperature during different crop seasons in long term maize-wheat-greengram experiment

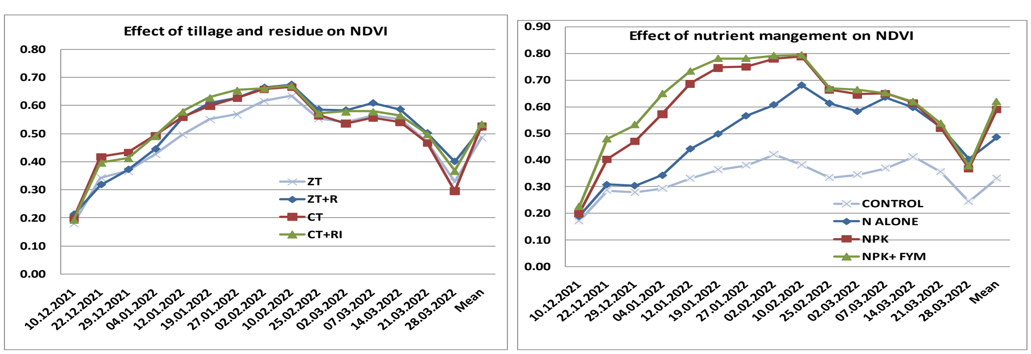
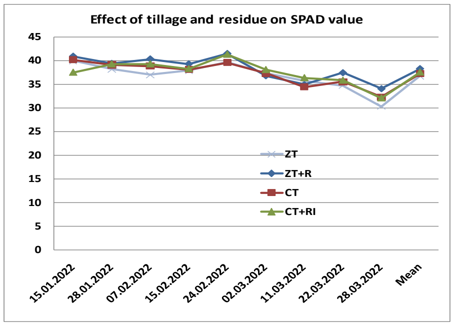


Fig 15: Effect of tillage, residue and nutrient management on NDVI in long term maize-wheat-greengram experiment.



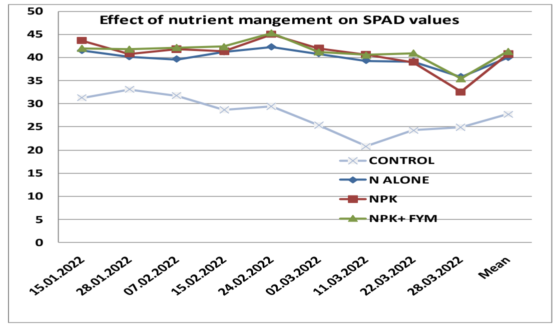


Fig 16: Effect of tillage, residue and nutrient management on SPAD values in long term maize-wheat-greengram experiment

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

With the same set of treatments as in wheat, here the full residue of wheat crop was either incorporated or retained on the surface before greengram sowing. After picking of pods, greengram was also either removed or retained or incorporated as per treatment. In ZT and CA pre-planting glyphosate + paraquat were also applied at 1.5 + 0.5 kg/ha. Maize hybrid CP 858 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 (83.92 q/ha). The main reason for the response in CA was better infiltration and less adverse effect of water logging due to heavy rain as observed in CT system (Photo below). The yield recorded in CT plots were 70.84 q/ha. Among nutrient management treatments, unfertilized plots recorded significantly lowest yield (52.16 q/ha).

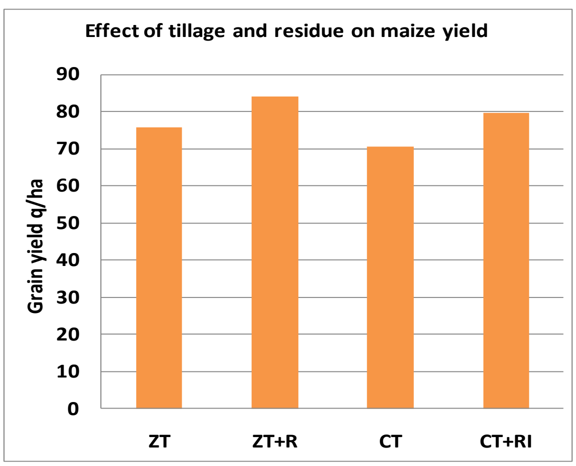


Fig 17: Effect of tillage and residue on maize yield

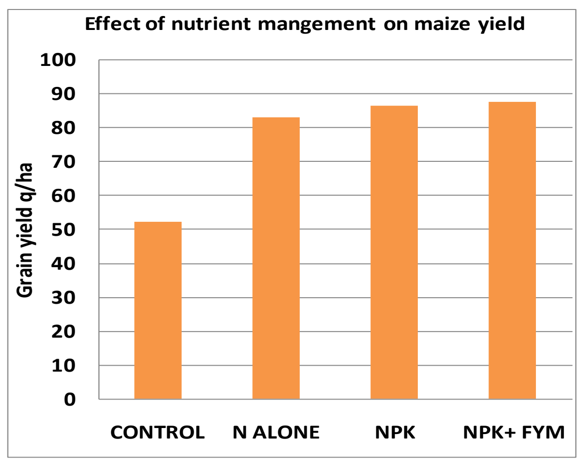


Fig 18: Effect of nutrient management on maize yield

Plate 5. Lesser adverse effect of heavy rainfall in CA maize

Maize-Wheat- System with *sesbania* and Greengram Manuring

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

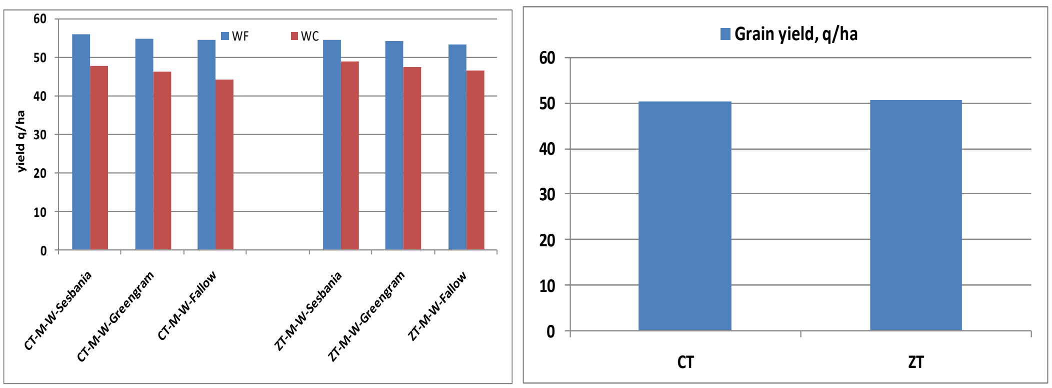


Fig 19: Effect of tillage and manuring on wheat yield in maize-wheat system

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

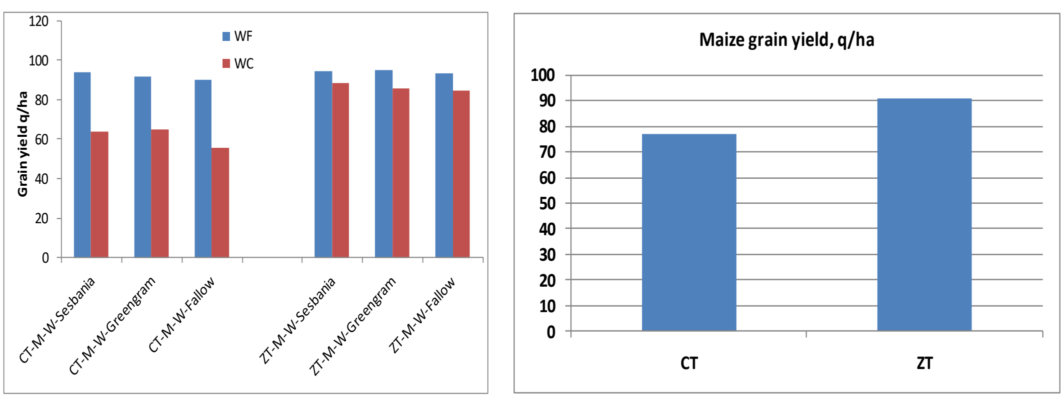


Fig 20: Effect of tillage and manuring on maize yield in maize-wheat system

5. Cotton-Wheat Cropping System (CW)

IARI

In CA-based cotton-wheat system (after 12 years), all the CA-based ZT permanent broad, narrow, and flat beds with residue resulted in significantly higher yields of cotton, wheat, and system productivity than conventional tillage (CT) system (Fig 21). In contrast to previous years, ZT permanent broad bed was superior than ZT flat bed with residue with 100% N in terms of cotton yield (~54%), wheat yield (~22%), and system productivity (~37%) than CT system. However, 75% N was comparable with 100% N, this leads to saving of 25% N. The cotton- wheat system under PFB+R led to 65% increase in net returns compared to CT. This CA-based cotton-wheat system could be a promising crop diversification option for rice-wheat system and an important adaptation and mitigation strategy to climate change. System could be a promising crop diversification option for rice-wheat system and an important adaptation and mitigation strategy to climate change.

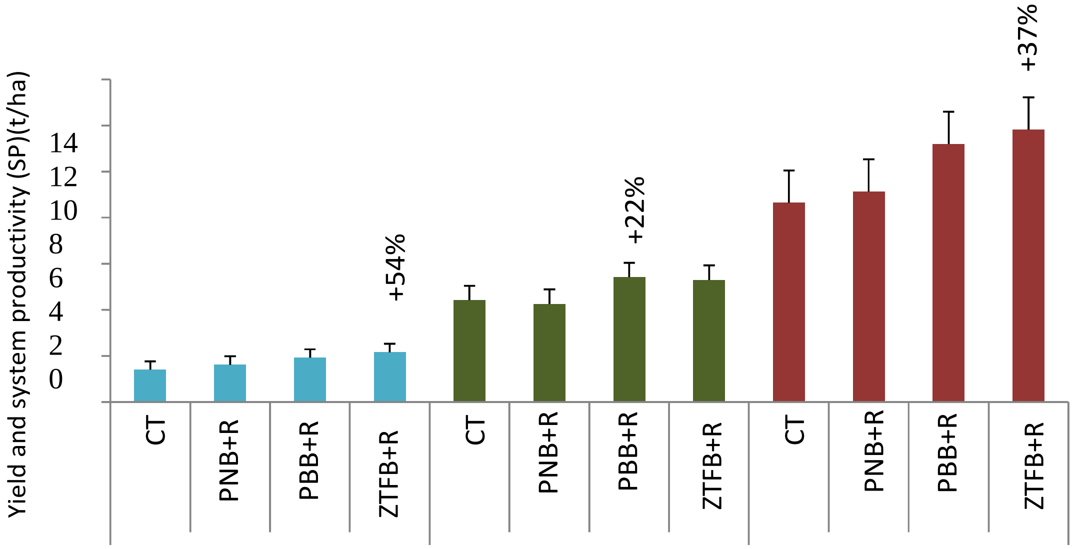


Fig 21:Effect of CA on cotton yield, wheat yield, and system productivity under cotton-wheat cropping system

Plate 6. Effect of CA on cotton-wheat cropping system

6. Pigeon pea-Wheat System (PWS)

IARI

Pigeon pea-wheat cropping system is a promising cropping system to achieve the food and nutritional security of the country. Under the CA-based pigeon pea-wheat system (after 12 years), all the CA-based ZT permanent broad, narrow, and flat beds with residue resulted in significantly higher yields of pigeon pea, wheat and system productivity than conventional tillage (CT) system (Fig 22). The pigeon pea sown on permanent broad beds (PBB) with wheat residue, wheat sown in PBB with pigeon pea residue resulted in ~90% higher pigeon pea yield, ~25% higher wheat yield and ~54% higher system productivity than conventional till pigeon pea-conventional till wheat system. Cotton-wheat system under PFB+R and pigeon pea-wheat and maize-wheat systems under PBB+R led to 61%, 88% and 32% increase in net returns respectively, compared to respective conventional till system. This CA-based pigeon pea-wheat system could be a promising crop diversification option for rice-wheat system to meet out the sustainable development goals of UN and an important adaptation and mitigation strategy to climate change.

Pigeon pea-wheat cropping system is a promising cropping system to achieve the food and nutritional security of the country. Under the CA-based pigeon pea-wheat system (after 12 years), all the CA-based ZT permanent broad, narrow, and flat beds with residue resulted in significantly higher yields of pigeon pea, wheat and system productivity than conventional tillage (CT) system (Fig 22). The pigeon pea sown on permanent broad beds (PBB) with wheat residue, wheat sown in PBB with pigeon pea residue resulted in ~90% higher pigeon pea yield, ~25% higher wheat yield and ~54% higher system productivity than conventional till pigeon pea-conventional till wheat system. Cotton-wheat system under PFB+R and pigeon pea-wheat and maize-wheat systems under PBB+R led to 61%, 88% and 32% increase in net returns respectively, compared to respective conventional till system. This CA-based pigeon pea-wheat system

could be a promising crop diversification option for rice-wheat system to meet out the sustainable development goals of UN and an important adaptation and mitigation strategy to climate change.

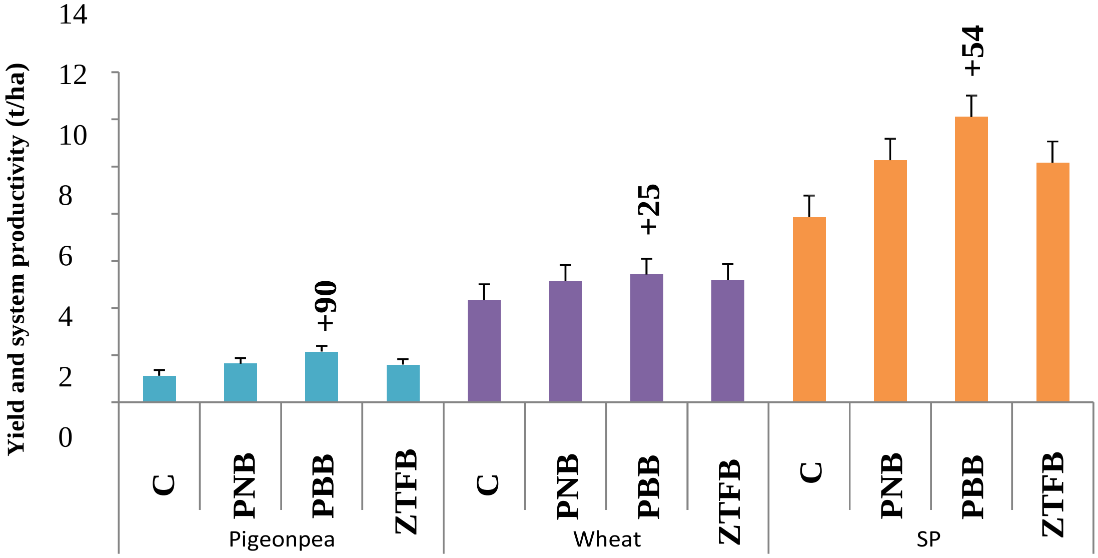


Fig 22: Effect of CA on pigeonpea yield, wheat yield, and system productivity under pigeonpea-wheat cropping system

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

IARI

The long-term CA based maize-mustard cropping system revealed that a triple zero-till cropping system (TZT) involving zero-till maize (ZTMz) with summer mungbean residue (MBR)- ZT mustard (ZTMs) with maize residue (MzR)– ZT summer mungbean (ZTSMB) with mustard residue (MsR) had superior maize yield, mustard yield, system productivity and net returns than other CA systems (Fig. 1.29). The increase was ~20% higher maize yield, ~27% higher mustard yield, and ~65% higher system productivity than conventional till maize-conventional till mustard system. This led to a saving of almost 25% N (~57.5 kg N/ha) and 50% S in maize-mustard system. The results indicates that sustainable intensification of the maize-mustard system with a legume mungbean could be an alternative option for rice-wheat system.

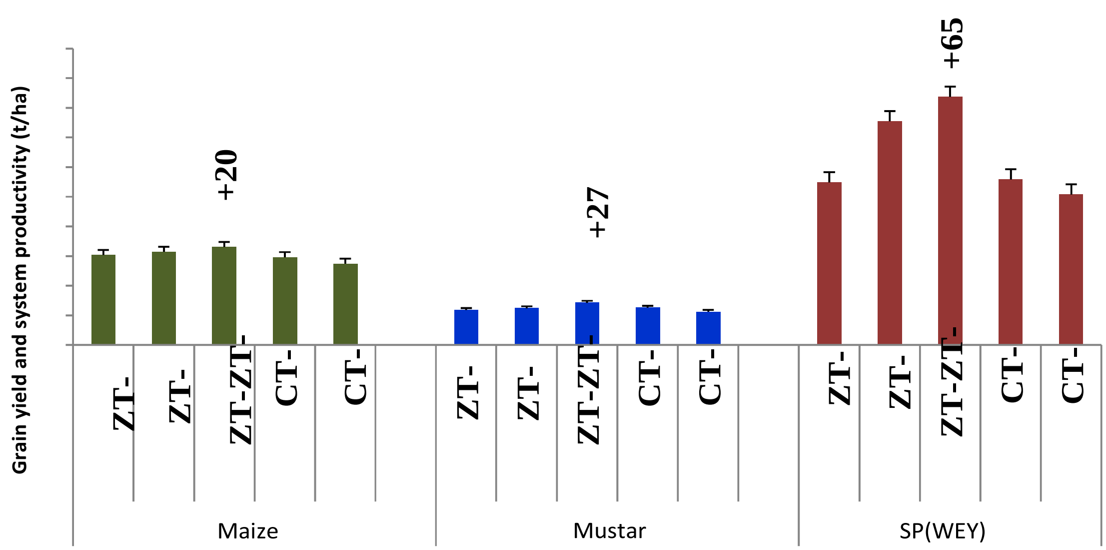


Fig 23: Effect of CA on maize yield, mustard yield, and system productivity under maize-mustard system

8. Sugarcane Cropping System

NIASM

In the year 2022–23, a field data of plant (2016–18) and four consequent ratoon crops (2018–2022) was analysed to study interactive effect of tillage, crop residues and nutrient management practices for enhancing productivity of sugarcane cropping system. The results revealed that in plant crop, treatment RT2 i.e. reduced tillage with application of 10% of RDF as basal, 40% through band placement and remaining 50% through fertigation improved the cane yields by 12.5–18.6% over farmers' practices i.e. conventional tillage (CT) with 10% of recommended dose of fertilizers (RDF) as basal and 90% through fertigation. In ratoon crop, pooled data indicated that RT2+M+N2 i.e. reduced tillage (RT2) with 50% application of RDF as basal using SORF in band placement and remaining 50% RDF through fertigation in standing crop with mulching improved the ratoon cane yields by 34.5–42.5% over conventional tillage (CT). Average yield attributes viz., cane weight, cane length, cane girth and numbers of internodes improved significantly by 1.73, 1.36, 1.38 and 1.33 times in RT2+M+N2 over farmers practices i.e. CT+NM+N1 (CT + Non Mulch + 25% of RDF as basal and remaining 75% by fertigation).

Long term effect of planting geometry, micro-irrigation and residue management practices for improving yield and WP of sugarcane cropping system

In another experiment, long term response of plant and ratoon crop yields to planting geometry, micro-irrigation and residue management practices (2017–22) were studied. The planting geometry ZPR–225 cm × 75 cm + SSDI (M_5) resulted in higher cane yields (15.6–22.8%) as compared to PSR (150 cm) + surface irrigation (SI) methods (M8) i.e. farmers practice. Maximum mean WP (9.77 kg m^{-3}) was observed in M_5S_1 i.e. zigzag paired row (75 cm, 225 cm) + sub-surface drip irrigation (SSDI) with mulch. Similar results were obtained quality indices of freshly harvested canes. The synergies of micro-irrigation and mulching (trash/ live mulch) significantly enhanced the cane yields.

B. Weed Management Practices in Conservation Agriculture

1. Rice Wheat Cropping System

IARI

Fourteen weeds, comprising six grassy, four broad-leaved (~BLW), and four sedge weeds were observed in rice. In DSRs observed a higher infestation *of Echinochloa colona, Dactyloctenium aegyptium, Dinebra retroflexa, Leptochloa chinensis,* and *Eleusine indica* than the PTR, which, on the contrary, had higher density of *Echinochloa crusgalli* (Fig. 24). Among the DSRs (C1-C5) system, the triple ZT system with three crops residue (C5) resulted in the lowest densities of *D. aegyptium*, *D. retroflexa*, and *L. chinensis*. PTR (C6) system was not infested with these weeds but had the highest density of *E. crusgalli*. Broad-leaved weeds *Phyllanthus niruri* and *Trianthema portulacastrum* infested DSRs (C1-C5) but not PTR (C6). The C5 caused significant reduction of these weeds compared to C4, having the highest densities. *Alternenthera philoxeroides* were found in C6 and C1, the former having a significantly higher density than the latter (Fig. 25). Perennial sedges *Cyperus esculentus* L., and *Cyperus rotundus* L., had higher densities in CA-based DSRs (C1-C5) and were absent in PTR (C6), whereas annual sedges *Cyperus difformis* L., and *Cyperus iria* L. were observed in PTR and absent in DSRs (Fig. 26). Among DSRs, C4 had the highest densities of *C. esculentus* and *C. rotundus*. The pyrazosulfuron fb cyhalofop fb bispyribac treatment resulted in significantly lower densities of all grassy weeds except *E. indica* and all broad-leaved weeds than UWC and pyrazosulfuron fb tank-mix cyhalofop + bispyribac. This herbicide treatment also led to lower densities of *C. esculentus, C. rotundus, C. difformis* and *C. iria* than other treatment

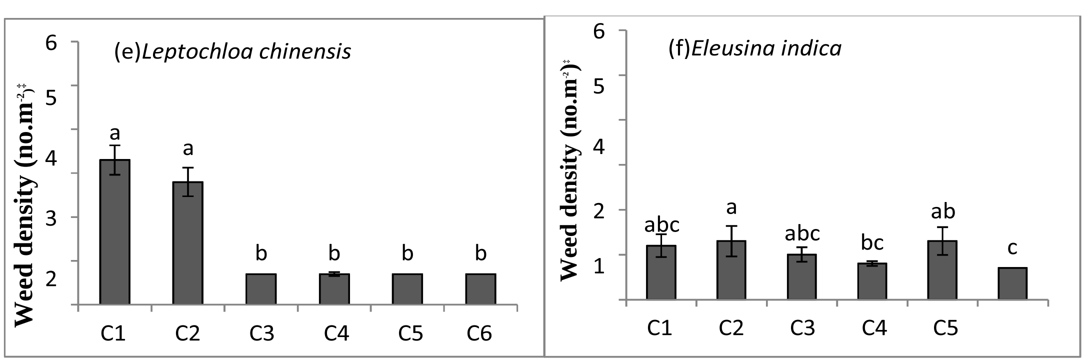


Fig 24: Species-wise monocot grassy weeds densities [transformed through square-root $(x+0.5)^{½}$ method‡] across the CA-based direct-seeded rice at 60 DAS/DAT (a) Echinochloa colona; (b) Echinochloa crusgalli; (c) Dactyloctenium aegyptium; (d) Dinebra retroflexa; (e) Leptochloa chinensis; (f) Eleusine indica.

Mean density of particular weeds having different lowercase letters on the vertical bars are significantly different at $P \leq 0.05$ as per Tukey's HSD test. Vertical bars represents mean ± standard error. C1, ZTDSR-ZTW; C2, ZTDSR + WR – ZTW+RR; C3, ZTDSR + WR+BM – ZTW+RR; C4, ZTDSR-ZTW-ZTMB; C5, ZTDSR+MR-ZTW+RR- ZTMB+WR and C6, PTR-CTW.

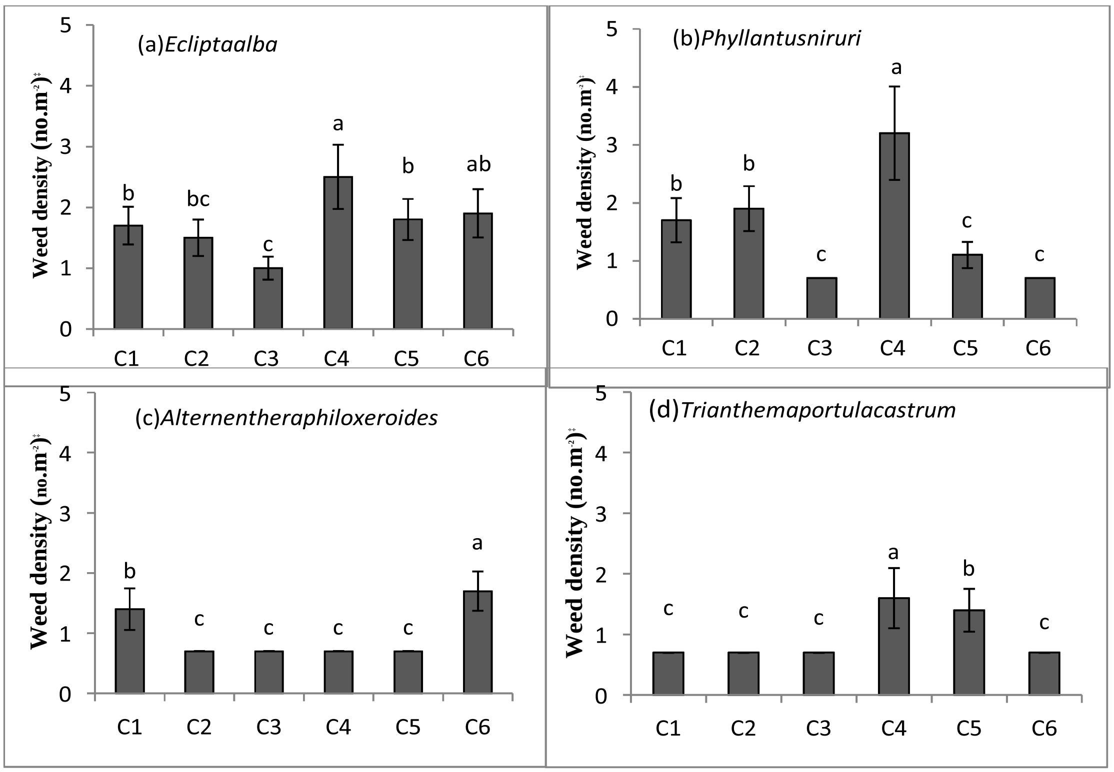
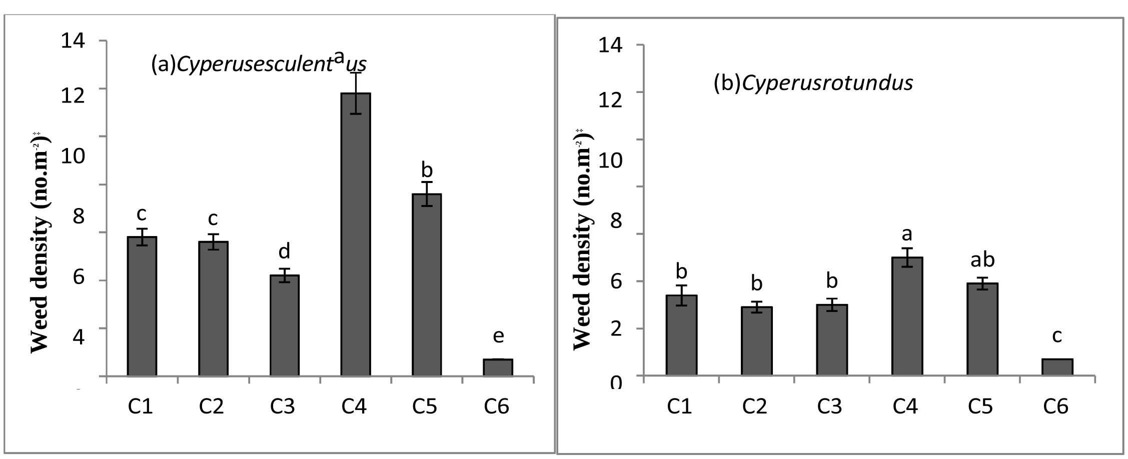


Fig 25: Species-wise broad-leaved weed densities [transformed through square-root $(x+0.5)^{½}$ method‡] across the CA-based direct-seeded rice at 60 DAS/DAT. (a) Eclipta alba; (b) Phyllanthus niruri; (c) Alternenthera philoxeroides; (d) Trianthema portulacastrum.

Mean density of particular weeds having different lowercase letters on the vertical bars are significantly different at $P \leq 0.05$ as per Tukey's HSD test. Vertical bars represents mean ± standard error. C1, ZTDSR-ZTW; C2, ZTDSR + WR – ZTW+RR; C3, ZTDSR + WR+BM – ZTW+RR; C4, ZTDSR-ZTW-ZTMB; C5, ZTDSR+MR-ZTW+RR-ZTMB+WR and C6, PTR-CTW



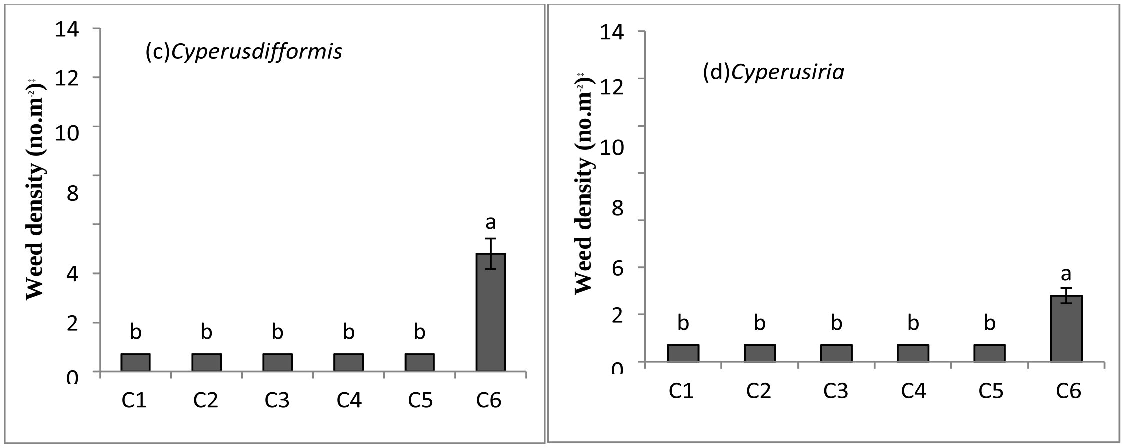


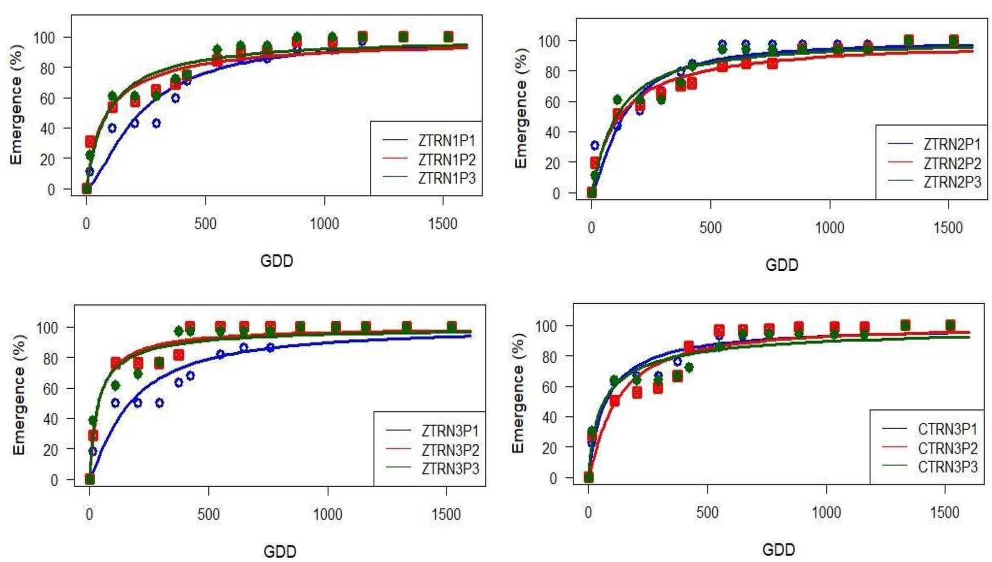
Fig 26: Species-wise sedge weed densities [transformed through square-root (x+0.5)½ method‡] across the CA- based direct-seeded rice at 60 DAS/DAT. (a) Cyperus esculentus; (b) Cyperus rotundus; (c) Cyperus difformis;(d) Cyperus iria.

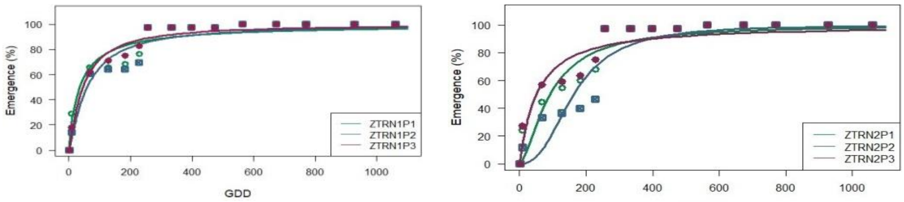
Mean density of particular weeds having different lowercase letters on the vertical bars are significantly different at P≤ 0.05 as per Tukey's HSD test. Vertical bars represents mean ± standard error. C1, ZTDSR-ZTW; C2, ZTDSR + WR – ZTW+RR; C3, ZTDSR + WR+BM – ZTW+RR; C4, ZTDSR-ZTW-ZTMB; C5, ZTDSR+MR-ZTW+RR-ZTMB+WR and C6, PTR-CTW

Weed emergence in a conservation agriculture-based Maize-Wheat cropping system

The observations on the cumulative emergence of *Melilotus indicus* and *Coronopus didymus* were observed throughout the wheat season in an ongoing long-term tillage experiment (10 years) of wheat under the maize-wheat cropping system. Cumulative emergence (%) data were fit in a two parameter Log-logistic [(ED50 as parameter) (2 parms): f(x)= [1]/[1+exp(b(log(x)−log(e)))]] model to find the time requirement for 50% emergence of these weeds (Fig. 27). Result revealed that the 50% emergence of *Melilotus indicus* took a longer time in the ZT system (27 days greater) compared to CT. The *Melilotus indicus* has responded to P application but not to N application rate in the ZT system. Whereas for the CT system, 100% N with 75% P applied plot took a longer time than zero P and 100% P plot. For *Coronopus didymus*, 50% emergence took a longer time in ZT system (21 days greater) than that of CT. The 50% germination took a longer time (28.1-112 GDD) under 75% P applied plots compared to 0% and 100% P in both ZT and CT systems. This was disregarded to the amount of N applied. The total weed density at the time of harvest was higher for the higher P rates. Zero tillage + residue retention with 75% of N and 75% P resulted in the higher total weed density. Overall, the farmers practicing the long-term tillage system should be proactive to adopt a better weed management program for efficient control of weeds throughout the season.

a) Seedling emergence: *Melilotus indicus*





b) Seedlingemergence:*Coronopusdidymus*

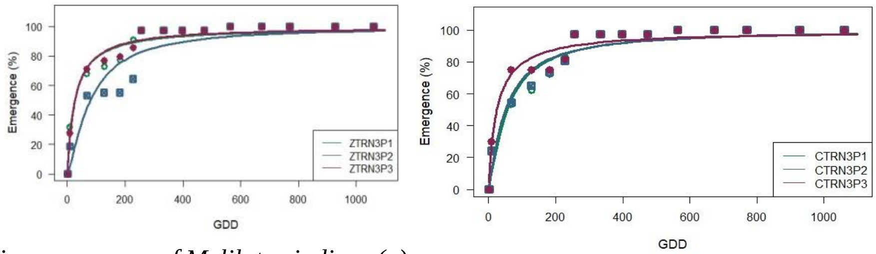


Fig 27: Cumulative emergence of Melilotus indicus (a) and Coronopus didymus (b)

IIWBR

A field experiment was conducted under conservation tillage in rice-wheat system and different weed control treatments were evaluated (Fig 28). There were four application timing of herbicides namely pre-plant (PP) at 2 Days before sowing, pre-emergence 1 DAS, early post emergence (EPO) at 21 DAS *i.e* 1 day before irrigation, post emergence (PoE) at 35 DAS. Wheat was sown in full rice residue load of 8 t/ha using Happy Seeder. The herbicides were sprayed using Knap Sack sprayer delivering 500 lit of water/ha. The weed dry weight was recorded at 90 DAS. The most effective herbicidal treatment in reducing the dry matter of total weeds *(15.3 g*/m^2) wasPP application of pyroxasulfone + pendimethalin + metribuzin at 125 + 1000 + 210 g/ha, however, it was statistically at par with PP application of pyroxasulfone + metribuzin 125 + 300 g/ha (9.9 g/m^2), EPO application of pyroxasulfone + pendimethalin + metribuzin at 125 + 1000 + 120 g/ha (13.2 g/m^2), and PP application of pyroxasulfone + metsulfuron 125 + 4 g/ha (20.9 g/m^2) .PP application of pyroxasulfone + pendimethalin at 125 + 1000 g/ha (28.3 g/m^2) was also found statistically similar to the PP application ofpyroxasulfone + pendimethalin + metribuzin at 125 + 1000 + 210 g/ha.

The uncontrolled growth of weeds during the crop-growing season caused a loss grain yield by 57.8%. All herbicide treatments resulted in noticeably higher grain yields than the weedy check treatment. The highest grain yield of 54.35 q ha^{-1} was recorded in weed free check. Among the herbicidal treatments, pre- plant and early post application of pyroxasulfone + pendimethalin + metribuzin (52.10 and 51.31 q ha^{-1}, respectively) and pre- plant application of pyroxasulfone + metribuzin 125 + 300 g/ha (51.57 q ha^{-1}) recorded statistically at par grain yield with weed free (54.35 q/ha). The grain yield obtained under various weed control treatments was significantly higher than weedy check.

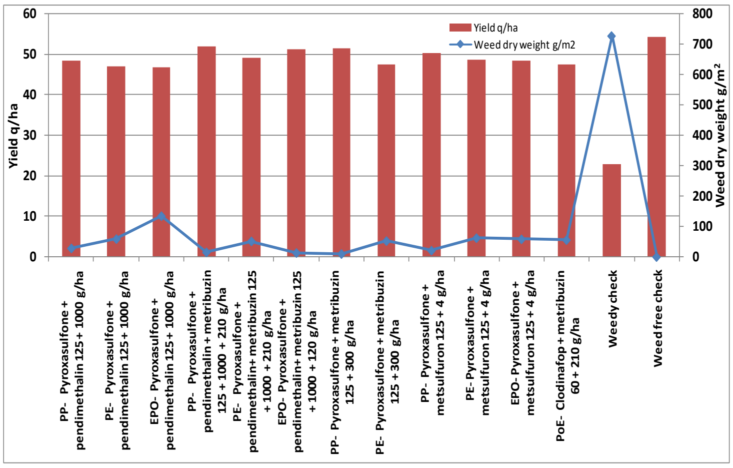


Fig 28: Effect of weed control treatments on weed dry weight and wheat grain yield under conservation tillage.

DWR
Wheat 2021-22

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

At 60 days after sowing (DAS), the wheat field was comprised of the relative density of weeds, i.e. *Medicago polymorpha* (74%), *Avenaludoviciana* (17%), whereas the rest of the weeds, like *Convolvulusarvensis*, *Chenopodium album*, *Sonchusoleraceus*, *Lathyrusaphacea*, *Solanum nigrum*, *D. sanguinalis*, *Physalis minima* were minor weeds present (Fig 29). The relative weed biomass followed the trend of relative density and recorded the highest with *Medicago polymorpha* (76%), *Avenaludoviciana*(15%) and rest were minor weeds. It was noticed that *Digitariasanguinalis*, *Physalis minima*, *Solanum nigrum* and *Alternatherasessilis* were late-emerging weeds in wheat.

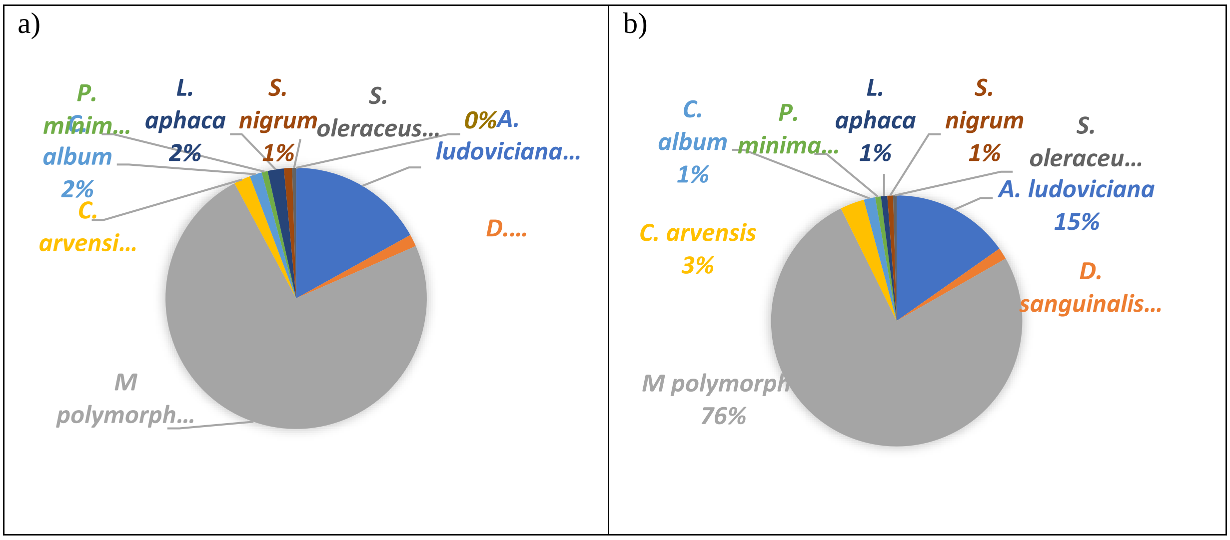


Fig 29: Relative weed density (a) and biomass (b) at 60 DAS in wheat under rice-wheat-greengram system

Table 4: 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/chickpea-greengram system

Treatment	Grassy weeds			Broadleaved weeds						
	Avena ludoviciana	*Digitaria sanguinalis*	*Cynodon datylon*	*Medicago polymorpha*	*Lathyrus aphaca*	*Convolvulus arvenisis*	*Chenopodium album*	*Physalis minima*	*Solanum nigrum*	*Sonchus oleraceus*
CT-CT-CT	2.2(11.3)	1.01(1)	0.89(0.7)	5.19(53.1)	1.69(3.3)	1.09(1.6)	1.01(1)	1.64(2.9)	1.3(1.6)	0.87(0.3)
ZTR-ZTR-ZTR	1.97(8.3)	1.36(2.3)	1.8(3.7)	4.56(41.5)	1.32(1.8)	1.23(1.6)	0.9(0.5)	1.13(1.1)	1.05(0.8)	1.09(0.9)
SEm±	0.04	0.14	0.27	0.22	0.26	0.09	0.04	0.22	0.19	0.002
CD (P=0.05)	0.23	NS	0.81	NS	NS	NS	NS	NS	NS	0.011
W1	6.22(39)	2.02(4.7)	1.5(2.5)	13.12(174.5)	2.15(4.7)	1.82(4.5)	1.69(3)	1.36(1.5)	1.5(2.2)	1.49(1.8)
W2	0.71(0)	1.31(2)	1.78(3.8)	2.62(7.3)	2.02(4.7)	1.21(1.5)	0.71(0)	1.84(3.8)	1.17(1)	0.85(0.3)
W3	0.71(0)	0.71(0)	0.71(0)	1.28(1.3)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)
W4	0.71(0)	0.71(0)	1.38(2.3)	2.49(6)	1.14(1)	0.9(0.5)	0.71(0)	1.63(2.7)	1.33(1.7)	0.85(0.3)
SEm±	0.19	0.29	0.26	0.34	0.32	0.35	0.19	0.25	0.16	0.14
CD (p=0.05)	0.61	0.94	0.79	1.06	0.99	1.04	0.59	0.77	0.49	0.44
C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CT-CT-CT	1.79(6.4)	0.93(0.6)	0.79(0.2)	3.79(32.9)	1.09(0.8)	1.07(1.5)	0.93(0.6)	1.38(1.8)	1.04(0.7)	0.81(0.2)
ZTR-ZTR-ZTR	1.58(4.4)	1.02(0.8)	1.11(0.9)	3.16(21.7)	0.93(0.5)	1.12(1.1)	0.83(0.3)	1(0.7)	0.89(0.4)	0.92(0.4)

SEm±	0.03	0.08	0.10	0.16	0.11	0.06	0.04	0.16	0.11	0.01
CD (P=0.05)	0.21	NS	NS	0.48	NS	NS	NS	NS	NS	0.04
W1	4.63(21.5)	1.55(2.4)	1(0.6)	10.19(105.7)	1.26(1.2)	1.61(3.5)	1.4(1.8)	1.16(0.9)	1.15(1)	1.18(0.9)
W2	0.71(0)	0.93(0.5)	1.13(1)	1.46(1.8)	1.22(1.2)	1.18(1.4)	0.71(0)	1.54(2.4)	0.96(0.5)	0.79(0.2)
W3	0.71(0)	0.71(0)	0.71(0)	0.89(0.3)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)
W4	0.71(0)	0.71(0)	0.96(0.6)	1.35(1.4)	0.85(0.2)	0.88(0.4)	0.71(0)	1.37(1.7)	1.05(0.7)	0.79(0.2)
SEm±	0.16	0.19	0.11	0.26	0.12	0.33	0.14	0.18	0.09	0.08
CD (p=0.05)	0.49	0.58	0.33	0.80	0.39	NS	0.42	0.57	0.27	0.25
C X W	NS	NS	NS	S	NS	NS	NS	NS	NS	NS

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

At 60 DAS, under crop establishment methods, the total weed density and biomass were recorded higher in the conventional system (CT-CT-CT) with 76.8 no./m^2 and 45.8 g/m^2, respectively. The lowest total weed density and biomass were measured in ZTR-ZTR-ZTR with 62.5 no./m^2 and 31.1 g/m^2, respectively (Table 4 & 5). The weed density and biomass of *Avena ludo vicianaand Medicago polymorpha* were significantly higher in CT-CT-CT and lowest in ZTR-ZTR-ZTR, whereas *Digitaria sanguinalis*, *Cynodon dactylon*, *Chenopodium album* and *Sonchus oleraceus* were more noticeable under the ZTR-ZTR-ZTR system. In general, ZTR systems have more grassy weeds and CT systems have more broadleaf weeds (BLWs).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 238.3 no./m^2 and 139.5 g/m^2, respectively and the lowest in integrated weed management [IWM, clodinafop propargyl +metsulfuron-methyl at 60+4 g/ha (pre-mix) followed by (*fb*) hand weeding (HW)] followed by herbicide rotation [clodinafop propargyl +metsulfuron-methyl at 60+4 g/ha (pre-mix)] (Table5).Likewise, weed control efficiency (WCE, %) was recorded as being highest with ZTR-ZTR-ZTR(18.6%) over CT-CT-CT system. Likewise, the weed control index (WCI, %) followed the trend of the WCE and recorded the highest with ZTR-ZTR-ZTR (32.2%) over the CT-CT-CT system. Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 99.5 and 99.8%, respectively, followed by herbicide rotation and recommended herbicide over weedy check.

Table 5: 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/chickpea-greengram cropping system

Treatment	**Total grasses**	**Total broadleaf weeds**	**Total weeds**	**WCE (%)**
	Weed density (no./m^2)			
Crop establishment methods (C)				
CT-CT-CT	2.46(12.9)	6.11(63.9)	6.56(76.8)	-
ZTR-ZTR-ZTR	3.08(14.3)	5.23(48.3)	6.03(62.5)	18.6
SEm±	0.23	0.01	0.09	
CD (P=0.05)	NS	0.05	0.28	
Weed management practices (W)				
W1	6.76(46.2)	13.76(192.1)	15.32(238.3)	0.0
W2	2.22(5.8)	4.23(18.7)	4.84(24.5)	89.7
W3	0.71(0)	1.28(1.3)	1.28(1.3)	99.5
W4	1.38(2.3)	3.43(12.2)	3.75(14.5)	93.9
SEm±	0.35	0.39	0.44	

CD (p=0.05)	1.09	1.23	1.38	
C X W	NS	NS	NS	
	Weed biomass (g/m^2)			
Crop establishment methods (C)				
CT-CT-CT	1.93(7.2)	4.5(38.6)	4.81(45.8)	-
ZTR-ZTR-ZTR	2.02(6.1)	3.67(25)	4.09(31.1)	32.2
SEm±	0.11	0.06	0.09	
CD (P=0.05)	NS	0.37	0.59	
Weed management practices (W)				
W1	4.94(24.6)	10.6(115)	11.69(139.5)	0.0
W2	1.31(1.4)	2.71(7.3)	2.95(8.8)	93.7
W3	0.71(0)	0.89(0.3)	0.89(0.3)	99.8
W4	0.96(0.6)	2.14(4.6)	2.27(5.1)	96.3
SEm±	0.22	0.34	0.37	
CD (p=0.05)	0.67	1.06	1.16	
C X W	NS	NS	NS	

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

During the experimentation, between the crop establishment methods, population of wheat plants at 15 DAS was comparable, whereas plant height at harvest was more with ZTR-ZTR-ZTR. The leaf area, leaf area index (LAI), plant dry biomass, tillers per meter running length, spike length and test weight were comparatively more in ZTR-ZTR-ZTR but was statistically comparable to CT-CT-CT (Table 6).Among weed management practices, plant population, plant height at harvest, LAI, spike length and test weight were comparable between the weed management practices, whereas leaf area at 60 DAS, plant dry weight accumulation and tillers per meter running length were highest with IWM followed by herbicide rotation and recommended herbicides. The lowest growth and yield parameters were recorded with weedy check (Table 6). The interaction between crop establishment methods and weed management practices were non-significant.

Table 6: Effect of crop establishment methods and weed management practices on growth and yield parameters of wheat under rice-wheat/chickpea-greengram cropping system

Treatment	Plant population at 15 DAS	Plant height (cm)	Leaf area at 60 DAS	Leaf area index	Plant dry weight at 60 DAS	Tillers/m row	Spike length (cm)	Test weight
Crop establishment methods (C)								
CT-CT-CT	23.8	103.58	221.58	2.5	2.33	89.50	15.48	37.54
ZTR-ZTR-ZTR	23.6	107.18	267.67	3.0	2.52	97.57	15.84	37.99
SEm±	0.31	0.59	16.61	0.18	0.18	2.85	0.11	0.27
CD (p=0.05)	NS	3.87	NS	NS	NS	NS	NS	NS
Weed management practices (W)								
W1	23.9	103.50	189.78	2.1	2.03	47.50	14.87	36.63
W2	23.1	104.25	228.74	2.5	2.18	106.47	15.82	37.74
W3	24.1	107.38	293.99	3.3	2.78	110.73	16.10	38.32
W4	23.6	106.38	265.97	3.0	2.71	109.43	15.85	38.35
SEm±	0.93	1.29	26.71	0.30	0.23	2.45	30.00	0.51
CD (p=0.05)	NS	NS	80.13	NS	0.69	7.79	NS	NS
C X W	NS	NS	NS	NS	NS	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 (4002 kg/ha) which was significantly higher over the CT-CT-CT system (3588 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 7). Among weed management practices, weedy check has the lowest grain, straw and biological yields (2092, 4949 and 9503 kg/ha, respectively). The highest crop yields were obtained under IWM (4567, 6618 and 11185 kg/ha, respectively), followed by herbicide rotation and recommended herbicides (Table 7). The harvest index was 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 for grain, straw and biological yield, but the harvest index was non-significant.

Table 7: Effect of crop establishment methods and weed management practices on yields of wheat under rice-wheat/chickpea-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	3588.4	5915.2	9503.5	33.68
ZTR-ZTR-ZTR	4002.2	6272.5	10274.6	38.71
SEm±	90.15	286.76	370.78	1.22
CD (p=0.05)	387.08	NS	NS	3.65
Weed management practices (W)				
W1	2092.0	4948.9	7040.9	33.07
W2	4167.3	6329.9	10497.2	36.90
W3	4567.4	6617.8	11185.2	36.22
W4	4354.3	6478.7	10833.0	38.60
SEm±	124.25	311.29	353.65	2.31
CD (p=0.05)	387.08	969.81	1101.75	NS
C X W	704.16	1918.01	2604.75	NS

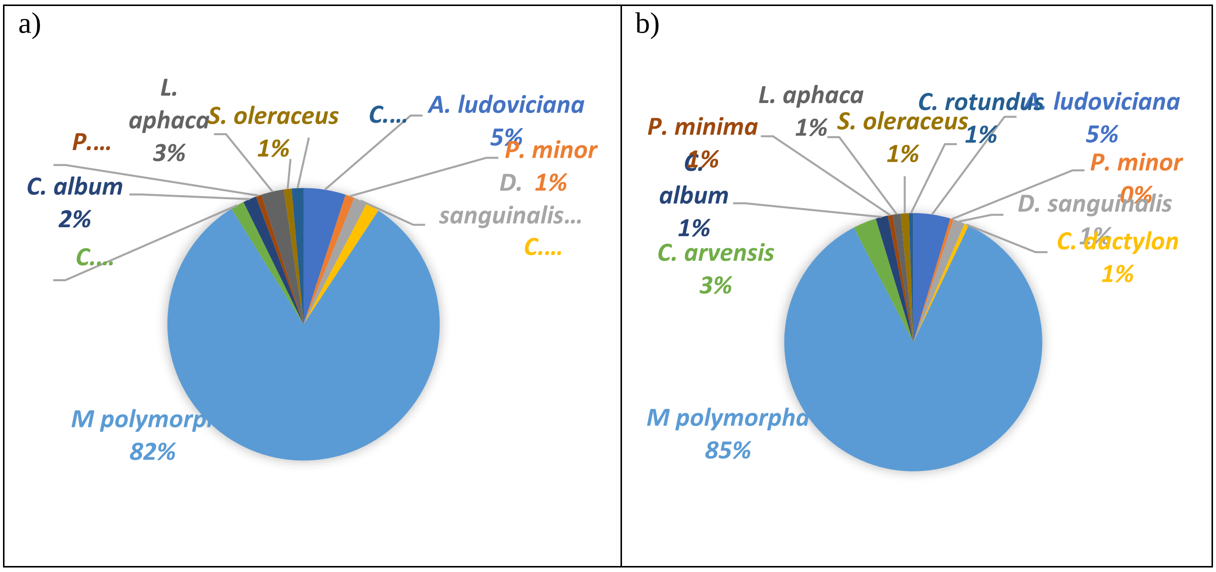


Fig 30: Relative density (a) and biomass (b) of weeds at 60 DAS in chickpea under rice-chickpea-greengram system

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 101.7 no./m^2 and 58.8 g/m^2, respectively. The lowest total weed density and biomass were measured in ZTR-ZTR-ZTR with 95.9 no./m^2 and 50.5 g/m^2, respectively(Table 8 & 9). The weed density and biomass of *Avenaludoviciana*, *Cynadon dactylon* *andSonchus oleraceus* weresignificantly higher in ZTR-ZTR-ZTR and lowest in CT-CT-CT, 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 (BLWs).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 249.5 no./m^2 and 164.2 g/m^2, respectively and the lowest in IWM (pendimethalin 678 g/ha *fb*HW) followed by herbicide rotation (pendimethalin 678 g/ha*fb* topramezone 20.16 g/ha) (Table 9). Likewise, WCE was better with the ZTR-ZTR-ZTR (5.7%) over CT-CT-CT system. Likewise, WCI followed the trend of WCE and recorded the highest with the ZTR-ZTR-ZTR (14.1%) over the CT-CT-CT system. Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 90.7 and 95.2%, respectively followed by herbicide rotation and recommended herbicide over weedy check.

Table 8: Effect of crop establishment methods and weed management practices on density and biomass of different weed species on chickpea at 60 DAS under rice-wheat/chickpea-greengram system

Treatment	**Grassy weeds**				**Sedges**	**Broadleaved weeds**					
	Avena ludoviciana	*Digitaria sanguinalis*	*Phalaris minor*	*Cynodon dactylon*	*Cyperus rotundus*	*Medicago denticulata*	*Lathyrus aphaca*	*Convolvulus arveni*	*Chenopodium album*	*Physalis minima*	*Sonchus oleraceus*
CT-CT-CT	2.54 (7.8)	1.08 (1.2)	0.96 (1.2)	1.24 (1.7)	1.6 (4.9)	7.83 (75.3)	1.64 (2.9)	1.85 (4.3)	1.01 (1)	0.88 (0.4)	1.14 (1)
ZTR-ZTR-ZTR	3.16 (13.9)	1.24 1.7)	1.01 (0.8)	1.55 (2.6)	0.71 (0)	7.51 (70.5)	1.22 (1.6)	1.5 (2.4)	0.94 (0.7)	0.82 (0.3)	1.29 (1.5)
SEm±	0.39	0.07	0.08	0.08	0.42	0.11	0.05	0.11	0.15	0.09	0.06
CD (P=0.05)	NS	NS	NS	0.24	NS	NS	0.31	NS	NS	NS	NS
W1	4.26 (18.8)	2.15 (4.7)	1.28 (2.2)	2.28 (5.3)	1.14 (1.8)	14.13 (200.3)	2.28 (5.3)	1.86 (3.7)	1.78 (3.3)	1.28 (1.3)	1.79 (2.8)
W2	3.33 (14)	1.09 (1)	0.94 (0.7)	1.32 (1.7)	1.14 (1.8)	6.04 (36.2)	1.41 (2)	2.09 (5.2)	0.71 (0)	0.71 (0)	1.11 (0.8)
W3	0.71(0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	4.83 (23.3)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
W4	3.13 (10.7)	0.71 (0)	1.03 (1.2)	1.28 (1.5)	1.62 (6.3)	5.67 (31.8)	1.33 (1.7)	2.05 (4.7)	0.71 (0)	0.71 (0)	1.26 (1.3)
SEm±	0.49	0.22	0.17	0.26	0.53	0.34	0.09	0.38	0.21	0.11	0.12
CD (p=0.05)	1.54	0.69	0.51	0.81	NS	1.07	0.81	1.15	0.62	0.34	0.36
C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CT-CT-CT	1.8 (3.5)	0.97 (0.7)	0.79 (0.3)	0.9 (0.4)	2.07 (4.9)	5.52 (44.9)	1.06 (0.7)	2.05 (5.6)	0.94 (0.7)	0.83 (0.3)	0.99 (0.6)
ZTR-ZTR-ZTR	2.17 (6)	0.96 (0.6)	0.79 0.2)	1.01 (0.6)	2.41 (7.4)	5.11 (38.6)	0.9 (0.4)	1.62 (3)	0.85 (0.3)	0.76 (0.1)	1.02 (0.7)
SEm±	0.22	0.04	0.02	0.04	0.21	0.08	0.02	0.13	0.09	0.05	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	0.24	0.16	0.39	NS	NS	NS
W1	3.39 (11.6)	1.58 (2.3)	0.9 (0.5)	1.29 (1.3)	3.99 (15.8)	11.7 (137.4)	1.32 (1.4)	2.05 (4.6)	1.44 (1.9)	1.05 (0.7)	1.52 (1.9)

W2	2(4.3)	0.85 (0.3)	0.76 (0.1)	0.91 (0.4)	2.22 (5.1)	3.55 (12.1)	0.97 (0.5)	2.32 (6.6)	0.71 (0)	0.71 (0)	0.89 (0.3)
W3	0.71(0)	0.71(0)	0.71 (0)	0.71 (0)	0.71 (0)	2.87 (7.9)	0.71 (0)	0.71(0)	0.71(0)	0.71 (0)	0.71 (0)
W4	1.84 (3.2)	0.71 (0)	0.79 (0.2)	0.91 (0.4)	2.03 (3.8)	3.15 (9.5)	0.93 (0.4)	2.27 (6)	0.71 (0)	0.71 (0)	0.9 (0.3)
SEm±	0.25	0.15	0.04	0.09	0.21	0.25	0.10	0.44	0.14	0.07	0.06
CD (p=0.05)	0.78	0.47	0.13	0.30	0.64	0.78	0.31	NS	0.44	0.21	0.19
C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

W1: control (weedy check); W2: recommended herbicide (pendimethalin+imazethapyr 1.0 kg/ha fb topramezone 20.16 g/ha); W3: integrated weed management [pendimethalin 678 g/ha *fb* hand weeding (30 DAS)]; W4: herbicide rotation (pendimethalin 678 kg/ha *fb* topramezone 20.16 g/ha)

Table 9: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 60 DAS in chickpea under rice-wheat/chickpea-greengram cropping system

Treatment	**Total grasses**	**Total broadleaf weeds**	**Total sedges**	**Total weeds**	**WCE (%)**
	Weed density (no./m^2)				
Crop establishment methods (C)					
CT-CT-CT	3.13(11.8)	8.37(85)	1.6(4.9)	9.26(101.7)	-
ZTR-ZTR-ZTR	3.78(19)	7.88(76.9)	0.71(0)	8.84(95.9)	5.7
SEm±	0.31	0.09	0.42	0.39	
CD (p=0.05)	NS	0.27	NS	NS	
Weed management practices (W)					
W1	5.54(30.9)	14.7(216.8)	1.14(1.8)	15.78(249.5)	0.0
W2	3.92(17.3)	6.67(44.2)	1.14(1.8)	7.91(63.3)	74.6
W3	0.71(0)	4.83(23.3)	0.71(0)	4.83(23.3)	90.7
W4	3.65(13.3)	6.31(39.5)	1.62(6.3)	7.69(59.1)	76.3
SEm±	0.39	0.35	0.53	0.37	
CD (p=0.05)	1.21	1.09	NS	1.15	
C X W	NS	NS	NS	NS	
	Weed biomass (g/m^2)				
Crop establishment methods (C)					
CT-CT-CT	2.07(4.9)	6.21(52.7)	1.09(1.2)	6.64(58.8)	-
ZTR-ZTR-ZTR	2.41(7.4)	5.52(43.1)	0.71(0)	6.03(50.5)	14.1
SEm±	0.21	0.04	0.18	0.18	
CD (p=0.05)	NS	0.24	NS	NS	
Weed management practices (W)					
W1	3.99(15.8)	12.13(147.9)	0.89(0.5)	12.8(164.2)	0.0
W2	2.22(5.1)	4.42(19.6)	0.89(0.5)	5.01(25.1)	84.7
W3	0.71(0)	2.87(7.9)	0.71(0)	2.87(7.9)	95.2
W4	2.03(3.8)	4.04(16.2)	1.1(1.5)	4.67(21.5)	86.9
SEm±	0.21	0.32	0.23	0.28	
CD (p=0.05)	0.64	1.01	NS	0.86	
C X W	NS	NS	NS	NS	

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

Between the crop establishment methods, the populations of chickpea plants at 15 DAS and at harvest were comparable, where plant height at harvest and leaf area at 60 DAS were higher with the CT-CT-CT system.

Contrarily, pods/plant, seeds/plant and seed index were significantly higher with the ZTR-ZTR-ZTR system. But, plant dry weight, branches/plant and seeds/pod were statistically comparable between the crop establishment methods (Table 10). Among weed management practices, plant population were comparable, whereas plant population at harvest, leaf area at 60 DAS, plant dry weight accumulation, branches/plant, pods/plant, seeds/pod and plant 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 10). The interaction between crop establishment methods and weed management practices was non-significant.

Table 10: Effect of crop establishment methods and weed management practices on growth and yield parameters of chickpea under rice-wheat/chickpea-greengram cropping system

Treatment	**Plant population at 15 DAS**	**Plant population at harvest**	**Plant height (cm)**	**Leaf area at 60 DAS**	**Plant dry weight at 60 DAS**	**Branches/plant at 60 DAS**	**Pods /plant**	**Seeds /plant**	**Seeds/pod**	**Seed index**
Crop establishment methods (C)										
CT-CT-CT	10.0	8.1	61.09	318.76	4.41	4.13	57.08	99.92	1.67	16.11
ZTR-ZTR-ZTR	9.5	7.8	56.61	269.90	4.59	4.50	58.88	107.17	1.74	16.45
SEm±	0.60	0.38	0.74	9.55	0.19	0.10	0.34	2.27	0.03	0.04
CD (p=0.05)	NS	NS	4.82	28.36	NS	NS	1.01	6.80	NS	0.26
Weed management practices (W)										
W1	9.5	4.8	56.75	222.53	2.89	2.15	19.33	26.17	1.36	15.42
W2	9.7	8.4	57.32	294.06	4.82	4.88	68.50	122.00	1.78	16.52
W3	10.0	9.5	61.40	349.41	5.27	5.33	74.83	136.50	1.82	16.68
W4	9.8	9.0	59.93	311.31	5.03	4.90	69.25	129.50	1.87	16.50
SEm±	0.45	0.34	1.80	42.28	0.40	0.15	1.30	2.40	0.02	0.07
CD (p=0.05)	NS	105	NS	125.95	1.24	0.46	4.04	7.57	0.07	0.22
C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

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

Between the crop establishment methods, the chickpea yields (seed, haulm and biological yield) and harvest index were statistically at par. 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 1.11). Among weed management practices, weedy check has the lowest grain, straw and biological yields (236, 849 and 1086 kg/ha, respectively). The highest crop yields were obtained under IWM (2337, 4323 and 6666 kg/ha, respectively) followed by herbicide rotation and recommended herbicides (Table 11). 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 11: Effect of crop establishment methods and weed management practices on yields of chickpea under rice-wheat/chickpea-greengram cropping system

Treatment	Seed yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Crop establishment methods (C)				
CT-CT-CT	1834.5	3577.5	5412.0	31.1
ZTR-ZTR-ZTR	1700.0	3435.3	5135.3	31.6
SEm±	52.80	143.09	201.78	1.34
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	236.3	849.3	1085.7	22.7
W2	2212.8	4521.5	6734.3	32.9
W3	2336.8	4323.2	6660.0	35.2
W4	2283.0	4331.7	6614.7	34.6
SEm±	74.67	202.35	248.08	1.01
CD (p=0.05)	228.68	619.72	772.89	3.15
C X W	NS	NS	NS	NS

Greengram-2022

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

At 45 days after sowing (DAS), the relative weed density in greengram under the study area was *Echinochloacolona* (31%),*Cyperusrotundus* (25%), *Digitaria sanguinalis* (10%), *Dinebra retroflexa* (9%), *Cyperusrotundus* (9%), *Physalis minima*(6%), *Amaranthus viridis* (5%) and other weeds like *Alternanthera sessilis*, *Phyllanthus sp. Eleucine indica*, *Cynadon dactylon etc.* Likewise, relative weed biomass recorded the highest for *Echinochloacolona* (51%),*Cyperusrotundus* (10%), *Digitaria sanguinalis* (7%), *Dinebra retroflexa* (7%), and other weeds (Fig 31).

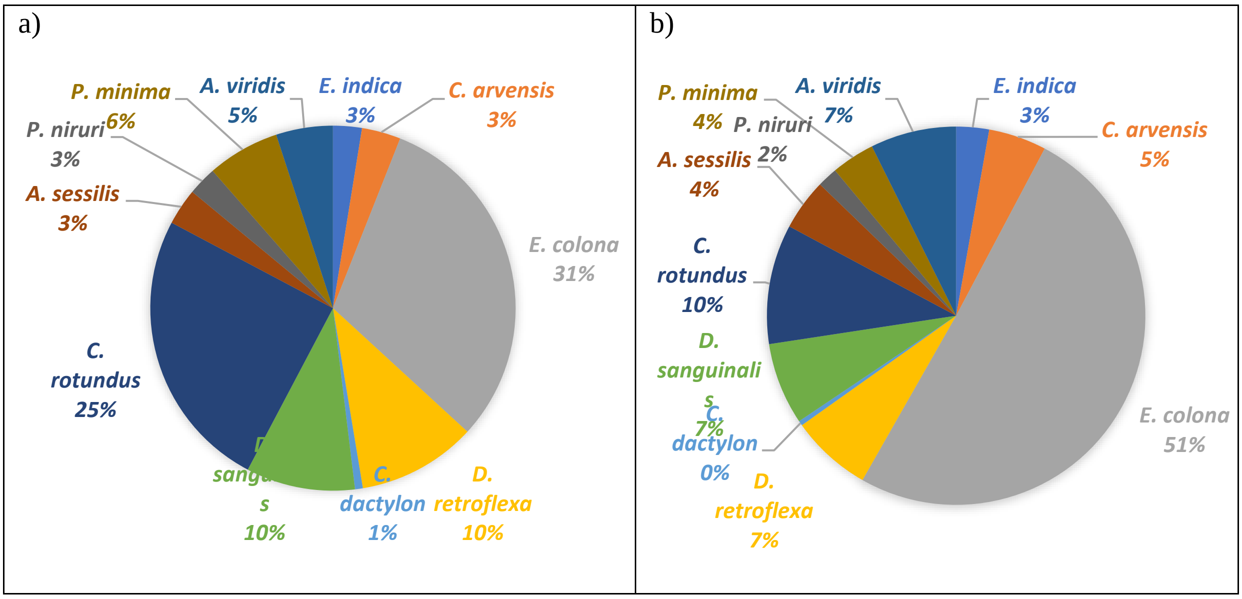


Fig 31: Relative weed density (a) and biomass (b) in greengram with rice-wheat-greengram system

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 conventional system (CT-CT-CT) with 53.8 no./m^2 and 36.2 g/m^2, respectively. The lowest total weed density and biomass were measured in the ZTR-ZTR-ZTR with 50.9 no./m^2 and 29.4 g/m^2, respectively (Table 12 & 13). The weed density and biomass of *E.colona were higher in the CT system,* *whereas the rest of the grassy weeds were higher in the ZTR system. All the broadleaf weeds except A. sessilis and Cyperus sp. were more common in the CT system than the ZT system.* In general, ZTR systems have more grassy weeds and CT systems have more of broadleaf weeds (BLWs) and sedges. Likewise, WCE was better with ZTR-ZTR-ZTR(5.4%) over CT-CT-CT system. WCI followed the trend of WCE and recorded the highest with ZTR-ZTR-ZTR (18.6%) over the CT-CT-CT system (Figure 32).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 142.2 no./m^2 and 108.7 g/m^2, respectively and the lowest in IWM (pendimethalin 678 g/ha *fb*HW) followed by herbicide rotation (pendimethalin 678 g/ha*fb* imazethapyr 100 g/ha) (Table 12 & 13). Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 93.2 and 98.0%, respectively followed by herbicide rotation and recommended herbicide over weedy check (Fig 32).

Table 12: Effect of crop establishment methods and weed management practices on weed density and biomass of weeds at 45 DAS in greengram under rice-wheat/chickpea-greengram cropping system

Treatment	***Grassy weeds***							***Broadleaved weeds***						***Sedge***
	E. colona	***D. retroflexa***	***D. sanguinalis***	***E. indica***	***D. annulatum***	***C. dactylon***		***P. niruri***	***A. viridis***	***A. sessilis***	***P. minima***	***C. arvenisis***		***C. difformis***
Weed density (no./m^2)														
Crop establishment methods (C)														
CT-CT-CT	2.99(13.3)	2.3(6.2)	2.13(5.1)	1.47(2.0)	0.71(0.0)	1.15(1.1)		1.3(1.5)	1.71(3.1)	1.09(1.2)	1.41(2.6)	1.71(2.8)		3.63(15)
ZT+R-ZT+R-ZT+R	2.59(9.5)	2.49(8.3)	2.66(8.2)	1.54(2.8)	1.64(2.1)	1.24(1.3)		0.71(0.0)	1.12(1.1)	2.08(5.3)	0.92(0.5)	1.34(1.6)		2.87(10.3)
SEm±	0.14	0.04	0.17	0.16	0.16	0.24		0.09	0.9	0.16	0.07	0.06		0.16
CD (p=0.05)	NS	NS	NS	NS	0.95	NS		0.58	0.58	1.04	0.43	NS		NS
Weed management practices (W)														
W1	6.16(38.2)	4.38(19.3)	4.22(17.7)	2.51(6.2)	1.31(2.2)	1.11(0.8)		1.36(1.8)	2.18(4.8)	3.02(9.5)	2.34(5.7)	1.85(3.3)		5.67(32.7)
W2	1.95(3.5)	2.36(5.8)	2.21(4.7)	1.47(2.0)	1.27(1.2)	1.75(2.8)		1(0.7)	1.33(1.7)	1.39(2.0)	0.9(0.5)	1.76(2.7)		2.78(7.3)
W3	1.41(1.7)	1.23(1.2)	1.38(1.5)	0.85(0.3)	0.71(0.0)	0.07(0.0)		0.79(0.2)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.98(0.8)		2(4)
W4	1.62(2.3)	1.6(2.5)	1.76(2.7)	1.19(1.2)	1.41(0.8)	1.22(1.2)		0.85(0.3)	1.43(1.8)	1.23(1.3)	0.71(0.0)	1.51(2.0)		2.54(6.7)
SEm±	0.26	0.35	0.13	0.23	0.33	0.14		0.13	0.23	0.13	0.13	0.22		0.25
CD (p=0.05)	0.8	1.08	0.41	0.71	NS	0.45		0.39	0.72	0.41	0.42	NS		0.78
C x W	NS	NS	NS	NS	NS	NS		S	NS	S	S	NS		NS
Weed biomass (g/m^2)														
Crop establishment methods (C)														
CT-CT-CT	2.94(16.4)	1.61(2.9)	1.54(2.6)	1.21(1.2)	0.71(0)	0.95(0.5)		1.05(0.7)	1.67(3.2)	1.13(1.3)	1.13(1.2)	1.48(2.2)		1.85(1.3)

ZT+R-ZT+R-ZT+R	2.4(10.1)	1.71(3.7)	1.75(3.5)	1.4(2.4)	1.22(1.3)	0.95(0.5)		0.71(0)	1.08(1)	1.74(3.8)	0.82(0.2)	1.11(0.9)		1.47(0.6)
SEm±	0.16	0.04	0.09	0.04	0.09	0.12		0.04	0.08	0.12	0.07	0.05		0.08
CD (p=0.05)	NS	NS	NS	NS	NS	NS		0.23	0.5	NS	0.24	0.34		NS
Weed management practices (W)														
W1	6.92(2)	3.24(2)	3.15(1.7)	2.46(0.9)	1.3(0.5)	0.94(1.1)		1.15(0.3)	2.34(1.7)	2.94(0.9)	1.69(0.2)	1.95(1.2)		3.09(1.3)
W2	1.54(0.7)	1.51(0.3)	1.45(0.3)	1.13(0.1)	0.98(0)	1.25(0)		0.86(0)	1.33(0)	1.1(0)	0.8(0)	1.3(0.3)		1.32(0.6)
W3	1.05(1)	0.86(0.7)	0.91(0.6)	0.75(0.3)	0.71(0.3)	0.71(0.3)		0.73(0.1)	0.71(0.9)	0.71(0.6)	0.71(0)	0.84(0.8)		1.01(1.1)
W4	1.18(0)	1.05(0)	1.06(0)	0.87(0)	0.87(0)	0.9(0)		0.77(0)	1.14(0)	0.99(0)	0.71(0)	1.11(0)		1.22(0)
SEm±	0.31	0.17	0.08	0.14	0.1	0.07		0.07	0.22	0.12	0.07	0.16		0.13
CD (p=0.05)	0.97	0.53	0.25	0.44	0.3	0.23		0.22	0.69	0.38	0.23	0.5		0.41
C x W	NS	NS	NS	S	S	NS		S	NS	S	S	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* imazethapyr 100 g/ha)

Table 13: 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/chickpea-greengram cropping system

Treatment	Total grasses	Total broadleaf weeds	Total sedges	Total weeds
Weed density (no./m^2)				
Crop establishment methods (C)				
CT-CT-CT	4.62(27.7)	2.96(11.2)	3.63(15)	6.6(53.8)
ZT+R-ZT+R-ZT+R	5(32.2)	2.64(8.4)	2.87(10.3)	6.29(50.9)
SEm±	0.08	0.23	0.16	0.03
CD (p=0.05)	NS	NS	NS	0.19
Weed management practices (W)				
W1	9.2(84.3)	5.02(25.2)	5.67(32.7)	11.93(142.2)
W2	4.49(20)	2.73(7.5)	2.78(7.3)	5.92(34.8)
W3	2.25(4.7)	1.07(1)	2(4)	3.15(9.7)
W4	3.29(10.7)	2.39(5.5)	2.54(6.7)	4.78(22.8)
SEm±	0.22	0.28	0.25	0.21
CD (p=0.05)	0.68	0.88	0.78	0.6
C x W	NS	NS	NS	NS
Weed biomass (no./m^2)				
Crop establishment methods (C)				
CT-CT-CT	3.77(23.6)	2.5(8.6)	1.85(4)	4.82(36.2)
ZT+R-ZT+R-ZT+R	3.7(21.4)	2.16(5.9)	1.47(2.2)	4.4(29.4)
SEm±	0.12	0.16	0.08	0.11
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	8.78(77.2)	4.7(22.0)	3.09(9.5)	10.42(108.7)
W2	2.93(8.2)	2.09(4.2)	1.32(1.3)	3.75(13.7)
W3	1.33(1.3)	0.87(0.3)	1.01(0.6)	1.62(2.2)
W4	1.89(3.2)	1.65(2.3)	1.22(1.1)	2.64(6.6)
SEm±	0.23	0.2	0.13	0.21
CD (p=0.05)	0.7	0.62	0.41	0.67
C x W	NS	NS	NS	NS

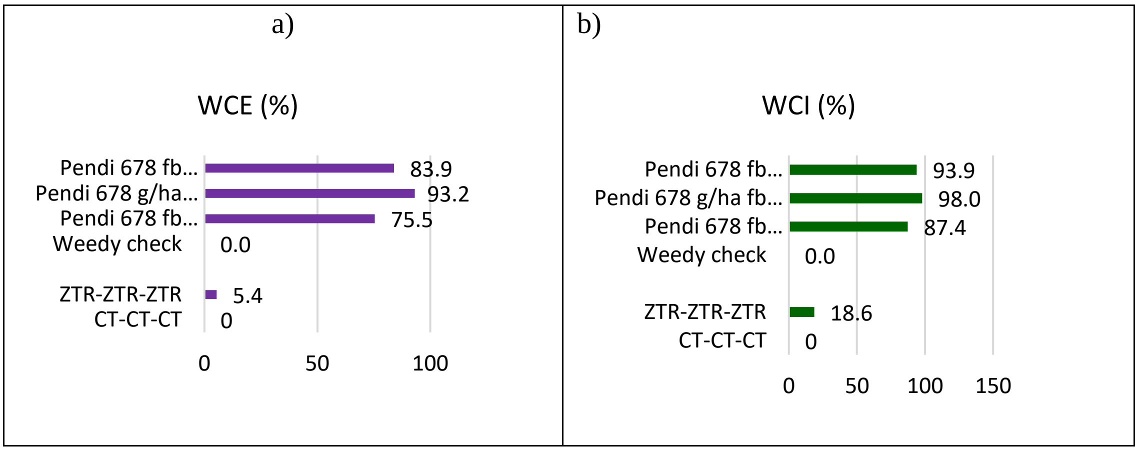


Fig 32: Weed control efficiency (a) and weed control index (b) in greengram under rice-wheat-greengram system

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

Between the crop establishment methods, plant height at harvest, leaf area and plant biomass were higher with the ZTR-ZTR-ZTR system but comparable to the CT-CT-CT system, whereas branches/plant was significantly higher with the ZTR-ZTR-ZTR system. Similarly, yield attributes, except seeds/pod pods/plant, pod length and test weight were statistically significant in the ZTR-ZTR-ZTR system over the CT-CT-CT system (Table 14).

Among weed management practices, all the growth parameters viz. plant height, leaf area, 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 14). The interaction between crop establishment methods and weed management practices was found to be non-significant for growth and yield parameters.

Table 14: Effect of crop establishment methods and weed management practices on growth parameters and yield attributes of greengram under rice-wheat/chickpea-greengram cropping system

Treatment	**Growth parameters**			
	Plant height (cm)	**Leaf area (cm^2/plant)**	**Plant biomass (g/plant)**	**Branches/plant**
Crop establishment methods (C)				
CT-CT-CT	71.12	1459.81	35.01	5.13
ZT+R-ZT+R-ZT+R	74.75	1546.47	37.99	7.44
SEm±	0.92	23.93	0.68	0.16
CD (p=0.05)	NS	NS	NS	1.03
Weed management practices (W)				
W1	63.76	762.46	22.90	4.16
W2	71.82	1383.18	37.36	5.68
W3	79.28	1989.92	43.13	8.20
W4	76.87	1877.00	42.60	7.09
SEm±	1.44	88.36	1.02	0.27
CD (p=0.05)	4.45	275.29	3.17	0.83
C x W	NS	NS	1.37	1.36
	Yield attributes			
	Pods/plant	**Seeds/pod**	**Pod length (cm)**	**Test weight (g)**
Crop establishment methods (C)				
CT-CT-CT	33.08	10.00	9.44	39.39
ZT+R-ZT+R-ZT+R	39.08	10.50	10.33	41.71
SEm±	0.10	0.10	0.07	0.32
CD (p=0.05)	0.67	NS	0.49	2.11
Weed management practices (W)				
W1	18.00	8.17	7.73	36.92
W2	35.50	10.17	9.10	39.93
W3	46.67	11.50	11.77	43.38
W4	44.17	11.17	10.93	41.96
SEm±	1.27	0.47	0.20	0.76
CD (p=0.05)	3.96	1.46	0.63	2.38
C x W	NS	NS	NS	NS

Seed and haulm yield of Greengram

Between the crop establishment methods, the greengram yields (seed, haulm and biological yield) and harvest index were statistically significant and recorded a higher value with the ZTR-ZTR-ZTR system. The highest seed yield (985 kg/ha), haulm yield (2656 kg/ha) and biological yield (3640.8 kg/ha) were higher with the ZTR-ZTR-ZTR system, but the harvest index was higher in the CT-CT-CT 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 15). Among weed management practices, weedy check has the lowest seed, haulm and biological yields (331, 1236 and 1567 kg/ha, respectively). The highest crop yields were obtained under IWM (1244, 2722 and 3966 kg/ha, respectively) followed by herbicide rotation and recommended herbicides (Table 15). 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 seed yield and the rest were significant.

Table 15: Effect of crop establishment methods and weed management practices on yield of greengram under rice-wheat/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	866.2	2084.6	2950.8	27.4
ZT+R-ZT+R-ZT+R	984.6	2656.1	3640.8	26.5
SEm±	12.15	57.46	69.57	0.14
CD (p=0.05)	79.60	376.43	455.77	0.89
Weed management practices (W)				
W1	330.5	1236.3	1566.9	20.4
W2	936.0	2483.2	3419.2	27.4
W3	1243.9	2721.7	3965.6	31.7
W4	1191.3	3040.3	4231.6	28.3
SEm±	24.75	51.00	70.00	0.58
CD (p=0.05)	77.09	158.90	218.07	1.80
C x W	NS	338.30	443.45	2.64

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

At 45 days after sowing (DAS), the relative weed density in greengram under the study area was *Cyperusrotundus* (38%), *Echinochloacolona* (27%), *Dinebra retroflexa* (11%), *Digitaria sanguinalis* (8%), *Eleucine indica* (4%), and other weeds like, *Alternanthera sessilis, Phyllanthus sp. Amaranthus viridis, Cynadon dactylon, Convolvulus arvensis etc.* Likewise, relative weed biomass recorded the highest for *Echinochloacolona* (48%),*Cyperusrotundus* (19%), *Dinebra retroflexa* (8%), *Digitaria sanguinalis* (7%),and other weeds (Fig 33).

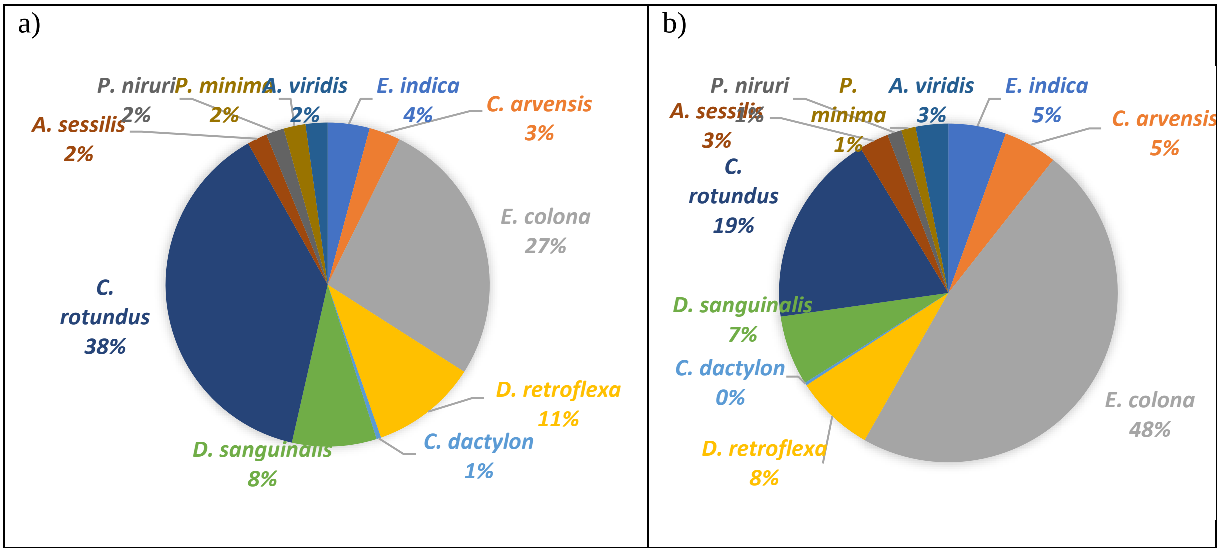


Fig 33: Relative weed density (a) and biomass (b) in greengram with rice-chickpea-greengram system

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 weed density in the ZT system was 52.8 no./m^2 and biomass was higher in the CT system (32.9 g/m^2) (Table 16 & 17). The weed density and biomass of *E. colona was more in CT system, whereas rest of the grassy weeds were more with ZTR system. All the broadleaf weeds and sedges except A. sessilis were more in the CT system than the ZT system.* In general, ZTR systems have more grassy weeds and CT systems have more broadleaf weeds (BLWs) and sedges. Likewise, the WCE comparable between both systems, while WCI recorded 19.0% more with

ZTR-ZTR-ZTR (Figure 1.40). Among weed management practices, weedy check recorded the highest total weed density and biomass with 151.8 no./m^2 and 97.9 g/m^2, respectively and the lowest in IWM (pendimethalin 678 g/ ha *fb* H W) followed by herbicide rotation (pendimethalin 678 g / ha *fb* imazethapyr 100 g / ha) (Table 16 & 17). Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 97.1 and 98.8%, respectively followed by herbicide rotation and recommended herbicide over weedy check (Fig 34**)**

Table 16: 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**
	E. colona	***D. retroflexa***	***D. sanguinalis***	***E. indica***	***D. annulatum***	***C. dactylon***	***P. niruri***	***A. viridis***	***A. sessilis***	***P. minima***	***C. arvenisis***	***C. difformis***
Weed density (no./m^2)												
Crop establishment methods (C)												
CT-CT-CT	2.58(11.3)	2.08(5.5)	2.01(4.7)	1.37(2.1)	0.71(0)	0.94(0.5)	1.28(2.6)	1.34(1.7)	0.99(0.8)	1.17(1.2)	2.02(4.3)	3.29(17.2)
ZT+R-ZT+R-ZT+R	2.46(8.9)	2.44(7.9)	2.52(7.7)	1.58(2.9)	1.92(3.8)	1.16(1.1)	0.71(0.5)	1.11(0.9)	1.38(2)	0.91(0.4)	1.76(3.3)	2.42(11)
SEm±	0.07	0.14	0.1	0.07	0.1	0.06	0.13	0.03	0.03	0.06	0.17	0.09
CD (p=0.05)	NS	NS	NS	NS	0.64	NS	NS	0.17	0.19	NS	NS	0.59
Weed management practices (W)												
W1	4.37(19)	4.12(16.8)	2.74(7.2)	1.41(2)	1.17(1)	4.37(19)	1.24(5.7)	1.59(2.5)	2.2(4.5)	1.56(2.2)	2.09(4.3)	7.01(49.3)
W2	2.42(5.5)	2.1(4.3)	1.75(2.8)	1.58(2.8)	1.34(1.5)	2.42(5.5)	0.94(0.5)	1.48(1.8)	1.13(1)	1.2(1)	2.24(5.3)	2.05(4.3)
W3	0.71(0)	1.28(1.3)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	1.31(2)	0.71(0)
W4	1.56(2.3)	1.56(2.2)	0.71(0)	1.55(2.7)	0.99(0.7)	1.56(2.3)	1.09(0)	1.11(0.8)	0.71(0)	0.71(0)	1.93(3.7)	1.65(2.7)
SEm±	0.18	0.18	0.13	0.05	0.17	0.18	0.11	0.19	0.06	0.1	0.36	0.24
CD (p=0.05)	0.57	0.57	0.41	0.16	NS	0.57	0.34	0.6	0.2	0.31	NS	0.73
C x W	NS	NS	NS	S	NS	NS	S	NS	S	NS	NS	NS
Weed biomass (g/m^2)												
Crop establishment methods (C)												

CT-CT-CT	2.62(13.6)	1.5(2.5)	1.45(2.3)	1.27(1.7)	0.71(0)	0.84(0.2)		1.01(1.2)	1.27(1.5)	1(0.8)	0.95(0.5)	1.65(2.7)		1.91(5.5)
ZT+R-ZT+R-ZT+R	2.28(8.8)	1.66(3.3)	1.66(3.2)	1.32(1.9)	1.53(2.1)	0.9(0.4)		0.71(0.2)	1(0.6)	1.23(1.5)	0.8(0.2)	1.34(1.6)		1.4(2.6)
SEm±	0.09	0.07	0.05	0.04	0.07	0.08		0.06	0.03	0.02	0.03	0.06		0.04
CD (p=0.05)	NS	NS	NS	NS	0.43	NS		NS	0.17	0.11	NS	NS		0.26
Weed management practices (W)														
W1	6.48(1.7)	3.14(1.7)	3(1.5)	2.48(1.3)	1.32(1.4)	0.96(0.6)		1.05(0.2)	1.55(1.5)	2.1(0.4)	1.18(0.3)	2.04(2.5)		3.87(0.7)
W2	1.49(0)	1.48(0)	1.37(0.3)	1.29(0)	1.26(0)	1.02(0)		0.82(0)	1.38(0)	0.94(0)	0.9(0)	1.63(0.6)		1.09(0)
W3	0.71(0.9)	0.71(0.5)	0.87(0.5)	0.71(0)	0.71(1.1)	0.71(0.2)		0.71(0)	0.71(0.4)	0.71(0)	0.71(0)	0.98(1.4)		0.71(0.4)
W4	1.12(0)	0.99(0)	0.99(0)	0.71(0)	1.19(0)	0.8(0)		0.87(0)	0.91(0)	0.71(0)	0.71(0)	1.34(0)		0.96(0)
SEm±	0.16	0.1	0.09	0.15	0.04	0.08		0.05	0.17	0.05	0.05	0.25		0.09
CD (p=0.05)	0.51	0.31	0.27	0.48	0.12	NS		0.16	0.53	0.16	0.15	NS		0.28
C x W	S	NS	NS	NS	S	NS		S	NS	S	S	NS		0.08

W1: 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* imazethapyr 100 g/ha)

Table 17: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 45 DAS in greengram under rice-chickpea-greengram cropping system

Treatment	Total grasses	Total broadleaf weeds	Total sedges	Total weeds
Weed density (no./m²)				
Crop establishment methods (C)				
CT-CT-CT	3.99(24)	2.83(9.3)	3.29(17.2)	6.02(51.8)
ZT+R-ZT+R-ZT+R	4.89(32.3)	2.45(6.7)	2.42(11)	6.25(52.8)
SEm±	0.1	0.23	0.09	0.17
CD (p=0.05)	0.67	NS	0.59	NS
Weed management practices (W)				
W1	9(80.8)	3.88(14.8)	7.01(49.3)	12.33(151.8)
W2	4.47(20.3)	3.1(9.7)	2.05(4.3)	5.96(35.3)
W3	1.28(1.3)	1.31(2)	0.71(0)	2.1(4.4)
W4	3.03(10)	2.27(5.5)	1.65(2.7)	4.14(17.7)
SEm±	0.27	0.32	0.24	0.24
CD (p=0.05)	0.85	0.99	0.73	0.75
C x W	NS	NS	NS	NS
Weed biomass (no./m²)				
Crop establishment methods (C)				
CT-CT-CT	3.34(20.4)	2.27(6.1)	1.91(5.5)	4.41(32.9)
ZT+R-ZT+R-ZT+R	3.6(19.7)	1.88(3.9)	1.4(2.6)	4.26(26.6)
SEm±	0.07	0.12	0.04	0.05
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	8.28(68.6)	3.52(12.2)	3.87(15.0)	9.87(97.9)
W2	2.9(8.2)	2.28(5.0)	1.09(0.7)	3.84(14.4)
W3	0.87(0.3)	0.98(0.6)	0.71(0.0)	1.25(1.2)
W4	1.83(3.2)	1.53(2.1)	0.96(0.4)	2.37(5.5)
SEm±	0.19	0.21	0.09	0.2
CD (p=0.05)	0.6	0.64	0.28	0.62
C x W	S	NS	S	S

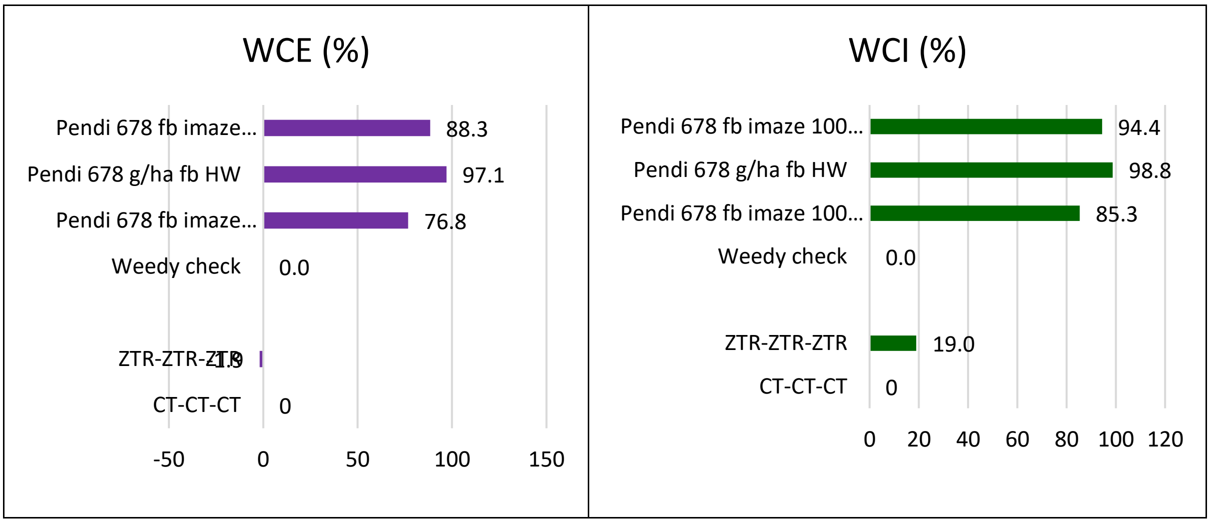


Fig 34: Weed control efficiency and weed control index of greengram under rice-chickpea-greengram system

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

Between the crop establishment methods, plant height at harvest and plant biomass were higher with the ZTR-ZTR-ZTR system but comparable to the CT-CT-CT system. Whereas, leaf area and branches/plant were significantly more with the ZTR-ZTR-ZTR system. Similarly, except pod/plant, all other yield parameters like seeds/pods, pod length and test weight were statistically significant in the ZTR-ZTR-ZTR system over the CT-CT-CT system (Table 18).

Among weed management practices, all the growth parameters, viz. plant height, leaf area, plant biomass and no. of 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 (Table18). The interaction between crop establishment methods and weed management practices was found to be non-significant for growth and yield parameters.

Table 18: Effect of crop establishment methods and weed management practices on growth parameters and yield attributes of greengram under rice-wheat/chickpea-greengram cropping system

Treatment	**Growth parameters**			
	Plant height (cm)	**Leaf area (cm^2/plant)**	**Plant biomass (g/plant)**	**Branches/plant**
Crop establishment methods (C)				
CT-CT-CT	72.84	1542.06	37.43	5.80
ZT+R-ZT+R-ZT+R	76.66	1863.62	45.25	8.38
SEm±	1.50	34.80	1.52	0.17
CD (p=0.05)	NS	227.95	NS	1.14
Weed management practices (W)				
W1	68.74	724.34	30.45	4.60
W2	72.57	1439.20	35.43	6.42
W3	80.43	2391.38	51.25	9.49
W4	77.25	2256.44	48.24	7.85
SEm±	0.99	63.10	1.33	0.22
CD (p=0.05)	3.08	196.59	4.15	0.69
C x W	7.27	NS	NS	1.29
	Yield attributes			
	Pods/plant	**Seeds/pod**	**Pod length (cm)**	**Test weight (g)**
Crop establishment methods (C)				
CT-CT-CT	32.58	10.50	9.75	39.74
ZT+R-ZT+R-ZT+R	42.17	11.17	10.62	42.57
SEm±	2.43	0.06	0.07	0.59
CD (p=0.05)	NS	0.37	0.48	NS
Weed management practices (W)				
W1	21.33	9.17	8.03	37.95
W2	36.18	10.51	9.42	39.92
W3	47.33	12.17	12.08	43.89
W4	44.67	11.50	11.22	42.87
SEm±	2.39	0.29	0.19	0.49
CD (p=0.05)	7.44	0.89	0.61	1.53
C x W	NS	NS	NS	NS

Seed and haulm yield of Greengram

The crop establishment methods and weed management practices significantly influenced the seed, haulm, biological yield and harvest index of greengram. Between the crop establishment methods, the greengram yields (seed, haulm and biological yield) were statistically significant and recorded a higher value with the ZTR-ZTR-ZTR system. The highest seed yield (1095 kg/ha), haulm yield (2653 kg/ha) and biological yield (3747 kg/ha) were higher with the ZTR-ZTR-ZTR system, but the harvest index was higher in the CT-CT-CT 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 19). Among weed management practices, weedy check has the lowest seed, haulm and biological yields (315, 1316 and 1631 kg/ha, respectively). The highest crop yields were obtained under IWM (1365, 2808 and 4173 kg/ha, respectively) followed by herbicide rotation and recommended herbicides (Table 19). 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 seed yield and harvest index, but significant for haulm and biological yields.

Table 19: Effect of crop establishment methods and weed management practices on yield of greengram under rice-wheat/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	933.47	1953.92	2887.39	30.19
ZT+R-ZT+R-ZT+R	1094.56	2652.83	3747.39	28.56
SEm±	16.96	49.12	36.79	1.87
CD (p=0.05)	111.09	321.82	241.01	NS
Weed management practices (W)				
W1	314.89	1316.13	1631.02	20.71
W2	1048.47	2115.48	3163.95	30.69
W3	1365.21	2808.28	4173.49	34.66
W4	1327.49	2973.62	4301.10	31.42
SEm±	30.55	48.37	51.98	1.90
CD (p=0.05)	95.16	150.68	161.94	5.91
C x W	NS	308.86	292.24	NS

Rice 2022

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

The rice field was severely infested with a wide range of weeds. At 60DAS, the relative density of weeds indicated that *Dinebra retroflexa* (50%), *Echinochloacolona*(18%), *Cyperusiria*(11%) and *Digitariasanguinalis*(9%) were the major weeds. With the progress of time, the weed-like *Alternanthera sessilis*(8%),*Eleucine indica* (4%) became dominant. Likewise, relative weed biomass followed a similar trend, *Dinebra retroflexa* (50%), *Echinochloacolona*(20%) and *Digitariasanguinalis*(10%) as the dominant weeds, with the progress of time, the weed-like *Alternanthera sessilis*(14%) and *Eleucine indica* (5%) were other weed biomass recorded (Fig 35).

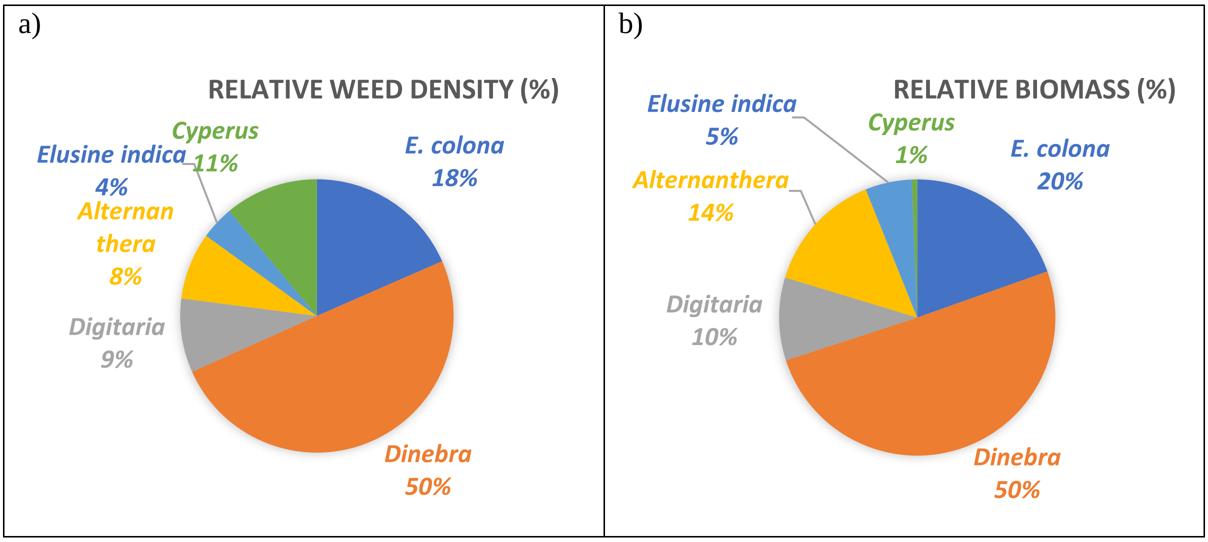


Fig 35: Relative weed density and biomass (%) in rice under rice-wheat-greengram system

Table 20: Effect of crop establishment methods and weed management practices on weed density and biomass of weeds at 60 DAS in rice under rice-wheat/chickpea-greengram cropping system

Treatment	Grassy weeds				Broadleaf weed	Sedge
	D. retroflexa	*E. colona*	*D. sanguinalis*	*E. indica*	*sessilis*	*Cyperus spp.*
	Weed density (no./m²)					
Crop establishment methods (C)						
CT-CT-CT	5.93(42)	4.75(24.3)	2.24(5.6)	2.66(7.1)	2.33(6.3)	4.23(18.8)
ZT+R-ZT+R-ZT+R	6.34(48)	4.48(22.1)	2.7(9.4)	2.42(6)	2.61(8.3)	3.89(16.1)
SEm±	0.05	0.07	0.37	0.09	0.09	0.04
CD (p=0.05)	0.32	NS	NS	0.64	NS	0.28
Weed management practices (W)						
W1	10.71(115.3)	6.86(47.2)	3.78(16.8)	3.24(10.2)	3.99(15.8)	5.49(30)
W2	5.66(31.8)	4.77(22.5)	2.88(8)	3.03(8.8)	3.33(10.7)	4.63(21.3)
W3	3.71(13.3)	3.09(9.2)	1.23(1.3)	1.67(2.5)	1.33(1.5)	2.66(6.8)
W4	4.47(19.5)	3.74(14)	1.98(3.8)	2.22(4.7)	1.24(1.3)	3.47(11.7)
SEm±	0.31	0.29	0.42	0.2	0.16	0.26
CD (p=0.05)	0.97	0.89	1.31	0.63	0.48	0.79
C x W	NS	NS	NS	NS	NS	NS
	Weed biomass (g/m²)					
Crop establishment methods (C)						
CT-CT-CT	4.38(25)	3.57(15.1)	1.8(3.5)	2.22(5.2)	2.58(8.4)	1.68(2.7)
ZT+R-ZT+R-ZT+R	4.75(30)	3.35(13.4)	2.15(6.3)	2.06(4.4)	3.04(11.5)	1.35(1.4)
SEm±	0.03	0.07	0.3	0.13	0.12	0.04
CD (p=0.05)	0.18	NS	NS	NS	NS	0.24
Weed management practices (W)						
W1	8.94(80.3)	6.02(36.2)	3.33(12.9)	3.21(10)	4.47(20.1)	1.93(3.7)
W2	4.16(17)	3.59(12.5)	2.24(4.6)	2.55(6.1)	4.12(16.6)	1.69(2.4)
W3	2.21(4.4)	1.91(3.2)	0.96(0.5)	1.21(1)	1.29(1.4)	1.18(0.9)
W4	2.96(8.4)	2.32(5)	1.38(1.5)	1.58(2.1)	1.35(1.7)	1.27(1.1)
SEm±	0.26	0.21	0.37	0.16	0.17	0.08
CD (p=0.05)	0.79	0.66	1.13	0.48	0.53	0.25
C x W	NS	NS	NS	NS	NS	0.40

W1: weedy check; W2: recommended herbicide (RH, pretilachlor+pyrazosulfuron 615 g/ha *fb* bispyribac-sodium 25 g/ha); W3: integrated weed management (IWM, pretilachlor+pyrazosulfuron 615 g/ha *fb* cyhalofop+penoxsulam 135 g/ha *fb* hand weeding); W4: herbicide rotation (HR, pretilachlor+pyrazosulfuron 615 g/ha *fb* cyhalofop+penoxsulam 135 g/ha)

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

At 60 DAS, under crop establishment methods, the total weed density was recorded as comparable between both establishment methods; however, weed biomass was higher with the ZTR-ZTR-ZTR system. The highest total weed density and biomass were recorded with ZTR-ZTR-ZTR (109.9 no./m^2 and 67.0 g/m^2, respectively) (Table 20 & 21). The weed density and biomass of *E. colona* were higher in the CT system, whereas rest of the grassy weeds were more with the ZTR system. The broadleaved weeds like*A. sessilis*was more with ZTR system, whereas sedges were more with CT system.In general, ZTR systems have more grasses and BLWs weeds and CT systems have more sedges. Likewise, WCE comparable between both systems, while WCI recorded 45.6% more with CT-CT-CT (Fig 7). Among weed management practices, weedy check recorded the highest total weed density and biomass with 235.3 no./m^2 and 163.2 g/m^2, respectively and the lowest in IWM (pretilachlor+pyrazosulfuron 615 g/ha *fb*HW) followed by herbicide rotation (pretilachlor+pyrazosulfuron 615 g/ha *fb* cyhalofop+penoxsulam 135 g/ha). Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 85.3 and 93.0%, respectively followed by herbicide rotation and recommended herbicide over weedy check (Fig 36).

Table 21: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 60 DAS in greengram under rice-wheat-greengram cropping system

Treatment	Total grasses	Total broadleaf weeds	Total sedges	Total weeds
Weed density (no./m^2)				
Crop establishment methods (C)				
CT-CT-CT	8.33(79)	2.33(6.3)	4.23(18.8)	9.64(104.2)
ZT+R-ZT+R-ZT+R	8.6(85.5)	2.61(8.3)	3.89(16.1)	9.8(109.9)
SEm±	0.13	0.09	0.05	0.08
CD (p=0.05)	NS	NS	0.28	NS
Weed management practices (W)				
W1	13.76(189.5)	3.99(15.8)	5.49(30)	15.33(235.3)
W2	8.44(71.2)	3.33(10.7)	4.63(21.3)	10.17(103.2)
W3	5.17(26.3)	1.33(1.5)	2.66(6.8)	5.92(34.7)
W4	6.51(42)	1.24(1.3)	3.47(11.7)	7.45(55)
SEm±	0.28	0.16	0.26	0.24
CD (p=0.05)	0.87	0.48	0.79	0.72
C x W	NS	NS	NS	NS
Weed biomass (no./m^2)				
Crop establishment methods (C)				
CT-CT-CT	6.24(48.8)	2.58(8.4)	1.68(2.7)	6.94(59.8)
ZT+R-ZT+R-ZT+R	6.48(54.1)	3.04(11.5)	1.35(1.4)	7.29(67)
SEm±	0.09	0.12	0.04	0.04
CD (p=0.05)	NS	NS	0.24	0.22
Weed management practices (W)				
W1	11.8(139.4)	4.47(20.1)	1.93(3.7)	12.78(163.2)
W2	6.37(40.2)	4.12(16.6)	1.69(2.4)	7.72(59.2)
W3	3.09(9.1)	1.29(1.4)	1.18(0.9)	3.45(11.4)
W4	4.18(17)	1.35(1.7)	1.27(1.1)	4.51(19.9)
SEm±	0.22	0.17	0.08	0.17
CD (p=0.05)	0.69	0.53	0.25	0.51
C x W	NS	NS	0.4	NS

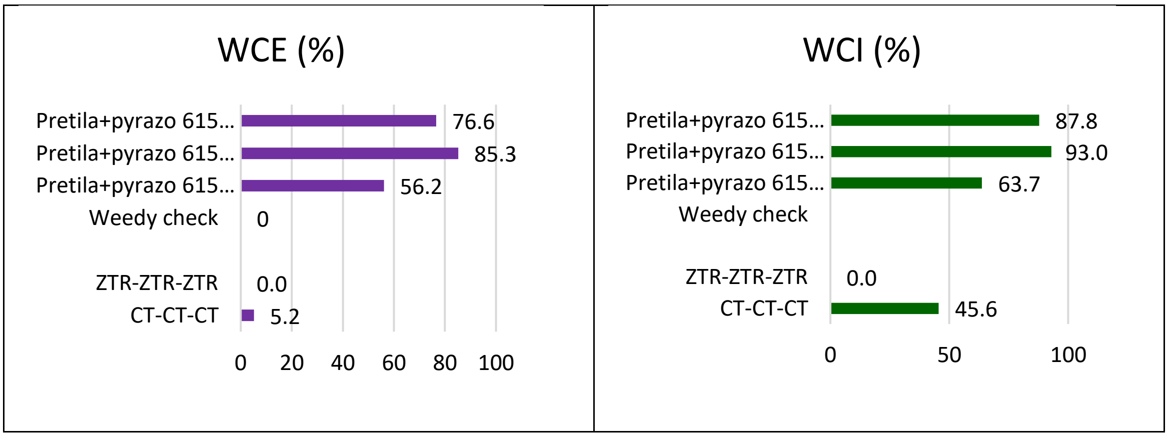


Fig 36: Weed control efficiency and weed control index of greengram under rice-chickpea-greengram system

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

Between the crop establishment methods, all the growth and yield parameters were comparable between the systems (Table 22). Among weed management practices, all the growth and yield parameters viz. plant height, tillers/running meter, panicles/running meter, panicle length, grains/panicle, panicle weight and test weight were highest with IWM and followed by herbicide rotation and recommended herbicides. The lowest growth parameters were recorded with weedy check plots (Table 22). 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 22: Effect of crop establishment methods and weed management practices on growth and yield parameters in rice under rice-wheat-greengram cropping system

Treatment	**Plant height (cm)**	**Tillers/ running m row**	**Panicles/ running m row**	**Panicle length (cm)**	**Grain/panicl e**	**Panicle weight (g/panicle)**	**Test weight (g/1000 grains)**
Crop establishment methods (C)							
CT-CT-CT	87.57	50.62	49.13	19.19	76.10	2.38	24.65
ZT+R-ZT+R-ZT+R	84.8	51.4	49.6	19.2	75.4	2.4	24.6
SEm±	0.87	2.87	2.8	0.48	2.99	0.09	0.2
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)							
W1	70.9	39.3	37.2	15.2	51.3	1.6	24.3
W2	86.7	52.1	49.8	19.9	68.7	2.1	24.5
W3	95.2	58.0	57.6	21.6	100.0	3.1	25.0
W4	92.0	54.6	52.8	20.1	83.0	2.6	24.7
SEm±	2.46	1.96	1.91	0.7	2.38	0.07	0.22
CD (p=0.05)	7.65	6.10	5.95	2.18	7.44	0.23	NS
C x W	NS	NS	NS	NS	NS	NS	NS

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

Between the crop establishment methods, the grain, straw, biological yield and harvest index were statistically comparable. However, the values of these parameters were more in the CT-CT-CT system (Table 23). Among weed management practices, weedy check has the lowest grain, straw, biological yield and harvest index (334, 811 and 1145 kg/ha, and 29.2%, respectively). The highest crop yields were obtained under IWM (2827, 5094 and 7921 kg/ha, and 35.7%, respectively) followed by herbicide rotation and recommended herbicides (Table 23). The interaction between crop establishment methods and weed management practices was found to be non-significant except for the harvest index.

Table 23: Effect of crop establishment methods and weed management practices on yields of rice under rice-wheat/chickpea-greengram cropping system

Treatment	**Grain yield (kg/ha)**	**Biological yield (kg/ha)**	**Straw yield (kg/ha)**	**HI**
Crop establishment methods (C)				
CT-CT-CT	1610.56	4663.89	3076.32	33.94
ZT+R-ZT+R-ZT+R	1551.2	4463.0	2888.8	32.8
SEm±	60.74	175.7	115.01	0.16
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	333.6	1144.5	810.9	29.2
W2	1169.1	3457.4	2288.3	33.8
W3	2827.4	7921.0	5093.7	35.7
W4	1993.5	5730.8	3737.3	34.8
SEm±	76.11	222.44	146.68	0.3
CD (p=0.05)	237.13	692.99	456.97	0.93
C x W	NS	NS	NS	1.54

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

The experimental field of rice was infested with a wide range of weeds. At 60DAS, the relative density of weeds was *Dinebra retroflexa* (47%), *Echinochloacolona*(16%), *Cyperusiria*(13%) and *Digitariasanguinalis*(13%), with the progress of time, the weed-like *Alternanthera sessilis*(6%) and *Eleucine indica* (5%) became dominant. Likewise, relative weed biomass followed a similar trend with the highest being *Dinebra retroflexa* (47%), *Echinochloacolona*(17%) and *Digitariasanguinalis*(14%) were the dominant weeds, with the progress of time, the weed-like *Alternanthera sessilis*(12%), *Eleucine indica* (6%) and *Cyperus sp.* (4%) were another weed biomass recorded (Fig 37).

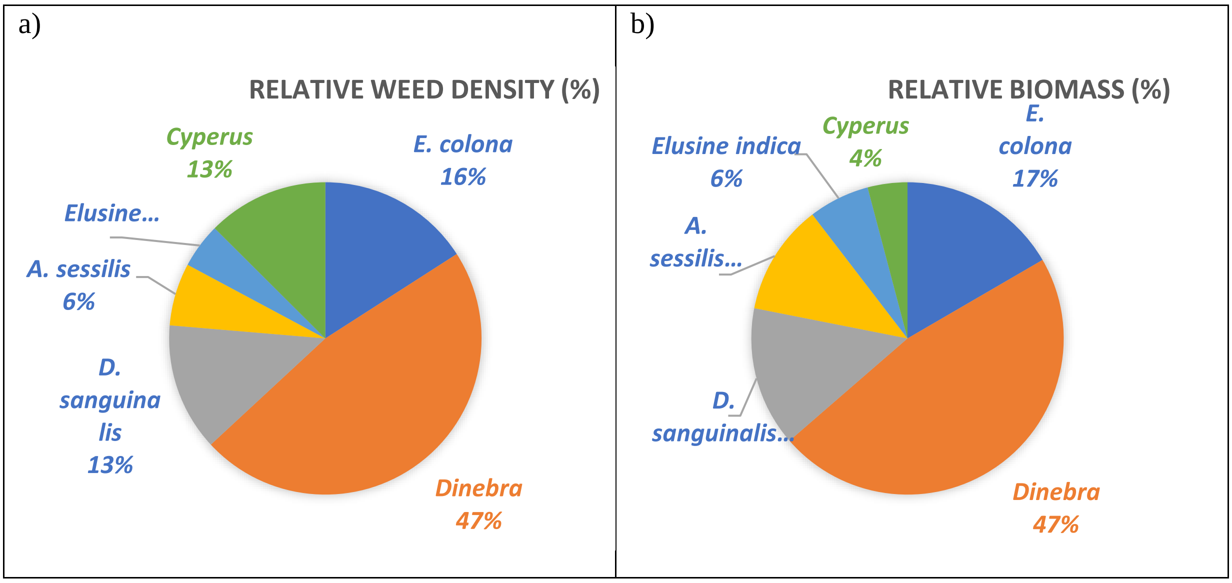


Fig 37: Relative weed density (a) and biomass (b) in rice under rice-chickpea- greengram system

Table 24: Effect of crop establishment methods and weed management practices on weed density and biomass of weeds at 60 DAS in rice under rice-wheat/chickpea-greengram cropping system

Treatment	**Grassy weeds**				**Broadleaf weed**	**Sedge**
	D. retroflexa	***E. colona***	***D. sanguinalis***	***E. indica***	***A.sessilis***	***Cyperus spp.***
	Weed density (no./m²)					
Crop establishment methods (C)						
CT-CT-CT	5.32(33.8)	4.31(19.8)	2.5(7.1)	3.04(9.3)	1.89(3.8)	4.14 (17.9)
ZT+R-ZT+R-ZT+R	6.01(43.2)	4.31(20.3)	3.3(12.8)	2.83(7.9)	2.41(6.8)	3.89 (16.2)
SEm±	0.3	0.08	0.10	0.18	0.02	0.07
CD (p=0.05)	NS	NS	0.60	NS	0.09	NS
Weed management practices (W)						
W1	9.88(98.8)	6.25(39)	4.65(22.3)	3.59(12.5)	3.41(11.7)	5.53 (30.5)
W2	5.23(27.2)	4.56(20.7)	3.14(9.5)	3.5(11.8)	2.66(6.8)	4.52 (20)
W3	3.61(12.7)	3.05(9)	1.09(1)	2.05(3.8)	1.39(1.7)	2.79 (7.7)
W4	3.93(15.2)	3.4(11.5)	2.72(7)	2.6(6.3)	1.14(1)	3.22 (10)
SEm±	0.3	0.29	0.20	0.12	0.24	0.26
CD (p=0.05)	0.9	0.89	0.63	0.36	0.73	0.82
C x W	NS	NS	1.03	NS	NS	NS
	Weed biomass (g/m²)					
Crop establishment methods (C)						
CT-CT-CT	3.94(20.1)	3.27(12.4)	1.99(4.4)	2.52(6.8)	2.05(4.7)	2.7 (8)
ZT+R-ZT+R-ZT+R	4.48(26.9)	3.24(12.3)	2.62(8.6)	2.34(5.6)	2.8(9.5)	2.3 (5.4)
SEm±	0.24	0.06	0.06	0.13	0.04	0.08
CD (p=0.05)	NS	NS	0.35	NS	0.27	NS

Weed management practices (W)						
W1	8.26(69)	5.5(30.1)	4.08(17.2)	3.55(12.3)	3.82(14.8)	3.48 (12.6)
W2	3.85(14.5)	3.44(11.5)	2.44(5.5)	2.93(8.2)	3.28(10.7)	3.09 (9.1)
W3	2.15(4.1)	1.9(3.2)	0.9(0.4)	1.42(1.6)	1.36(1.6)	1.33 (1.3)
W4	2.57(6.3)	2.18(4.4)	1.81(2.8)	1.82(2.9)	1.23(1.3)	2.1 (3.9)
SEm±	0.23	0.21	0.14	0.09	0.27	0.18
CD (p=0.05)	0.72	0.65	0.44	0.28	0.83	0.56
C x W	NS	NS	0.69	NS	NS	0.89

W1: weedy check; W2: recommended herbicide (RH, pretilachlor+pyrazosulfuron 615 g/ha *fb* bispyribac-sodium 25 g/ha); W3: integrated weed management (IWM, pretilachlor+pyrazosulfuron 615 g/ha *fb* cyhalofop+penoxsulam 135 g/ha *fb* hand weeding); W4: herbicide rotation (HR, pretilachlor+pyrazosulfuron 615 g/ha *fb* cyhalofop+penoxsulam 135 g/ha)

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

At 60 DAS, under crop establishment methods, the total weed density was recorded as comparable between both establishment methods; however, weed biomass was more with the ZTR-ZTR-ZTR system. The highest total weed density and biomass were recorded with the ZTR-ZTR-ZTR (107.2 no./m^2 and 56.3 g/m^2, respectively) (Table 24 & 25). The weed density and biomass of E. indica was higher in the CT system, whereas the rest of the grassy weeds were more with the ZTR system. The broadleaved weeds, like A. sessilis was more in the ZTR system, whereas sedges were more in the CT system. In general, ZTR systems have more grasses and BLWs weeds and CT systems have more sedges. Likewise, WCE was 14.5% more with the CT-CT-CT system, while WCI recorded 47.4% more with the CT-CT-CT (Fig 38).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 214.8 no./m^2 and 156.0 g/m^2, respectively and the lowest in IWM (pretilachlor + pyrazosulfuron 615 g/ha *fb*HW) followed by herbicide rotation (pretilachlor + pyrazosulfuron 615 g/ha*fb* cyhalofop + penoxsulam 135 g/ha) (Table 24 & 25). Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 83.3 and 92.2%, respectively followed by herbicide rotation and recommended herbicide over weedy check (Fig 38).

Table 25: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 60 DAS in rice under rice-chickpea-greengram cropping system

Treatment	Total grasses	Total broadleaf weeds	Total sedges	Total weeds
Weed density (no./m^2)				
Crop establishment methods (C)				
CT-CT-CT	7.9(70)	1.89(3.8)	4.14(17.9)	9.11(91.7)
ZT+R-ZT+R-ZT+R	8.58(84.2)	2.41(6.8)	3.89(16.2)	9.71(107.2)
SEm±	0.14	0.02	0.07	0.11
CD (p=0.05)	NS	0.09	NS	NS
Weed management practices (W)				
W1	13.11(172.7)	3.41(11.7)	5.53(30.5)	14.64(214.8)
W2	8.32(69.2)	2.66(6.8)	4.52(20)	9.8(96)
W3	5.19(26.5)	1.39(1.7)	2.79(7.7)	6.02(35.8)
W4	6.35(40)	1.14(1)	3.22(10)	7.17(51)
SEm±	0.31	0.24	0.26	0.22
CD (p=0.05)	0.95	0.73	0.82	0.67
C x W	NS	NS	NS	NS
Weed biomass (no./m^2)				
Crop establishment methods (C)				
CT-CT-CT	5.96(43.6)	2.05(4.7)	2.7(8)	6.8(56.3)

ZT+R-ZT+R-ZT+R	6.48(53.4)	2.80(9.5)	2.3(9.5)	7.42(68.3)
SEm±	0.12	0.04	0.08	0.08
CD (p=0.05)	NS	0.27	NS	0.51
Weed management practices (W)				
W1	11.31(128.6)	3.82(14.8)	3.48(12.6)	12.48(156)
W2	6.33(39.7)	3.28(10.7)	3.09(9.1)	7.72(59.4)
W3	3.12(9.3)	1.36(1.6)	1.33(1.3)	3.56(12.2)
W4	4.1(16.4)	1.23(1.3)	2.1(3.9)	4.69(21.6)
SEm±	0.22	0.27	0.18	0.16
CD (p=0.05)	0.68	0.83	0.56	0.51
C x W	NS	NS	0.89	NS

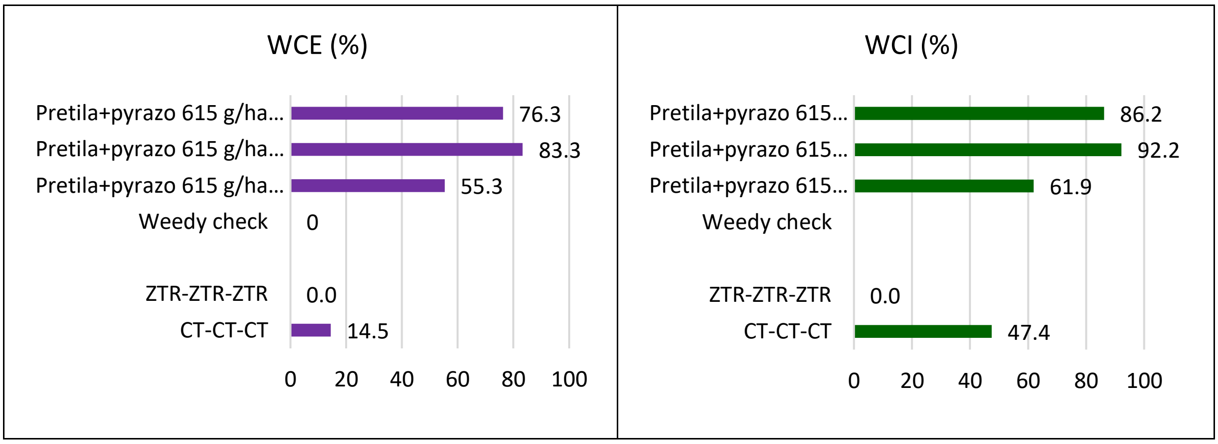


Fig 38: Relative weed density (a) and weed biomass (b) in rice under rice-chickpea-greengram system

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

Between the crop establishment methods, all the growth and yield parameters were comparable between the systems (Table 26). Among weed management practices, all the growth and yield parameters viz. plant height, tillers/running meter, panicles/running meter, panicle length, grains/panicle and panicle weight were highest with IWM and followed by herbicide rotation and recommended herbicides. The test weight was non-significant between weed management practices. The lowest growth parameters were recorded in weedy check plots (Table 26). 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 26: Effect of crop establishment methods and weed management practices on total weed density and total weed biomass at 60 DAS in rice under rice-wheat/chickpea-greengram cropping system

Treatment	Plant height (cm)	Tillers/ running m row	Panicles/ running m row	Panicle length (cm)	Grain/panicle	Panicle weight (g/panicle)	Test weight (g/1000 grains)
Crop establishment methods (C)							
CT	87.14	51.17	49.65	19.79	78.24	2.45	24.42
ZTR	86.6	50.2	48.5	19.5	77.1	2.4	24.5
Sem±	2.01	1.19	1.16	0.31	1.13	0.03	0.03
CD at 5%	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)							
W1	74.3	40.5	38.4	15.5	52.7	1.6	24.0
W2	84.5	52.9	50.7	20.3	69.9	2.2	24.5
W3	95.6	55.4	55.1	21.9	105.5	3.3	25.6
W4	93.1	53.9	52.1	20.8	82.5	2.6	24.7
SEm±	1.73	1.68	1.62	0.51	2.06	0.06	0.23

CD (p=0.05)	5.4	5.23	5.05	1.59	6.42	0.2	NS
C x W	NS	NS	NS	NS	NS	NS	NS

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

Between the crop establishment methods, the grain, straw, biological yield and harvest index were statistically comparable. However, the values of these parameters were more in CT-CT-CT system (Table 27). Among weed management practices, weedy check has the lowest grain, straw, biological yield and harvest index (408, 927 and 1335 kg/ha, and 30.5%, respectively). The highest crop yields were obtained under IWM (2980, 5433 and 8413 kg/ha, and 35.4%, respectively) followed by with herbicide rotation and recommended herbicides. The interaction between crop establishment methods and weed management practices was found to be non-significant.

Table 27: Effect of crop establishment methods and weed management practices on yields of rice under rice-wheat-greengram cropping system

Treatment	Grain yield (kg/ha)	Biological yield (kg/ha)	Straw yield (kg/ha)	HI
Crop establishment methods (C)				
CT-CT-CT	1772.09	5132.97	3360.88	33.72
ZT+R-ZT+R-ZT+R	1710.7	4948.1	3237.4	33.5
SEm±	61.2	163.05	101.85	0.13
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	408.3	1334.8	926.5	30.5
W2	1395.6	4126.3	2730.8	33.8
W3	2979.6	8412.5	5432.9	35.4
W4	2182.0	6288.4	4106.4	34.7
SEm±	57.74	166.02	110.02	0.3
CD (p=0.05)	179.89	517.23	342.77	0.92
C x W	NS	NS	NS	NS

System crop, water and energy productivity

The highest system productivity in terms of rice equivalent yield was recorded in the ZTR (R)-ZTR (C)-ZTR (G) system with (9.86 t/ha) followed by CT (R)-CT (C)-CT (G) and both were statistically comparable. The lowest system productivity was recorded with CT (R)-CT (W)-CT (G) (8.17 t/ha). The system irrigation water productivity and total water productivity were highest with ZTR (R)-ZTR (C)-ZTR (G) (24.7 and 5.9 kg/ha/mm, respectively) with the highest net returns (Rs 1.48 x 10^5), but the B: C was recorded highest with ZTR (R)-ZTR (W)-ZTR (G) (2.62), net energy (2.02 x 10^5 MJ/ha), energy ratio (5.75), whereas energy productivity was highest with ZTR (R)-ZTR (C)-ZTR (G) (0.23 kg/MJ) (Table 28).

Among weed management practices, the highest system productivity in terms of rice equivalent yield was obtained with IWM in the system (12.69 t/ha) followed by herbicide rotation (11.54 t/ha). The lowest system productivity was obtained with weedy check (2.83 t/ha). The system irrigation water productivity (25.2 kg/ha/mm), water productivity (7.0 kg/ha/mm), net returns (Rs 2.07 x 10^5/ha), B: C (2.42), energy ratio (6.32) and energy productivity (0.29 kg/MJ) in IWM were mainly due to higher crop yields, better water use, optimum production cost and energy use. These were followed by herbicide rotation and recommended herbicides. The lowest values of all said parameters were obtained with weedy check (Table 28).

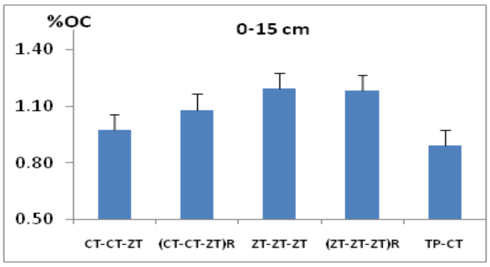
Table 28: Effect of crop establishment methods and weed management practices on system productivity, water productivity, profitability and energy productivity in rice-wheat/chickpea-greengram cropping system

Treatment	REY, t/ha	SIWP (kg/ha/mm)	SWP (kg/ha/mm)	NR (L/ha)	B:C	NE (LMJ/ha)	ER	EP (kg/MJ)

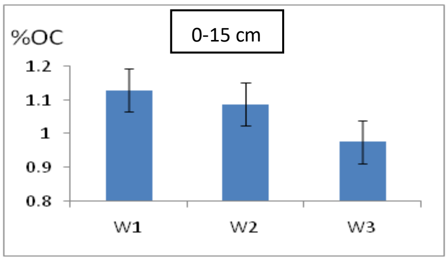
Crop establishment methods (C)								
CT (R)-CT (W)-CT (G)	8.17	11.7	4.1	1.13	2.14	1.80	4.82	0.17
ZTR (R)-ZTR (W)-ZTR (G)	8.94	17.9	5.0	1.41	2.62	2.02	5.75	0.21
CT (R)-CT (C)-CT (G)	9.69	18.6	5.4	1.33	2.26	1.42	3.77	0.21
ZTR (R)-ZTR (C)-ZTR (G)	9.86	24.7	5.9	1.48	2.56	1.53	4.30	0.23
CD (0.05)	0.55	1.06	0.31	0.11	0.11	0.06	0.13	0.01
Weed management practices (W)								
W1	2.83	5.6	1.6	-0.02	0.99	0.53	2.12	0.07
W2	9.60	19.1	5.3	1.43	2.54	1.69	4.64	0.21
W3	12.69	25.2	7.0	2.07	3.08	2.42	6.32	0.29
W4	11.54	22.9	6.4	1.87	2.96	2.12	5.56	0.25
CD (0.05)	0.49	0.93	0.27	0.12	0.12	0.12	0.27	0.01
C x W	0.97	1.86	0.53	0.23	0.25	0.24	0.54	0.02

Effect of crop establishment and weed management practices on SOC content

Analysis of soil samples from an ongoing long-term field trial shows that the SOC content of surface layer (0-15 cm depth) changed significantly due to conservation practices followed during the last 8 years (Fig 39). The SOC content was lowest in the plots where the traditional practice of transplanted TPR-CT-ZT was practiced. The practice of CT-DSR-CT-ZTshowed significant improvement in SOC content over traditional TP-CT-ZT. The recycling of crop residues in CTR-CTR-ZTR significantly improved the SOC content over CT-CT-ZT alone treatment. The highest SOC was recorded under ZT-ZT-ZT and ZTR-ZTR-ZTR. However, the SOC content of sub-surface soil layer (15-50 cm) did not vary among the tillage treatments tested. This indicated that the benefit of tillage and crop residue recycling in terms of SOC built-up has not reached below plough layer till now.



Effect of tillage



Effect of weed control measures

Among the weed management practices, weedy check plots showed the highest SOC content; and the plots where herbicides were integrated weed management with herbicide rotation showed the lowest SOC in surface layer (Figure10b). Gigantic growth of weed biomass and its subsequent recycling in the soil, season after season, during the last 8 years could be the possible reason behind the highest SOC level as observed under weedy check. The integrated weed management with herbicide rotation plots encountered relatively lower weed biomass recycling compared to continuous use of recommended herbicides.

Plate 7. Effect of conservation agriculture system on weed dynamics, crop productivity and soil health on maize based cropping system

Wheat 2021-22

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

At 60 days after sowing (DAS), thewheat field was comprised of the relative density of weeds, i.e. *Medicago polymorpha* (78%), *Avenaludoviciana*(13%), whereas the rest of the weeds, like *Convolvulusarvensis,Chenopodium album*, *Sonchusoleraceus*, *Lathyrusaphacea*, *D. sanguinalis*, *Physalis minima* were minor weeds present (**Fig 40**). The relative weed biomass followed the trend of relative density and recorded the highest with *Medicago polymorpha* (78%), *Avenaludoviciana*(11%) and rest were minor weeds. It was noticed that *Digitariasanguinalis*, *Physalis minima*, and*Alternatherasessilis* were late-emerging weeds in wheat.

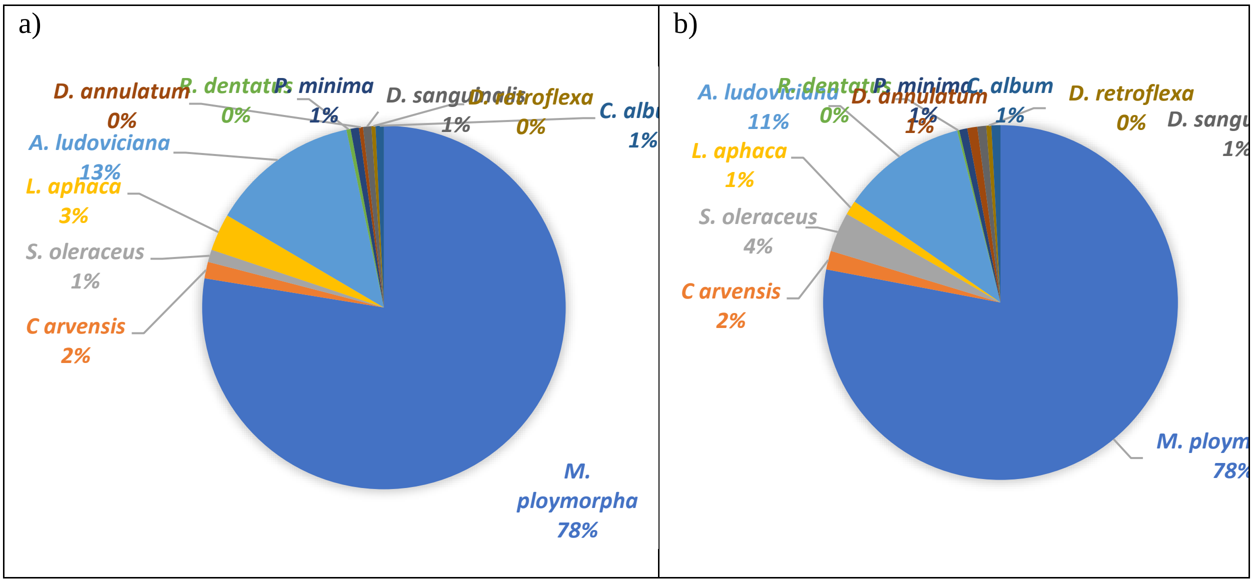


Fig 40: Relative weed density and biomass at 60 DAS in wheat under maize-wheat-greengram cropping system

Table 29: Effect of crop establishment methods and weed management practices on density and biomass of different weed species on wheat at 60 DAS under maize-wheat-greengram system

Treatment	*M. polymorpha*	*C. arvensis*	*S. oleraceus*	*A. ludoviciana*	*D. annulatum*	Others	Total grasses	Total BLW	Total Weeds
	Weed density (no./m²)								
Crop establishment methods (C)									
CT-CT-CT	5.12(55.7)	1.33(1.7)	1.09(0.9)	2.02(9.1)	1.04(0.8)	2.55(8.2)	2.64(11.7)	5.93(64.6)	6.43 (76.3)
ZTR-ZTR-ZTR	4.44(45.8)	1.18(1.2)	1.28(1.6)	2.2(11.2)	1.28(1.5)	2.51(7.8)	3.15(16.2)	5.13(52.8)	5.96 (68.9)
SEm±	0.19	0.11	0.10	0.21	0.19	0.02	0.25	0.23	0.08
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.46
Weed management practices (W)									
W1	13.92(193.8)	1.82(3)	2(3.7)	6.33(40.5)	1.47(2)	4.17(17.3)	6.89(48.2)	14.56(212.2)	16.14 (260.3)
W2	2.32(5)	1.45(1.8)	1.08(0.8)	0.71(0)	1.28(1.3)	3.22(10)	2.23(4.7)	3.81(14.3)	4.4 (19)
W3	1(0.7)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	1(0.7)	1(0.7)
W4	1.88(3.3)	1.05(0.8)	0.94(0.5)	0.71(0)	1.19(1.2)	2.02(4.5)	1.76(2.8)	2.74(7.5)	3.24 (10.3)
SEm±	0.17	0.15	0.14	0.22	0.20	0.32	0.28	0.22	0.25
CD (p=0.05)	0.53	0.46	0.43	0.69	NS	1.00	0.85	0.67	0.77
C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Weed biomass (g/m²)								
Crop establishment methods (C)									
CT-CT-CT	3.81(35.1)	1.1(1)	1.24(1.7)	1.65(5)	1.09(0.9)	1.75(3.3)	2.2(7.1)	4.32(39.9)	4.78 (47)
ZTR-ZTR-ZTR	3.2(24.7)	1.01(0.6)	1.08(1)	1.75(5.9)	1.59(2.9)	1.68(3)	2.66(10.3)	3.62(27.7)	4.48 (38)
SEm±	0.11	0.05	0.04	0.15	0.28	0.04	0.25	0.12	0.06
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)									
W1	10.8(117.3)	1.52(2)	2.3(5.1)	4.69(21.9)	1.75(3.3)	2.72(7)	5.27(28.1)	11.31(128.7)	12.5 (156.7)
W2	1.32(1.3)	1.1(0.8)	0.85(0.3)	0.71(0)	1.5(2.2)	1.99(3.6)	1.97(3.7)	2.19(4.4)	2.9 (8)
W3	0.79(0.1)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.79(0.1)	0.79 (0.1)
W4	1.11(0.8)	0.9(0.4)	0.77(0.1)	0.71(0)	1.4(2)	1.46(1.9)	1.77(3)	1.6(2.2)	2.34 (5.2)

SEm±	0.13	0.11	0.12	0.15	0.28	0.20	0.26	0.15	0.19
CD (p=0.05)	0.41	0.35	0.37	0.47	NS	0.62	0.79	0.46	0.59
C X W	0.57	NS	NS	NS	NS	NS	NS	0.65	0.84

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

At 60 DAS, under crop establishment methods, the total weed density and biomass were recorded higher in the conventional system (CT-CT-CT) with 76.3 no./m^2 and 47.0 g/m^2, respectively. The lowest total weed density and biomass were measured in ZTR-ZTR-ZTR with 68.9 no./m^2 and 38.0 g/m^2,respectively(Table 29 & 30). The weed density and biomass of *Avenaludoviciana, Sonchus oleraceus andDicanthium annulatum*were significantly higher in the ZTR-ZTR-ZTR and lowest in CT-CT-CT, whereas *Medicagopolymorpha, Chenopodium album* and *Convolvulus arvensis* were more noticeable under theCT-CT-CT system. In general, ZTR systems have more grassy weeds and CT systems have more broadleaf weeds (BLWs).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 260.3 no./m^2 and 156.3 g/m^2, respectively and the lowest in integrated weed management [IWM, clodinafop propargyl +metsulfuron-methyl at 60+4 g/ha (pre-mix) followed by (*fb*) hand weeding (HW)] followed by herbicide rotation [clodinafop propargyl +metsulfuron-methyl at 60+4 g/ha (pre-mix)] (Tabl**e 30**). Likewise, weed control efficiency (WCE, %) was recorded as being highest with ZTR-ZTR-ZTR(9.6%) over CT-CT-CT system. Likewise, the weed control index (WCI, %) followed the trend of the WCE and recorded the highest with ZTR-ZTR-ZTR (19.1%) over the CT-CT-CT system. Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 99.7 and 99.9%, respectively, followed by herbicide rotation and recommended herbicide over weedy check (Fig 41).

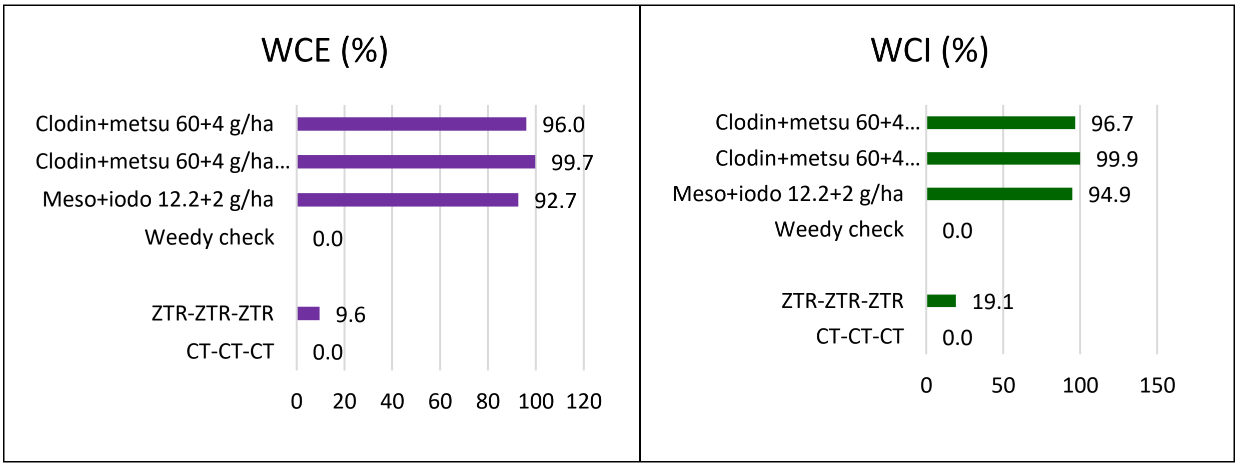


Fig 41: Weed control efficiency (%) and weed control index (%) as influenced by crop establishment methods and weed management practices in wheat

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

During the experimentation, between the crop establishment methods, plant height at harvest, leaf area, plant dry biomass and number of spikes per meter running length were more with ZTR-ZTR-ZTR but was statistically comparable to CT-CT-CT. The no. of grains/spike and test weight were significantly higher in the ZTR-ZTR-ZTR over the CT-CT-CT (Table 30).Among weed management practices, plant height at harvest, leaf area and number of spikes per meter running length, no. of grains/spike and test weight were statistically significant in IWM followed by herbicide rotation and recommended herbicides. The plant dry weight was comparable between the weed management practices. The lowest growth and yield parameters were recorded with weedy check (Table 30). The interaction between crop establishment methods and weed management practices were non-significant.

Table 30: Effect of crop establishment methods and weed management practices on growth and yield parameters of wheat under maize-wheat-greengram system

Treatment	Plant height (cm)	Leaf area (cm^2)	Dry weight (g/plant)	No. of spike/m row length	No. of grains/spike	Spike weight (g)
Crop establishment methods (C)						
CT-CT-CT	107.78	229.18	15.33	98.42	67.67	3.29
ZTR-ZTR-ZTR	110.02	261.72	16.45	101.40	70.83	3.34
SEm±	1.11	7.82	1.01	0.76	0.16	0.02
CD (p=0.05)	NS	NS	NS	NS	0.95	NS
Weed management practices (W)						
W1	107.53	193.66	14.29	62.57	57.17	3.18
W2	107.87	216.75	15.03	108.97	72.00	3.33
W3	110.63	306.14	17.65	116.20	75.33	3.39
W4	109.57	265.25	16.58	111.90	72.50	3.37
SEm±	0.70	16.63	1.34	1.90	1.09	0.04
CD (p=0.05)	2.15	51.25	NS	5.87	3.34	0.12
C X W	NS	NS	NS	NS	NS	NS

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

Lower weed density and biomass, and higher WCE helped in harvesting a higher grain yield in ZTR-ZTR-ZTR (4164 kg/ha) which was comparable to the CT-CT-CT system (3730 kg/ha). The straw yield, biological yields and harvest index were statistically at par between crop establishment methods (Table 31). Among weed management practices, weedy check has the lowest grain, straw and biological yields (2092, 4949 and 9503 kg/ha, respectively). The highest crop yields were obtained under IWM (4708, 6884 and 11592 kg/ha, respectively), followed by herbicide rotation and recommended herbicides. The harvest index was highest with IWM, followed by herbicide rotation and recommended herbicides. The interaction between crop establishment methods and weed management practices was found to be significant for grain, straw and biological yield, but the harvest index was non-significant.

Table 31: Effect of crop establishment methods and weed management practices on grain and straw yield of wheat under maize-wheat-greengram system

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	HI
Crop establishment methods (C)				
CT-CT-CT	3729.83	6042.58	9772.41	0.37
ZTR-ZTR-ZTR	4164.39	6707.91	10872.30	0.38
SEm±	94.76	246.60	331.43	0.01
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	2201.10	5093.90	7295.00	0.30
W2	4341.73	6680.27	11022.00	0.39
W3	4707.72	6883.80	11591.52	0.41
W4	4537.90	6843.00	11380.90	0.40
SEm±	134.45	244.73	359.89	0.01
CD (p=0.05)	414.29	754.09	1108.92	0.02
C X W	585.90	1066.45	1568.27	NS

Chickpea 2021-22

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

At 60 days after sowing (DAS), the relative density of weeds in chickpea fields comprised of *Medicago polymorpha* (86%), *Avenaludoviciana*(8%), whereas the rest of the weeds like

Convolvulusarvensis,Chenopodium album, Sonchusoleraceus, Rumex dentatus were minor weeds present (Fig 42). The relative weed biomass followed the trend of relative density and recorded the highest with *Medicago polymorpha* (88%), *Avenaludoviciana*(7%) and the rest were minor weeds.

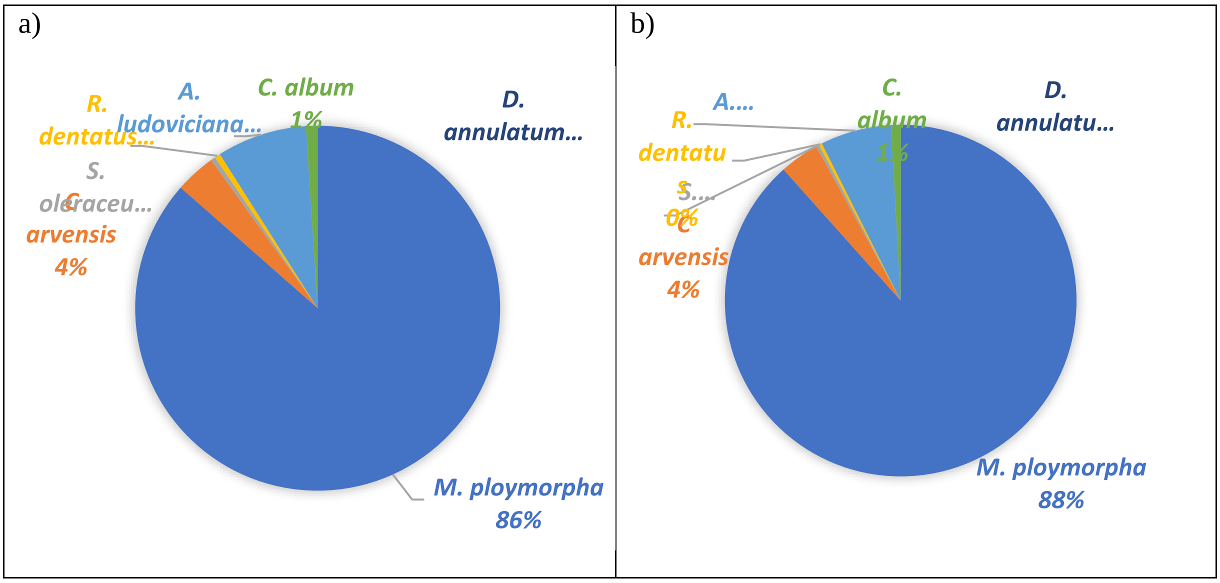


Fig 42: Relative weed density and biomass at 60 DAS in chickpea under maize-wheat-greengram cropping system

Table 32: Effect of crop establishment methods and weed management practices on density and biomass of different weed species on chickpea at 60 DAS under maize-chickpea-greengram system

Treatment	*M. polymorpha*	*C. arvensis*	*S. oleraceus*	*A. ludoviciana*	*D. annulatum*	Others	Total grasses	Total BLW	Total Weeds
	Weed density (no./m^2)								
Crop establishment methods (C)									
CT-CT-CT	7.33(65.2)	2.11(5.3)	1.06(0.8)	2.74(8.8)	0.78(0.2)	1.01(0.8)	2.78(9.0)	7.81(72)	8.35(81)
ZTR-ZTR-ZTR	6.88(59.4)	1.84(3.8)	1.32(1.6)	3.05(11)	1.36(1.7)	1.31(2.3)	3.35(12.7)	7.43(67)	8.25(79.7)
SEm±	0.26	0.13	0.10	0.22	0.20	0.31	0.18	0.33	0.28
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)									
W1	12.73(167)	2.22(5.7)	1.56(2.2)	4.11(16.8)	1(0.7)	1.48(2.2)	4.19(17.5)	13.11(177)	13.81(194.5)
W2	5.46(29.7)	1.98(4.3)	1.11(0.8)	3.34(11.2)	1.23(1.3)	1.27(2)	3.56(12.5)	6.09(36.8)	7.04(49.3)
W3	4.97(24.8)	1.41(1.8)	0.71(0)	0.71(0)	0.9(0.5)	1.18(2)	0.9(0.5)	5.33(28.7)	5.37(29.2)
W4	5.27(27.7)	2.3(6.2)	1.38(1.7)	3.41(11.7)	1.14(1.2)	0.71(0)	3.59(12.8)	5.95(35.5)	6.97(48.3)
SEm±	0.68	0.19	0.16	0.23	0.14	0.32	0.24	0.60	0.57
CD (p=0.05)	2.10	0.60	0.50	0.70	NS	NS	0.73	1.86	1.77
C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Weed biomass (g/m^2)								
Crop establishment methods (C)									
CT-CT-CT	5.03(37.4)	1.58(2.7)	0.91(0.4)	1.78(3.5)	0.73(0)	0.89(0.4)	1.79(3.5)	5.36(40.9)	5.63(44.4)
ZTR-ZTR-ZTR	4.61(32.2)	1.57(2.5)	1.05(0.7)	1.88(3.9)	1.21(1.2)	1(0.7)	2.21(5.1)	5.06(36.1)	5.53(41.2)
SEm±	0.13	0.20	0.05	0.12	0.18	0.15	0.14	0.22	0.23
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)									
W1	10.54(114.7)	1.87(3.8)	1.23(1.1)	3.08(9.2)	0.89(0.4)	1.25(1.3)	3.14(9.6)	10.82(120.8)	11.29(130.4)

W2	3.22(10)	1.75(3.3)	0.92(0.4)	1.78(2.8)	1.13(1)	0.93(0.5)	2.05(3.8)	3.8(14.2)	4.27(18)
W3	2.58(6.3)	1.2(1.1)	0.71(0)	0.71(0)	0.89(0.4)	0.9(0.5)	0.89(0.4)	2.86(7.9)	2.92(8.4)
W4	2.94(8.3)	1.5(2.1)	1.06(0.7)	1.75(2.7)	0.98(0.7)	0.71(0)	1.93(3.4)	3.37(11.1)	3.84(14.4)
SEm±	0.54	0.17	0.09	0.13	0.12	0.17	0.16	0.50	0.47
CD (p=0.05)	1.65	NS	0.27	0.40	NS	NS	0.49	1.54	1.44
C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS

Effect of CA practices on weed biomass in rice-green gram cropping system

An experiment was conducted to study the effect of establishment methods of rice in ZT under DSR and TPR and to decipher effect of CA practices on weed biomass under different rice varieties in rice-green gram cropping system. The main plot consisted of (1) direct seeded rice (DSR) and (2) puddle transplanted rice (TPR). Sub-plots consisted of (1) with residue and (2) without residue retention with three replications. Therefore, a total of eight treatment combinations were: ZT-DSR with residue, ZT-DSR without residue, ZT-TPR with residue, ZT-TPR without residue, conventional-DSR with residue, conventional-DSR without residue, conventional-TPR with residue (T7), conventional-TPR without residue.10 popular rice varieties released from ICAR-NRRI, Cuttack were grown under these eight treatment combinations to evaluate the differential effect on weed biomass. The weed biomass was significantly lower in TPR compared to DSR. Weed biomass was significantly high under puddled condition compared to zero tillage. At advanced stage, under zero tillage, weed biomass was higher with residue incorporation. However, under puddled condition, residue incorporation resulted in lower weed biomass.

Table 33: Weed biomass at 45 DAS/ DAT as influenced by treatments

	DSR			TPR		
Varieties	**Zero till**	**Conventional**	**Mean**	**Zero till**	**Conventional**	**Mean**
CR Dhan 201	1.52	1.56	1.54	2.00	1.53	1.77
CR Dhan 202	1.44	1.87	1.65	1.21	1.58	1.39
CR Dhan 203	1.85	1.04	1.45	1.51	1.76	1.64
CR Dhan 204	1.90	1.76	1.83	2.29	1.59	1.94
CR Dhan 300	1.91	1.50	1.70	1.43	1.44	1.44
CR Dhan 303	1.38	1.45	1.42	2.15	1.53	1.84
CR Dhan 304	1.93	1.18	1.56	1.45	1.49	1.47
CR Dhan 305	1.46	1.07	1.27	1.29	1.63	1.46
Naveen	1.64	1.60	1.62	1.52	1.93	1.73
Swarna	1.79	1.56	1.68	1.57	1.62	1.60
Mean	**1.68**	**1.46**	**1.57**	**1.64**	**1.61**	**1.63**

Table 34: Weed biomass at 45 DAS/ DAT as influenced by treatments

	Zero till			Conventional		
Varieties	**Residue**	**No residue**	**Mean**	**Residue**	**No residue**	**Mean**
CR Dhan 201	1.83	1.70	1.76	1.55	1.54	1.55
CR Dhan 202	1.44	1.20	1.32	1.70	1.75	1.72
CR Dhan 203	1.70	1.66	1.68	1.21	1.60	1.40
CR Dhan 204	2.43	1.77	2.10	1.45	1.90	1.68
CR Dhan 300	1.91	1.43	1.67	1.62	1.31	1.47
CR Dhan 303	1.92	1.61	1.77	1.43	1.56	1.49
CR Dhan 304	1.80	1.58	1.69	1.33	1.35	1.34
CR Dhan 305	1.78	0.97	1.37	1.38	1.32	1.35
Naveen	1.71	1.45	1.58	1.73	1.81	1.77
Swarna	1.51	1.84	1.68	1.40	1.78	1.59

Varieties	Zero till			Conventional		
	Residue	No residue	Mean	Residue	No residue	Mean
Mean	1.80	1.52	1.66	1.48	1.59	1.54

Yield of Rice-green gram cropping system under CA

The experiment was laid out in a split-plot design. The main plot treatments comprised of two cropping systems under CA viz., (1) zero tillage DSR in wet season followed by zero tillage green gram in dry season (ZT-DSR-ZT-GG), (2) zero tillage mechanical transplanted rice in wetseason followed by zero tillage green gram in dry season (ZT-TPR-ZT-GG), and (3) conventional tillage system of rice- green gram (CT-DSR-CT-GG) as control.

Rice and green gram yield were significantly influenced by CA practices. Rice yield in ZT-TPR-ZT-GG was at par with CT-DSR-CT-GG and significantly higher than ZT-DSR-ZT-GG. Our results reveal that among the zero tillage systems, TPR is superior to DSR in terms of rice yields. The difference in the yields of green gram varieties was non-significant and their interaction with tillage practices was also non-significant.

Weed density and biomass at 60 DAS in chickpea under maize-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 81.0 no./m^2 and 44.4 g/m^2, respectively. The comparatively lower weed density and biomass were measured in the ZTR-ZTR-ZTR but was statistically comparable. The weed density and biomass of *Avenaludoviciana*, *Dicanthium annulatum andSonchus oleraceus* were significantly higher in ZTR-ZTR-ZTR and lowest in CT-CT-CT, 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 (BLWs).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 191.5 no./m^2 and 130.4 g/m^2, respectively and the lowest in IWM (pendimethalin 678 g/ha *fb*HW) followed by herbicide rotation (pendimethalin 678 g/ha*fb* topramezone 20.16 g/ha) (Table 32). Likewise, WCE was comparable with both the establishment methods, whereas WCI was 7.3% better in the ZTR-ZTR-ZTRover the CT-CT-CT system. Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 85.0 and 93.6%, respectively followed by herbicide rotation and recommended herbicide over weedy check.

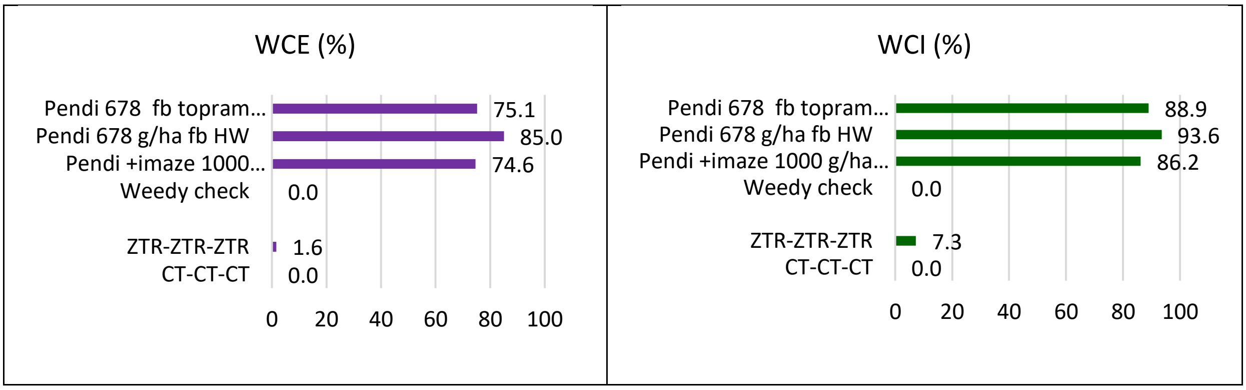


Fig 43: Weed control efficiency (%) and weed control index (%) as influenced by crop establishment methods and weed management practices in wheat

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

Between the crop establishment methods, plant height at harvest and leaf area at 60 DAS were higher with the CT-CT-CT system but was comparable. Contrarily, plant biomass, branches/plant, pods/plant, seeds/plant and seed index were higher with the ZTR-ZTR-ZTR system but at par to the CT-CT-CT system (Table 35). Among weed management practices, plant height at harvest and leaf area at 60 DAS were at par to weed management practices. However, plant biomass, branches/plant, pods/plant, seeds/plant 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. The interaction between crop establishment methods and weed management practices was non-significant.

Table 35: Effect of crop establishment methods and weed management practices on growth and yield parameters of wheat under maize-chickpea-greengram system

Treatment	Plant height (cm)	Leaf area (cm^2)	Plant Dry weight (g)	Branches/ plant	Pods/ plant	Seed/ plant	Seed/ pod	Seed index
Crop establishment methods (C)								
CT-CT-CT	63.23	328.62	9.54	4.92	58.08	103.42	1.73	16.38
ZTR-ZTR-ZTR	59.20	278.25	9.74	5.08	59.17	108.75	1.79	16.73
SEm±	0.68	9.84	0.19	0.16	0.33	1.73	0.02	0.04
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	0.24
Weed management practices (W)								
W1	58.85	229.42	7.98	2.83	19.83	30.17	1.53	15.62
W2	60.20	303.16	9.97	5.50	69.50	126.00	1.81	16.82
W3	63.43	360.22	10.43	6.17	75.33	139.50	1.85	16.98
W4	62.27	320.94	10.19	5.50	69.83	128.67	1.84	16.80
SEm±	1.78	43.59	0.41	0.21	1.30	2.69	0.02	0.07
CD (p=0.05)	NS	NS	1.26	0.65	4.01	8.30	0.07	0.22
C X W	NS	NS	NS	NS	NS	NS	NS	NS

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

Between the crop establishment methods, the seed yield of chickpea was recorded higher in the CT-CT-CT system (1863 kg/ha) over ZTR-ZTR-ZTR system. However, haulm and biological yield, and harvest index were statistically at par. Among weed management practices, weedy check has the lowest grain, straw and biological yields (229, 682 and 910 kg/ha, respectively). The highest crop yields were obtained under IWM (2411, 4288 and 6699 kg/ha, respectively) followed by herbicide rotation and recommended herbicides (Table 36). 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 36: Effect of crop establishment methods and weed management practices on seed and straw yield of wheat under maize-chickpea-greengram system

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	HI (%)
Crop establishment methods (C)				
CT-CT-CT	1863.17	3578.33	5441.50	32.02
ZTR-ZTR-ZTR	1750.50	3314.42	5064.92	32.98
SEm±	14.10	259.08	253.43	2.11
CD (p=0.05)	85.79	NS	NS	NS
Weed management practices (W)				
W1	228.67	681.67	910.33	25.01
W2	2240.00	4523.33	6763.33	33.21
W3	2410.83	4288.17	6699.00	36.25
W4	2347.83	4292.33	6640.17	35.53
SEm±	61.82	186.81	233.65	0.95
CD (p=0.05)	190.48	575.60	719.93	2.91
C X W	NS	NS	NS	NS

Greengram 2022

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

At 45 days after sowing (DAS), the relative weed density in greengram under the study area was *Echinochloacolona* (44%),*Cyperusrotundus* (22%), *Dinebra retroflexa* (12%), *Digitaria sanguinalis* (9%) and other weeds like *Alternanthera sessilis*, *Physalis minima*, *Amaranthus viridis*,*Phyllanthus sp. Eleucine indica*, *Cynadon dactylon*, *Convolvulus arvensis etc.* Likewise, relative weed biomass recorded the highest for *Echinochloacolona* (55%),*Cyperusrotundus* (9%), *Digitaria sanguinalis* (8%), *Dinebra retroflexa* (8%), and other weeds (Fig 44).

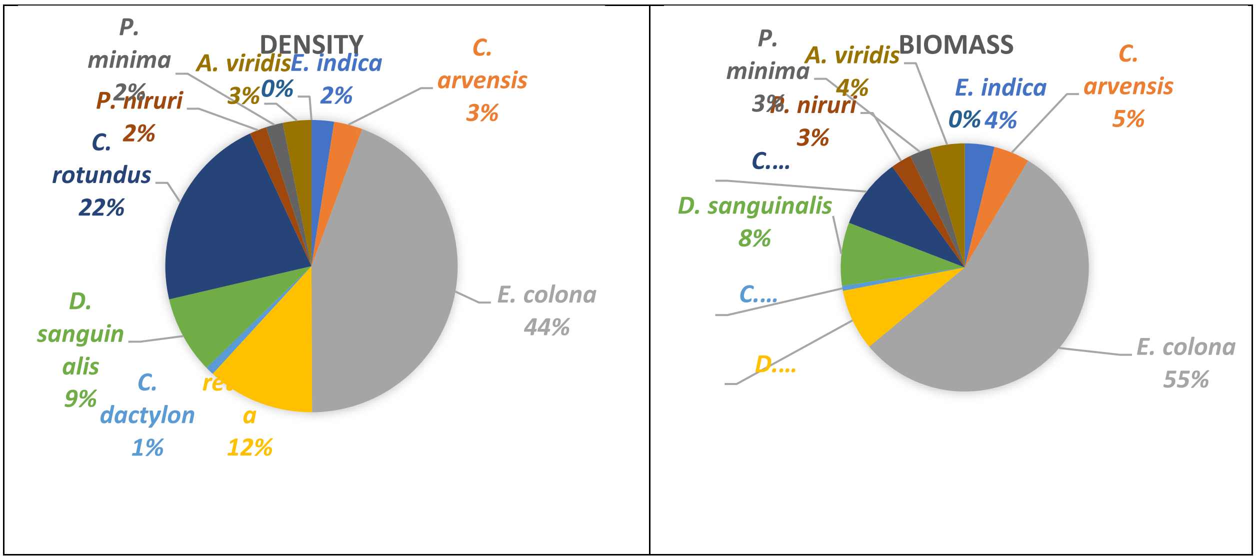


Fig 44: Relative weed density and biomass at 60 DAS in greengram under maize-wheat-greengram cropping system

Table 37: Effect of crop establishment methods and weed management practices on density and biomass of different weed species in greengram at 45 DAS under maize-wheat-greengram system

Treatment	*E. colona*	*D. sanguinalis*	*C. arvensis*	*D. annulatum*	*Phyllanthus sp.*	Others weeds
	Weed density (no./m^2)					
Crop establishment methods (C)						
CT-CT-CT	3.76(19.83)	3.15(10.08)	1.85(3.50)	0.71(0.00)	1.31(1.58)	5.78(38.50)
ZTR-ZTR-ZTR	3.54(17.08)	2.86(9.75)	1.40(1.83)	1.47(2.08)	0.71(0.00)	4.82(30.17)
SEm±	0.20	0.23	0.12	0.11	0.09	0.14
CD (p=0.05)	NS	NS	NS	0.69	0.56	0.83
Weed management practices (W)						
W1	7.03(49.83)	4.69(21.83)	2.03(4.17)	1.41(2.17)	1.40(2.00)	9.17(84.33)
W2	4.48(19.83)	2.67(7.00)	1.96(3.50)	1.18(1.17)	1.00(0.67)	5.45(29.33)
W3	1.41(1.67)	2.26(5.00)	1.01(1.00)	0.71(0.00)	0.79(0.17)	2.53(6.50)
W4	1.67(2.50)	2.40(5.83)	1.51(2.00)	1.05(0.83)	0.85(0.33)	4.07(17.17)
SEm±	0.29	0.17	0.23	0.14	0.13	0.22
CD (p=0.05)	0.88	0.54	0.72	0.43	0.41	0.67
C X W	NS	0.76	NS	0.60	0.58	0.94
	Weed biomass (g/m^2)					
Crop establishment methods (C)						
CT-CT-CT	4.15(29.64)	2.29(5.58)	1.78(3.33)	0.71(0.00)	1.28(1.56)	3.68 (17.88)
ZTR-ZTR-ZTR	3.58(20.71)	2.11(5.44)	1.34(1.58)	1.32(1.75)	0.71(0.00)	3.32(15.60)
SEm±	0.21	0.14	0.09	0.09	0.07	0.07
CD (p=0.05)	NS	NS	NS	0.52	0.42	NS
Weed management practices (W)						
W1	8.84(80.16)	3.94(15.17)	2.20(5.03)	1.35(1.82)	1.46(2.28)	6.79(45.94)
W2	4.39(18.91)	1.86(3.11)	1.83(2.96)	1.13(0.98)	0.98(0.61)	4.16(16.87)

W3	1.01(0.55)	1.45(1.70)	0.93(0.60)	0.71(0.00)	0.75(0.07)	1.20(1.01)
W4	1.23(1.08)	1.55(2.06)	1.28(1.25)	0.86(0.70)	0.79(0.15)	1.86(3.15)
SEm±	0.34	0.12	0.20	0.11	0.12	0.13
CD (p=0.05)	1.04	0.37	0.61	0.33	0.36	0.40
C X W	NS	0.52	0.86	0.47	0.50	NS

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

At 45 DAS, under crop establishment methods, the total weed density and biomass were recorded higher in the conventional system (CT-CT-CT) with 73.5 no./m^2 and 58.0 g/m^2, respectively. The lowest total weed density and biomass were measured in the ZTR-ZTR-ZTR with 60.9 no./m^2 and 44.9 g/m^2,respectively(Table 38). Likewise, WCE was better with ZTR-ZTR-ZTR(17.1%) over CT-CT-CT system. WCI followed the trend of WCE and recorded the highest with ZTR-ZTR-ZTR (22.6%) over the CT-CT-CT system (Fig 45).
Among weed management practices, weedy check recorded the highest total weed density and biomass with 164.1 no./m^2 and 150.4 g/m^2, respectively and the lowest in IWM (pendimethalin 678 g/ha *fb*HW) followed by herbicide rotation (pendimethalin 678 g/ha*fb* imazethapyr 100 g/ha) (Table 38). Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 91.3 and 97.4%, respectively followed by herbicide rotation and recommended herbicide over weedy check.

Table 38: Effect of crop establishment methods and weed management practices on group wise weed density and biomass, and total weeds in greengram at 45 DAS under maize-wheat-greengram system

Treatment	**Total grassy weeds**	**Total broad-leaved weeds**	**Sedges**	**Total weeds**
	Weed density (no./m^2)			
Crop establishment methods (C)				
CT-CT-CT	6.25(45.58)	2.81(9.50)	3.98(18.42)	7.95(73.50)
ZTR-ZTR-ZTR	5.76(42.58)	2.27(6.00)	3.11(12.33)	6.90(60.92)
SEm±	0.20	0.20	0.13	0.16
CD (p=0.05)	NS	NS	0.78	0.96
Weed management practices (W)				
W1	10.34(106.67)	4.15(17.17)	6.31(40.50)	12.81(164.13)
W2	6.69(44.50)	2.84(8.17)	3.04(8.83)	7.85(61.50)
W3	2.97(8.67)	1.10(1.17)	2.10(4.50)	3.77(14.33
W4	4.02(16.50)	2.08(4.50)	2.74(7.67)	5.27(28.67)
SEm±	0.21	0.30	0.28	0.27
CD (p=0.05)	0.66	0.94	0.85	0.83
C X W	NS	NS	0.78	0.96
	Weed biomass (g/m^2)			
Crop establishment methods (C)				
CT-CT-CT	5.48(43.83)	2.65(9.27)	1.98(4.89)	6.36(57.99)
ZTR-ZTR-ZTR	4.89(36.23)	2.20(5.97)	1.58(2.71)	5.51(44.90)
SEm±	0.24	0.15	0.08	0.17
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	10.85(118.62)	4.46(19.96)	3.43(11.86)	12.21(150.44)
W2	5.85(33.80)	2.79(7.94)	1.47(1.71)	6.62(43.45)
W3	1.74(2.63)	0.97(0.67)	1.04(0.63)	2.06(3.39)
W4	2.32(5.07)	1.48(1.91)	1.19(0.98)	2.85(7.96)
SEm±	0.25	0.27	0.15	0.30
CD (p=0.05)	0.77	0.82	0.45	0.93
C X W	NS	NS	0.64	NS

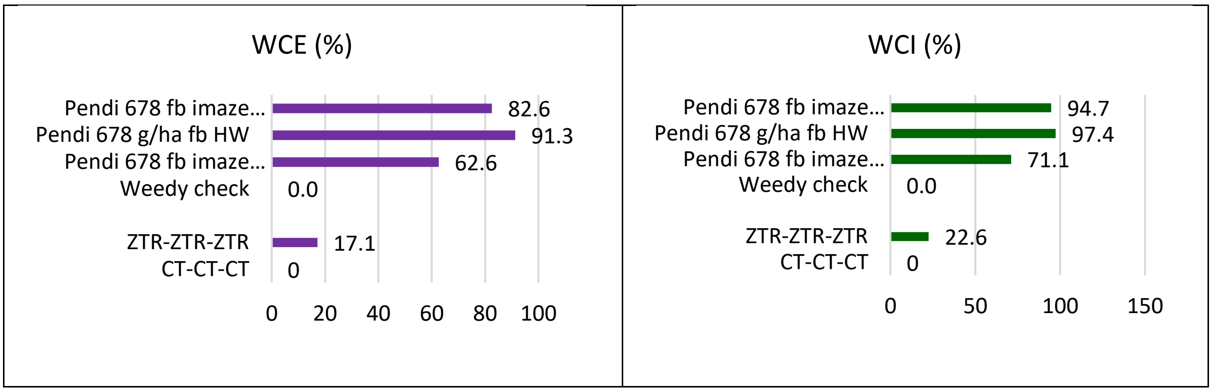


Fig 45: Weed control efficiency (%) and weed control index (%) as influenced by crop establishment methods and weed management practices in greengram under maize-chickpea-greengram system

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

Between the crop establishment methods, plant height at harvest, leaf area, plant biomass, no. of seeds/pod and test weight were higher with the ZTR-ZTR-ZTR system but statistically comparable to the CT-CT-CT system, whereas no. of pods/plant and pod length were significantly higher with the ZTR-ZTR-ZTR system (Table 39).

Among weed management practices, all the growth parameters viz. plant height, leaf area and plant biomass 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 like no. of pods/plant, no. of seeds/pod and pod length were recorded highest with IWM followed by herbicide rotation and recommended herbicide. The lowest yield parameters were recorded with weedy check (Table 39). The interaction between crop establishment methods and weed management practices was found to be non-significant for growth and yield parameters.

Table 39: Effect of crop establishment methods and weed management practices on growth and yield parameters in greengram under maize-wheat-greengram system

Treatment	Plant height (cm)	Leaf area (45 DAS)	Plant biomass (g/plant)	No. of pods/plant	No. of seeds/pod	Pod length (cm)	Test weight (g)
Crop establishment methods (C)							
CT-CT-CT	62.46	1214.52	30.22	27.72	8.66	8.22	34.58
ZTR-ZTR-ZTR	65.56	1332.76	33.14	34.07	9.35	8.99	36.01
SEm±	1.05	62.19	0.91	0.57	0.12	0.10	0.34
CD (p=0.05)	NS	NS	NS	3.49	NS	0.62	NS
Weed management practices (W)							
W1	58.01	718.36	21.65	16.39	7.25	7.00	33.85
W2	63.36	1131.36	32.07	31.07	9.03	8.01	34.75
W3	67.99	1676.67	36.85	38.29	10.15	9.97	36.71
W4	66.68	1568.17	36.14	37.83	9.58	9.44	35.87
SEm±	1.47	105.94	1.21	1.19	0.46	0.21	0.78
CD (p=0.05)	4.52	326.45	3.72	3.67	1.41	0.65	NS
C X W	NS	NS	NS	NS	NS	NS	NS

Seed and haulm yield of Greengram

Between the crop establishment methods, the greengram yields (seed, haulm and biological yield) were statistically significant and recorded a higher value with the ZTR-ZTR-ZTR system. The highest seed yield (865 kg/ha), haulm yield (2265 kg/ha) and biological yield (3130 kg/ha) were higher with the ZTR-ZTR-ZTR system, but the harvest index was statistically at par between crop establishment methods. 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 40). Among weed management practices, weedy check has the lowest seed, haulm and biological yields (324, 1141 and 1464 kg/ha, respectively). The highest seed yield was obtained under IWM (1070 kg/ha), but haulm yield and biological yields were more in herbicide rotation (2527 and 3576 kg/ha, respectively) followed by IWM 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 all the yield parameters except test weight.

Table 40: Effect of crop establishment methods and weed management practices on yield of greengram under maize-wheat-greengram system

Treatment	Grain yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Crop establishment methods (C)				
CT-CT-CT	776.59	1806.33	2582.92	28.21
ZTR-ZTR-ZTR	865.15	2265.27	3130.42	27.18
SEm±	12.53	52.13	64.35	0.20
CD (p=0.05)	76.24	317.20	391.57	NS
Weed management practices (W)				
W1	323.47	1140.53	1464.00	21.27
W2	840.18	2144.15	2984.33	28.21
W3	1070.33	2331.67	3402.00	31.71
W4	1049.50	2526.83	3576.33	29.58
SEm±	29.67	74.14	91.46	0.79
CD (p=0.05)	91.43	228.43	281.82	2.43
C X W	NS	NS	NS	3.44

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

At 45 days after sowing (DAS), the relative weed density in greengram under the study area was *Cyperusrotundus* (36%), *Echinochloacolona* (29%), *Dinebra retroflexa* (14%), *Digitaria sanguinalis* (9%), *Eleucine indica* (4%), and other weeds like, *Alternanthera sessilis, Phyllanthus sp. Amaranthus viridis, Cynadon dactylon, Convolvulus arvensis etc.* Likewise, relative weed biomass recorded the highest for *Echinochloacolona* (60%), *Dinebra retroflexa* (9%), *Digitaria sanguinalis* (8%),*Cyperusrotundus* (6%), and other weeds (Fig 46).

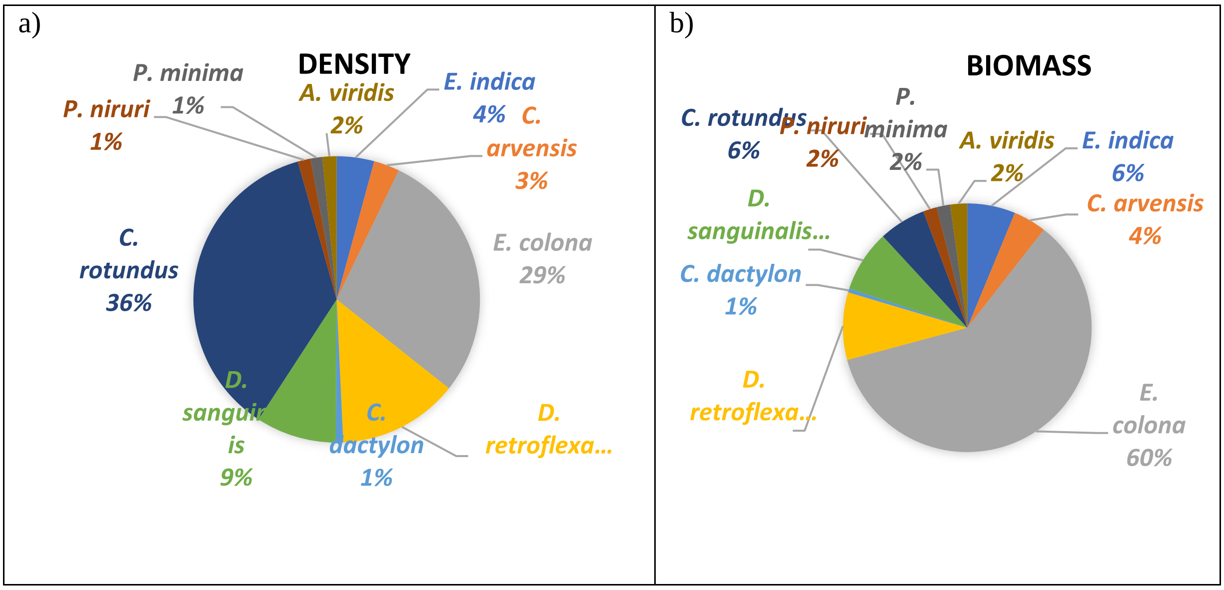


Fig 46: Relative weed density and biomass at 60 DAS in greengram under maize-chickpea-greengram cropping system

Table 41: Effect of crop establishment methods and weed management practices on density and biomass of different weed species in greengram at 60 DAS under maize-chickpea-greengram system

Treatment	*E. colona*	*D. sanguinalis*	*C. arvensis*	*D. annulatum*	*Phyllanthus sp.*	Others weeds
	Weed density (no./m²)					
Crop establishment methods (C)						
CT-CT-CT	3.26(17.67)	2.34(6.67)	1.81(3.67)	0.71(0.00)	1.32(1.58)	4.93(38.17)
ZTR-ZTR-ZTR	2.61(10.67)	2.73(8.50)	1.33(1.92)	1.95(3.92)	0.71(0.00)	4.09(23.00)
SEm±	0.18	0.07	0.06	0.12	0.14	0.17
CD (p=0.05)	NS	NS	0.34	0.71	NS	NS
Weed management practices (W)						
W1	6.76(47.33)	4.47(19.67)	2.00(4.00)	1.41(2.00)	1.28(1.50)	9.2 (87.83)
W2	2.48(6.00)	2.29(5.33)	2.41(6.00)	1.61(3.00)	0.94(0.50)	5.08(25.67)
W3	0.71(0.00)	1.39(1.67)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.79(0.17)
W4	1.78(3.33)	1.99(3.67)	1.17(1.17)	1.58(2.83)	1.13(1.17)	2.96(8.67)
SEm±	0.37	0.25	0.28	0.06	0.11	0.22
CD (p=0.05)	1.13	0.77	0.87	0.20	0.35	0.67
C X W	NS	NS	NS	0.28	0.50	0.95
	Weed biomass (g/m²)					
Crop establishment methods (C)						
CT-CT-CT	3.82(29.18)	1.83(4.23)	1.85(3.97)	0.71(0.00)	1.21(1.22)	3.10(14.59)
ZTR-ZTR-ZTR	2.89(14.77)	2.00(4.60)	1.33(1.92)	1.54(3.29)	0.71(0.00)	3.45(17.04)
SEm±	0.32	0.05	0.05	0.08	0.10	0.10
CD (p=0.05)	NS	NS	0.30	0.50	NS	NS
Weed management practices (W)						
W1	8.54(77.76)	3.73(13.52)	2.19(4.96)	1.28(1.68)	1.29(1.53)	6.70(44.88)
W2	2.86(8.69)	1.64(2.40)	2.44(6.18)	1.38(2.52)	0.94(0.51)	3.98(15.81)
W3	0.71(0.00)	0.99(0.53)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.72(0.02)
W4	1.31(1.43)	1.29(1.21)	1.01(0.65)	1.13(2.38)	0.90(0.40)	1.69(2.54)
SEm±	0.55	0.16	0.28	0.05	0.07	0.20
CD (p=0.05)	1.70	0.49	0.85	0.15	0.22	0.61
C X W	NS	0.52	NS	0.21	0.31	NS

Weed density and biomass at 45 DAS in greengram under maize-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 weed density in the ZT system was 70.4 no./m² and biomass was higher in the CT system (53.2 g/m²) (Table 41 & 42). The weed density and biomass of *E. colona, C. arvensis and other weeds were more in CT system, whereas rest of the grassy weeds were more with ZTR system. All the broadleaf weeds and sedges except A. sessilis were more in the CT system than the ZT system.* In general, ZTR systems have more grassy weeds and CT systems have more broadleaf weeds (BLWs) and sedges. Likewise, the WCE was 29.3% more in ZTR-ZTR-ZTR system, while WCI recorded 23.8% more over CT-CT-CT.

Among weed management practices, weedy check recorded the highest total weed density and biomass with 162.3 no./m² and 144.1 g/m², respectively and the lowest in IWM (pendimethalin 678 g/ha *fb*HW) followed by herbicide rotation (pendimethalin 678 g/ha*fb* imazethapyr 100 g/ha). Weed management practices significantly influenced the WCE and WCI, and recorded the highest in IWM with 98.9 and 99.6%, respectively followed by herbicide rotation and recommended herbicide over weedy check (Fig 47).

Table 42: Effect of crop establishment methods and weed management practices on group wise weed density and biomass, and total weeds in greengram at 60 DAS under maize-chickpea-greengram system

Treatment	Total grassy weeds	Total broadleaved weeds	Sedges	Total weeds
	Weed density (no./m²)			

Crop establishment methods (C)				
CT-CT-CT	5.01(37.92)	2.59(8.00)	3.61(21.83)	6.67(58.26)
ZTR-ZTR-ZTR	5.31(36.92)	2.75(9.58)	1.21(1.50)	6.02(70.43)
SEm±	0.20	0.10	0.12	0.18
CD(p=0.05)	NS	NS	0.76	NS
Weed management practices (W)				
W1	10.18(104.50)	4.30(18.50)	5.26(39.33)	12.61(162.33)
W2	5.43(29.67)	3.41(11.67)	2.23(5.17)	6.83(46.50)
W3	1.39(1.67)	0.79(0.17)	0.71(0.00)	1.43(1.83)
W4	3.64(13.83)	2.17(4.83)	1.44(2.17)	4.51(20.83)
SEm±	0.28	0.29	0.19	0.31
CD (p=0.05)	0.86	0.91	0.57	0.95
C X W	NS	NS	0.81	NS
	Weed biomass (g/m^2)			
Crop establishment methods (C)				
CT-CT-CT	4.80(42.11)	2.50(8.02)	1.59(3.07)	5.56(53.19)
ZTR-ZTR-ZTR	4.45(29.63)	2.73(10.04)	1.04(0.84)	5.21(40.51)
SEm±	0.22	0.11	0.09	0.14
CD(p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	10.62(116.40)	4.61(21.31)	2.44(6.42)	11.87(144.13)
W2	4.72(22.01)	3.50(12.39)	1.24(1.11)	5.98(35.52)
W3	0.99(0.53)	0.72(0.02)	0.71(0.00)	1.00(0.56)
W4	2.17(4.53)	1.62(2.38)	0.87(0.28)	2.69(7.20)
SEm±	0.40	0.27	0.12	0.40
CD (p=0.05)	1.23	0.82	0.35	1.25
C X W	NS	NS	0.50	NS

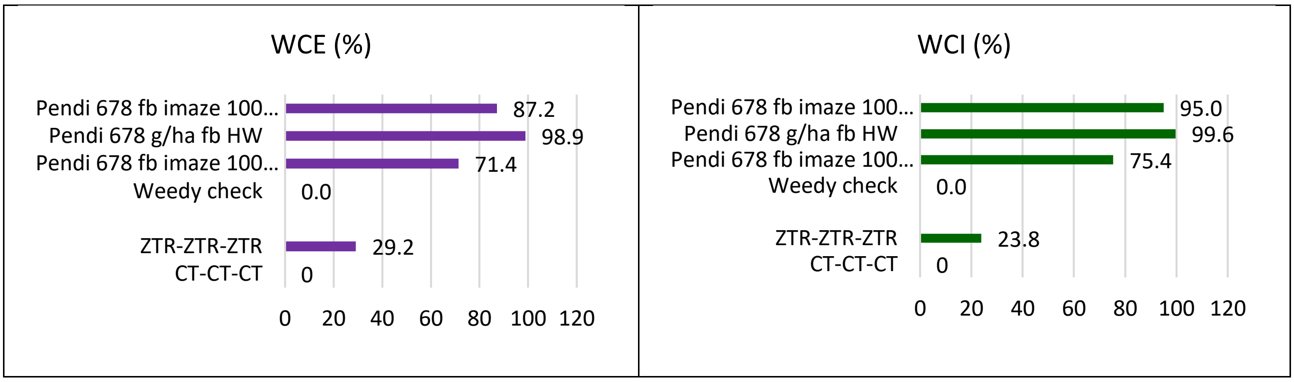


Fig 47: Weed control efficiency (%) and weed control index (%) as influenced by crop establishment methods and weed management practices in greengram under maize-chickpea-greengram system

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

Between the crop establishment methods, all the growth parameters (plant height at harvest, leaf area and plant biomass) and yield attributes (no. of pods/plant, no. of seeds/pod and test weight) were higher with the ZTR-ZTR-ZTR system but comparable to the CT-CT-CT system. Whereas pod length was significantly more with the ZTR-ZTR-ZTR system (Table 43).

Among weed management practices, all the growth parameters, viz. plant height at harvest, leaf area and plant biomass 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 (no. of pods/plant, no. of seeds/pod, pod length and test weight) 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 growth and yield parameters.

Table 43: Effect of crop establishment methods and weed management practices on growth and yield parameters in greengram under maize-chickpea-greengram system

Treatment	Plant height (cm)	Leaf area (45 DAS)	Plant biomass (g/plant)	No. of pods/plant	No. of seeds/pod	Pod length (cm)	Test weight (g)
Crop establishment methods (C)							
CT-CT-CT	64.29	1356.09	32.84	29.08	9.08	8.48	34.75
ZTR-ZTR-ZTR	65.42	1534.78	38.89	36.50	9.92	9.21	36.92
SEm±	1.95	88.06	1.37	2.08	0.16	0.10	0.52
CD (p=0.05)	NS	NS	NS	NS	NS	0.60	NS
Weed management practices (W)							
W1	61.84	619.38	26.84	20.50	8.17	7.25	34.00
W2	63.32	1267.70	31.36	31.67	9.17	8.27	35.00
W3	68.03	1984.67	43.33	40.17	10.50	10.21	37.50
W4	66.21	1910.00	41.94	38.83	10.17	9.65	36.83
SEm±	1.36	69.78	1.35	2.24	0.33	0.21	0.49
CD (p=0.05)	4.20	215.01	4.17	6.89	1.03	0.63	1.50
C X W	NS	NS	NS	NS	NS	NS	NS

Seed and haulm yield of greengram

The crop establishment methods and weed management practices significantly influenced the seed and biological yield of greengram. Between the crop establishment methods, the greengram yields (seed and biological yield) were statistically significant and recorded a higher value with the ZTR-ZTR-ZTR system. The highest seed yield (948 kg/ha) and biological yield (3211 kg/ha) were higher with the ZTR-ZTR-ZTR system, but the haulm yield and harvest index were statistically at par between the crop establishment methods. 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 44). Among weed management practices, weedy check has the lowest seed, haulm and biological yields (293, 1172 and 1466 kg/ha, respectively). The highest seed yield obtained under IWM (1155 kg/ha) followed by herbicide rotation and recommended herbicides, whereas haulm yield and biological yields were more in herbicide rotation (2558 and 3684 kg/ha, respectively) but was at par to IWM. 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 seed and haulm yield and harvest index, but significant for biological yields.

Table 44: Effect of crop establishment methods and weed management practices on growth and yield parameters in greengram under maize-chickpea-greengram system

Treatment	Grain yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)
Crop establishment methods (C)				
CT-CT-CT	789.88	1790.62	2580.50	29.16
ZTR-ZTR-ZTR	947.99	2263.01	3211.00	28.92
SEm±	5.25	100.02	99.87	1.71
CD (p=0.05)	31.93	NS	607.70	NS
Weed management practices (W)				
W1	293.45	1172.38	1465.83	20.41
W2	900.78	2018.22	2919.00	30.23
W3	1155.35	2358.65	3514.00	34.02
W4	1126.17	2558.00	3684.17	31.50
SEm±	38.33	84.45	90.83	2.08
CD (p=0.05)	118.10	260.22	279.87	6.42
C X W	NS	NS	395.80	NS

Maize-2022

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 60DAS, the relative density of weeds indicated that *Cyperus sp.* (28%), *Dinebra retroflexa* (26%), *Echinochloacolona*(14%), *Phyllanthus urinaria* (10%), *Eleucine indica* (6%) and *Digitariasanguinalis*(5%) were the major weeds. With the progress of time, the weed-like *Alternanthera sessilis, Oldenlandia sp., Convolvulus arvensis, Mecardonia procumbens and Trianthema portulacastrum* became other weeds. Likewise, relative weed biomass followed a similar trend, *Dinebra retroflexa* (30%), *Cyperus sp.* (25%), *Echinochloacolona*(14%), *Phyllanthus urinaria* (9%), *Eleucine indica* (5%) and *Digitariasanguinalis*(5%) as the dominant weeds, apart from these other weeds were minor at 60 DAS (Fig 48).

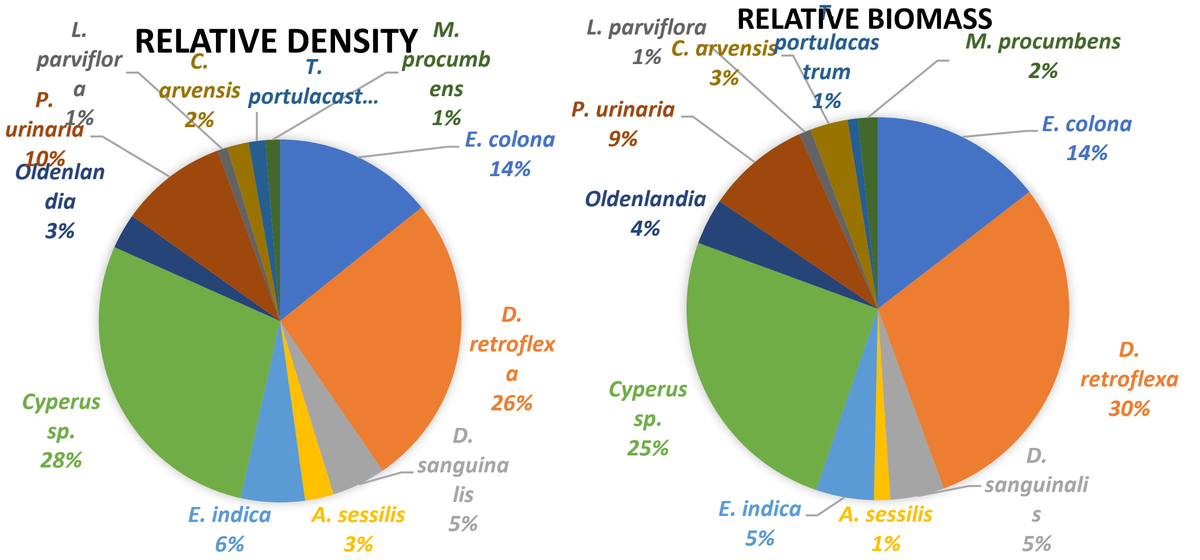


Fig 48: Relative weed density and biomass at 60 DAS in greengram under maize-wheat-greengram cropping system

Table 45: Effect of crop establishment methods and weed management practices on weed density and biomass in maize under maize-wheat-greengram system

Treatment	*Echinocloa spp.*	*D. retroflexa*	*A. sessilis*	*Cyperus spp.*	*Phyllanthus sp.*	*C. arvensis*	Others
	Weed density (no./m^2)						
Crop establishment methods (C)							
CT-CT-CT	3.46(13.67)	3.79(19.67)	1.67(2.83)	4.95(28.00)	2.35(7.08)	1.69(2.75)	4.09(18.33)
ZTR-ZTR-ZTR	2.88(9.50)	4.56(26.00)	1.41(1.83)	4.26(19.83)	1.70(3.58)	1.36(1.85)	3.79(15.50)
SEm±	0.13	0.12	0.09	0.11	0.17	0.14	0.27
CD (p=0.05)	NS	0.75	NS	0.67	NS	NS	NS
Weed management practices (W)							
W1	5.18(26.83)	7.97(64.33)	2.11(4.67)	7.23(52.67)	4.05(16.50)	2.00(3.67)	6.05(36.50)
W2	3.40(11.67)	3.93(15.50)	1.52(2.17)	4.90(24.00)	1.68(2.67)	1.50(2.00)	3.68(13.33)
W3	2.14(4.33)	2.70(7.17)	1.38(1.50)	3.15(9.50)	1.34(1.50)	1.25(1.50)	3.26(10.17)
W4	1.96(3.50)	2.09(4.33)	1.17(1.00)	3.15(9.50)	1.03(0.67)	1.35(1.50)	2.77(7.67)
SEm±	0.30	0.38	0.24	0.22	16.00	0.25	0.25
CD (p=0.05)	0.91	1.16	NS	0.68	0.51	NS	0.78
C X W	NS	NS	NS	NS	NS	NS	NS
	Weed biomass (g/m^2)						
Crop establishment methods (C)							
CT-CT-CT	2.58(7.82)	2.72(11.07)	1.48(2.28)	2.25(5.8)	1.84(4.47)	1.50(2.04)	2.75(8.73)

ZTR-ZTR-ZTR	2.30(6.34)	3.26(14.95)	1.37(1.74)	2.03(4.46)	1.37(2.05)	1.28(1.42)	2.78(8.52)
SEm±	0.11	0.15	0.10	0.07	0.15	0.09	0.18
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)							
W1	4.46(9.65)	6.39(41.2)	2.20(5.02)	3.76(13.77)	3.31(10.97)	2.05(3.88)	4.17(21.87)
W2	2.52(6.18)	2.85(7.97)	1.37(1.62)	2.15(4.18)	1.30(1.36)	1.36(1.5)	2.55(6.17)
W3	1.93(1.5)	1.41(1.56)	1.07(0.68)	1.23(4.03)	0.95(0.44)	0.96(0.54)	1.82(2.87)
W4	1.37(0.98)	1.30(1.32)	1.06(0.71)	1.43(1.55)	0.87(0.28)	0.18(1.18)	1.97(3.59)
SEm±	0.22	0.26	0.22	0.09	0.11	0.19	0.17
CD (p=0.05)	0.68	0.79	0.69	0.27	0.35	0.57	0.51
C X W	NS	NS	NS	NS	0.49	NS	NS

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 was recorded as higher in CT-CT-CT (92.3 no./m^2); however, weed biomass was at between the establishment methods (Table 45 & 46). The weed density and biomass of *D. retroflexa was higher in the ZTR system, whereas rest of the grassy weeds were more with the CT system.* Likewise, WCE was 15.7% more with ZTR-ZTR-ZTR system, whereas WCI was 6.1% better in ZTR-ZTR-ZTR over the CT-CT-CT.

Among weed management practices, weedy check recorded the highest total weed density and biomass with 205.2 no./m^2 and 116.4 g/m^2, respectively and the lowest density in atrazine + topramezone (500+25.2 g/ha) but weed biomass was lowest in IWM (atrazine + pendimethalin 500 + 500 g/ha *fb*HW) followed by herbicide rotation and recommended herbicide. The WCE was highest with herbicide rotation (86.3%), whereas WCI was more in IWM (92.6%) but both were close to each other followed by recommended herbicide over weedy check (Fig 49).

Table 46: 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./m^2)			
Crop establishment methods (C)				
CT-CT-CT	6.02(43.83)	4.25(20.50)	4.95(28.00)	8.86(92.33)
ZTR-ZTR-ZTR	6.33(47.58)	2.9(10.42)	4.26(19.83)	8.19(77.83)
SEm±	0.19	0.13	0.11	0.07
CD (p=0.05)	NS	0.78	0.17	0.40
Weed management practices (W)				
W1	10.72(115.00)	6.06(37.50)	7.23(52.67)	14.32(205.17)
W2	6.0(36.83)	3.15(10.50)	4.90(24.00)	8.45(71.33)
W3	4.19(17.17)	2.96(9.00)	3.15(9.50)	6.00(35.67)
W4	3.71(13.83)	2.18(4.83)	3.15(9.50)	5.32(28.17)
SEm±	0.33	0.32	0.22	0.25
CD (p=0.05)	1.01	0.98	0.68	0.79
C X W	NS	NS	NS	NS
	Weed biomass (g/m^2)			
Crop establishment methods (C)				
CT-CT-CT	4.30(24.77)	3.11(11.63)	2.25(5.80)	5.67(42.21)
ZTR-ZTR-ZTR	4.63(28.46)	2.3(6.79)	2.03(4.46)	5.53(39.71)
SEm±	0.18	0.06	0.07	0.13
CD (p=0.05)	NS	0.38	NS	NS
Weed management practices (W)				
W1	8.80(77.32)	4.99(25.27)	3.76(13.77)	10.79(116.36)
W2	4.37(18.80)	2.48(5.99)	2.15(4.18)	5.42(28.97)
W3	2.2(4.63)	1.80(2.95)	1.23(1.02)	3.01(8.61)
W4	2.44(5.71)	1.72(2.63)	1.43(1.55)	3.18(9.89)

SEm±	0.22	0.21	0.09	0.22
CD (p=0.05)	0.67	0.64	0.27	0.68
C X W	NS	NS	NS	NS

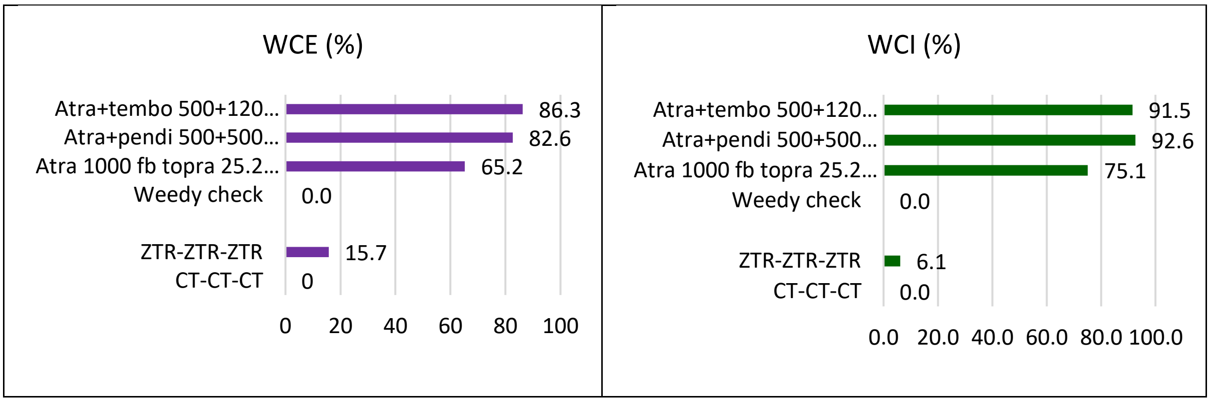


Fig 49: Weed control efficiency (%) and weed control index (%) as influenced by crop establishment methods and weed management practices in maize under maize-wheat-greengram system

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 47). Among weed management practices, all the growth and yield parameters (plant height, leaf area and plant biomass) and yield attributes (cobs/plant, row/cob, grains/cob, 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 47: 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)	Leaf Area (60 DAS)	Dry weight (g/plant)	Cob/plant	Row/cob	grains/cob	Cob length(cm)	Cob weight (g)	Seed index
Crop establishment methods (C)									
CT-CT-CT	217.78	4289.56	268.79	0.98	11.53	446.70	16.00	121.62	28.39
ZTR-ZTR-ZTR	226.49	4398.92	318.61	1.05	12.10	463.19	16.32	132.65	28.97
SEm±	0.72	72.53	14.83	0.02	0.37	0.39	0.17	2.24	0.93
CD (p=0.05)	4.37	NS	NS	NS	NS	2.38	NS	NS	NS
Weed management practices (W)									
W1	201.72	3711.33	227.18	0.97	9.43	246.97	14.20	100.50	26.74
W2	221.92	4155.43	270.33	1.00	12.07	499.83	16.63	124.90	28.33
W3	231.65	4711.68	321.49	1.03	12.63	535.07	16.86	136.78	29.57
W4	233.25	4798.53	355.79	1.07	13.13	537.91	16.94	146.36	30.09
SEm±	2.58	107.79	13.47	0.03	0.60	6.55	0.49	3.09	0.93
CD (p=0.05)	7.95	332.14	41.51	NS	1.84	20.18	1.50	9.53	NS
C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS

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

Between the crop establishment methods, the grain, straw, biological yield and harvest index were statistically comparable. However, the values of these parameters were more in the ZTR-ZTR-ZTR system (Table 48). Among weed management practices, weedy check has the lowest grain, straw, biological yield and harvest index (2216, 4189 and 6405 kg/ha, and 34.6%, respectively). The highest crop yields were obtained under herbicide rotation (7015, 10805 and 17820 kg/ha, and 39.4%, respectively) followed by IWM and recommended herbicides. The interaction between crop establishment methods and weed management practices was found to be non-significant except for the harvest index.

Table 48: Effect of crop establishment methods and weed management practices on yield in maize under maize-wheat-greengram system

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)
Crop establishment methods (C)				
CT-CT-CT	5291.85	8862.49	14154.33	36.73
ZTR-ZTR-ZTR	5756.84	9289.83	15046.67	37.98
SEm±	127.09	380.09	488.13	0.60
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	2215.72	4189.28	6405.00	34.57
W2	6094.19	10648.64	16742.83	36.61
W3	6772.89	10662.11	17435.00	38.88
W4	7014.57	10804.60	17819.17	39.36
SEm±	193.58	461.54	637.27	0.63
CD (p=0.05)	596.47	1422.13	1963.60	1.95
C X W	NS	NS	NS	2.75

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 60DAS, the relative density of weeds indicated that *Dinebra retroflexa* (30%), *Echinochloacolona*(17%), *Cyperus sp.* (13%), *Phyllanthus urinaria* (12%), *Eleucine indica* (9%) *Alternanthera sessilis* (5) and *Digitariasanguinalis*(5%) were the major weeds. With the progress of time, the weed-like *Oldenlandia sp.*, *Convolvulus arvensis*, *Mecardonia procumbens* and *Trianthema portulacastrum* became other weeds. Likewise, relative weed biomass followed a similar trend, *Dinebra retroflexa* (37%), *Echinochloacolona*(15%), *Phyllanthus urinaria* (12%), *Cyperus sp.* (11%), *Eleucine indica* (7%) and *Digitariasanguinalis*(4%) as the dominant weeds, apart from these other weeds were minor at 60 DAS (Fig 50).

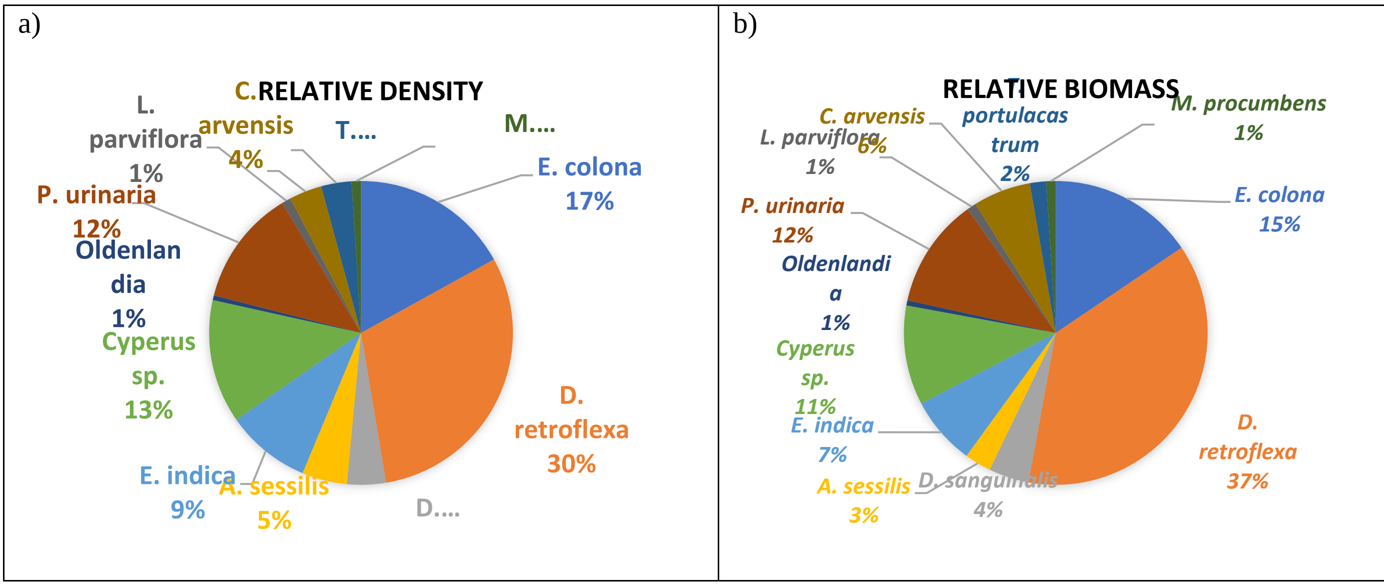


Fig 50: Relative weed density and biomass at 60 DAS in greengram under maize-wheat-greengram cropping system

Table 49: Effect of crop establishment methods and weed management practices on weed density and biomass in maize under maize-chickpea-greengram system

Treatment	*Echinocloa spp.*	*D. retroflexa*	*A. sessilis*	*Cyperus spp.*	*Phyllanthus sp.*	*C. arvensis*	Others
	Weed density (no./m²)						
Crop establishment methods (C)							
CT-CT-CT	3.30(12.42)	3.69(19.17)	1.34(1.50)	4.50(22.75)	2.26(6.25)	1.93(3.50)	3.75(15.33)
ZTR-ZTR-ZTR	2.67(8.33)	4.28(23.580	1.21(1.08)	3.79(16.00)	1.61(2.92)	1.59(2.25)	3.76(15.00)
SEm±	0.19	0.17	0.16	0.91	0.19	0.07	0.11
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)							
W1	5.00(25.00)	7.88(62.67)	1.60(2.17)	6.61(43.67)	3.60(13.17)	2.39(5.33)	5.66(31.83)
W2	3.14(9.50)	3.56(12.67)	1.36(1.50)	4.22(18.17)	1.70(3.17)	1.76(2.67)	3.79(14.00)
W3	2.10(4.17)	2.69(6.83)	1.11(0.83)	2.92(8.17)	1.22(1.17)	1.2(1.33)	2.69(8.33)
W4	1.72(2.83)	1.83(3.33)	1.03(0.67)	2.80(7.50)	1.11(0.83)	1.61(2.17)	2.62(6.50)
SEm±	0.25	0.33	0.14	0.20	0.19	0.15	0.21
CD (p=0.05)	0.76	1.00	NS	0.61	0.60	0.46	0.65
C X W	NS	NS	NS	NS	NS	NS	NS
	Weed biomass (g/m²)						
Crop establishment methods (C)							
CT-CT-CT	2.44(6.79)	2.74(11.86)	1.24(1.27)	2.00(4.7)	1.78(3.99)	1.75(2.94)	2.48(6.89)
ZTR-ZTR-ZTR	2.12(5.38)	3.07(13.49)	1.18(1.01)	1.93(4.09)	1.36(1.97)	1.56(2.34)	2.65(7.63)
SEm±	0.15	0.16	0.13	0.09	0.12	0.08	0.10
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
Weed management practices (W)							
W1	4.06(16.26)	6.49(42.22)	1.72(2.58)	3.47(11.63)	3.13(9.75)	2.58(6.25)	4.25(17.84)
W2	2.38(5.27)	2.45(5.7)	1.25(1.15)	1.97(3.52)	1.35(1.48)	1.62(2.2)	2.56(6.12)
W3	1.39(1.49)	1.45(1.64)	0.92(0.37)	1.25(1.08)	0.91(0.36)	0.97(0.49)	1.59(2.06)
W4	1.28(1.33)	1.2(1.16)	0.94(0.45)	1.36(1.35)	0.90(0.33)	1.44(1.62)	1.86(3.02)
SEm±	0.18	0.21	0.11	0.10	0.14	0.12	0.17
CD (p=0.05)	0.56	0.66	0.33	0.29	0.42	0.37	0.51
C X W	NS	NS	NS	NS	NS	NS	NS

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 (80.9 no./m² and 38.4 g/m², respectively) but both were statistically comparable (Table 49 & 50). The weed density and biomass of *D. retroflexa was higher in the ZTR system, whereas rest of the grassy weeds were more with the CT system.* Likewise, WCE was 14.5% more with ZTR-ZTR-ZTR system, whereas WCI was 6.4% better in ZTR-ZTR-ZTR over the CT-CT-CT (Fig 51).

Among weed management practices, weedy check recorded the highest total weed density and biomass with 183.8 no./m² and 106.5 g/m², respectively and the lowest density in atrazine + topramezone (500+25.2 g/ha) but weed biomass was lowest in IWM (atrazine + pendimethalin 500 + 500 g/ha *fb*HW) followed by herbicide rotation and recommended herbicide. The WCE was highest with herbicide rotation (87.0%), whereas WCI was more in IWM (93.0%) but both were close to each other followed by recommended herbicide over weedy check (Fig 51).

Table 50: 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	Total grassy weeds	Total broadleaved weeds	Sedges	Total weeds
	Weed density (no./m²)			
Crop establishment methods (C)				

CT-CT-CT	5.70(40.08)	4.02(18.08)	4.50(22.75)	8.27(80.92)
ZTR-ZTR-ZTR	6.00(42.83)	3.05(10.33)	3.7(6.00)	7.68(69.17)
SEm±	**0.21**	**0.14**	**0.19**	**0.12**
CD (p=0.05)	**NS**	**0.86**	**NS**	**NS**
Weed management practices (W)				
W1	10.34(107.17)	5.72(33.00)	6.61(43.67)	13.55(183.83)
W2	5.64(31.67)	3.44(11.83)	4.22(18.17)	7.85(51.67)
W3	3.99(15.50)	2.71(7.17)	2.92(8.17)	5.5(30.83)
W4	3.43(11.50)	2.26(4.83)	2.80(7.50)	4.92(23.83)
SEm±	**0.29**	**0.22**	**2.20**	**0.26**
CD (p=0.05)	**0.88**	**0.67**	**0.61**	**0.80**
C X W	NS	NS	NS	NS
	Weed biomass (g/m^2)			
Crop establishment methods (C)				
CT-CT-CT	4.15(23.48)	2.9(10.26)	2.10(4.70)	5.41(38.44)
ZTR-ZTR-ZTR	4.38(25.30)	2.37(6.52)	1.93(4.09)	5.25(35.91)
SEm±	**0.18**	**0.14**	**0.09**	**0.14**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**
Weed management practices (W)				
W1	8.49(72.16)	4.77(22.73)	3.47(11.63)	10.32(106.52)
W2	4.03(15.88)	2.52(6.04)	1.97(3.52)	5.08(25.44)
W3	2.20(4.37)	1.55(2.03)	1.25(1.08)	2.81(7.49)
W4	2.34(5.15)	1.78(2.76)	1.36(1.35)	3.10(9.27)
SEm±	**0.24**	**0.17**	**0.10**	**0.23**
CD (p=0.05)	**0.73**	**0.53**	**0.29**	**0.71**
C X W	NS	NS	NS	NS

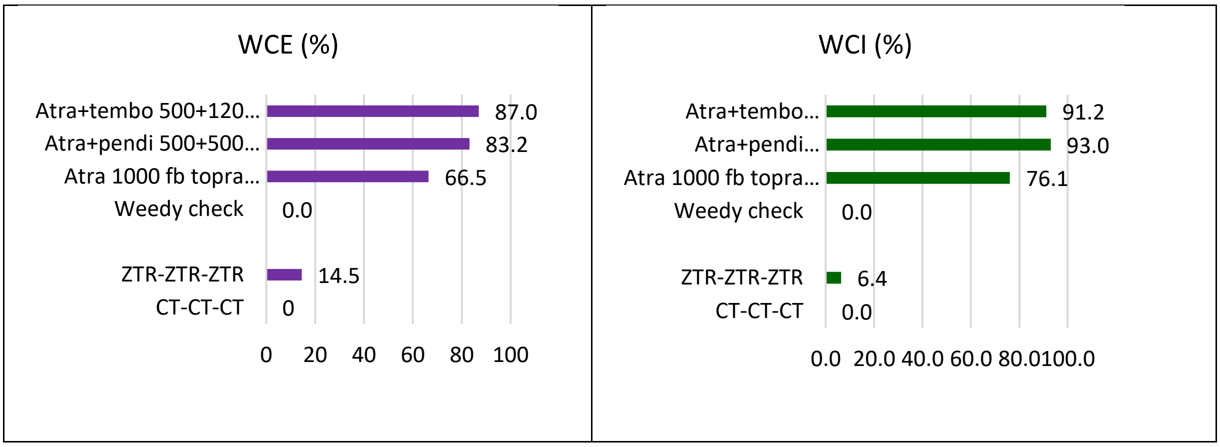


Fig 51: Weed control efficiency (%) and weed control index (%) as influenced by crop establishment methods and weed management practices in maize under maize-chickpea-greengram system

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 (Table 51). Among weed management practices, all the growth and yield parameters (plant height, leaf area and plant biomass) and yield attributes (cobs/plant, row/cob, grains/cob, 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 (Table 51). The interaction between crop establishment methods and weed management practices was found to be non-significant for all the growth and yield parameters.

Table 51: 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)	Leaf area (60 DAS)	Dry weight (g/plant)	Cob/plant	Row/cob	grains/cob	Cob length(cm)	Cob weight (g)	Seed index
CT-CT-CT	221.93	4500.56	314.20	1.05	11.72	376.43	15.71	126.72	30.83
ZTR-ZTR-ZTR	229.64	4669.39	358.86	1.09	12.70	403.82	16.02	139.03	31.24
SEm±	1.37	58.47	8.29	0.03	0.28	18.47	0.40	4.59	1.52
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
W1	200.42	4024.62	256.02	1.00	10.86	301.96	14.33	104.32	29.33
W2	227.53	4329.79	299.49	1.00	11.93	392.15	16.02	127.12	31.09
W3	235.54	4952.95	379.83	1.10	12.83	429.59	16.43	144.54	31.67
W4	239.64	5032.54	410.79	1.18	13.21	436.78	16.68	155.52	32.04
SEm±	1.54	98.78	7.70	0.04	0.32	7.08	0.17	3.84	1.74
CD (p=0.05)	4.74	304.37	23.71	0.12	0.97	21.82	0.53	11.83	NS
C X W	NS	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, straw, biological yield and harvest index were statistically comparable. However, the values of these parameters were more in the ZTR-ZTR-ZTR system (Table52). Among weed management practices, weedy check has the lowest grain, straw, biological yield and harvest index (2856, 6276 and 9132 kg/ha, and 32.0%, respectively). The highest crop yields were obtained under herbicide rotation (7337, 10085 and 17422 kg/ha, and 42.3%, respectively) followed by IWM and recommended herbicides. The interaction between crop establishment methods and weed management practices was found to be non-significant.

Table 52: 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 (%)
Crop establishment methods (C)				
CT-CT-CT	5511.65	8814.93	14326.58	37.77
ZTR-ZTR-ZTR	6121.30	9094.24	15215.53	39.58
SEm±	117.82	532.79	649.94	1.09
CD (p=0.05)	NS	NS	NS	NS
Weed management practices (W)				
W1	2855.79	6275.88	9131.67	32.02
W2	6102.09	9584.57	15686.67	38.99
W3	6971.06	9872.51	16843.57	41.39
W4	7336.96	10085.38	17422.33	42.30
SEm±	191.06	617.34	757.45	1.22
CD (p=0.05)	588.72	1902.21	2333.92	3.77
C X W	NS	NS	NS	NS

System crop, water and energy productivity

The highest system productivity in terms of maize equivalent yield was recorded in the ZTR (M)-ZTR (C)-ZTR (G) system with (14.2 t/ha) followed by CT (M)-CT (C)-CT (G) and ZTR (M)-ZTR (W)-ZTR (G). The lowest system productivity was recorded with CT (M)-CT (W)-CT (G)) (11.9 t/ha). The system irrigation water productivity and total water productivity were highest with ZTR (M)-ZTR (C)-ZTR (G) (11.0 and 8.9 kg/ha/mm, respectively) with the highest net returns (Rs 2.28 x 10^5), but the B: C was recorded highest with ZTR (M)-ZTR (W)-ZTR (G) (3.52), net energy (3.50 x 10^5 MJ/ha), energy rato (11.0), whereas energy productivity was highest with ZTR (M)-ZTR (C)-ZTR (G) (0.40 kg/MJ) (Table 1.52).

Among weed management practices, the highest system productivity in terms of maize equivalent yield was obtained with herbicide rotation and IWM in the system (16.5 t/ha). The lowest system productivity was obtained with weedy check (5.1 t/ha). The system irrigation water productivity (12.9 kg/ha/mm), water productivity (9.7 kg/ha/mm), net returns (Rs 2.84 x 10^5/ha), B: C (3.94), energy ratio (10.93) and energy productivity (0.45 kg/MJ) in herbicide rotation and was statistically at par to IWM. These were mainly due to higher crop yields, better water use, optimum production cost and energy use. These were followed by recommended herbicides. The lowest values of all said parameters were obtained with weedy check (Table 53).

Table 53: Effect of crop establishment methods and weed management practices on system productivity, water productivity, profitability and energy productivity in maize-wheat/chickpea-greengram cropping system

Treatment	System productivity (MEY, t/ha)	SIWP (kg/ha/mm)	SWP (kg/ha/mm)	Net returns (L/ha)	B:C	Net energy (LMJ/ha)	ER	EP (kg/MJ)
Crop establishment methods (C)								
CT (M)-CT (W)-CT (G)	11.9	9.3	6.3	1.92	3.00	3.16	9.10	0.31
ZTR (M)-ZTR (W)-ZTR (G)	13.2	10.2	7.8	2.26	3.52	3.50	11.00	0.38
CT (M)-CT (C)-CT (G)	13.3	10.3	7.8	2.03	2.99	2.69	7.64	0.34
ZTR (M)-ZTR (C)-ZTR (G)	14.2	11.0	8.9	2.28	3.37	2.91	8.95	0.40
CD (p=0.05)	0.68	0.53	0.40	0.16	0.17	0.26	0.72	0.02
Weed management practices (W)								
W1	5.1	4.0	3.0	0.46	1.58	1.47	5.01	0.14
W2	14.4	11.2	8.5	2.40	3.50	3.41	10.01	0.39
W3	16.5	12.8	9.7	2.80	3.87	3.65	10.74	0.45
W4	16.5	12.9	9.7	2.84	3.94	3.72	10.93	0.45
CD (p=0.05)	0.53	0.41	0.32	0.12	0.13	0.19	0.53	0.02
C x W	1.06	0.83	0.63	0.24	0.26	ns	ns	0.03

Plate 8. Effect of crop establishment methods and weed management practices on maize-wheat/chickpea-greengram cropping system

C. Water Management Practices in Conservation Agriculture

Rice Wheat Cropping System

CSSRI

Micro-irrigation methods

Rice crop during *kharif* 2022

Data are given in Fig 51 for the comparison of different irrigation systems in rice crop during *kharif* 2022. Results of micro-irrigation systems and surface irrigation systems are discussed below as:

a) Drip irrigation system in rice crop

During *kharif*2022, 5.88 t ha^{-1} rice yield was reported under drip irrigation system with DSR in reduced tillage (DRIP-RTDSR). Rice yield under DRIP-RTDSR was 8.88% higher than the conventional PTR (5.40 t ha^{-1}). Similarly, it was 2.61-13.73% higher than the RTDSR under surface irrigation system (SIS-RTDSR).

b) Surface irrigation in rice crop

DSR with reduced tillage under surface irrigation method (SIS-RTDSR) produced grain yield of 5.17 t ha^{-1} (Fig 51). Grain yield in DSR under surface irrigation method (SIS-RTDSR) was lowestamong conventional PTR and different micro irrigation applied (3.54-12.07 %).

c) Mini sprinkler irrigation system in rice crop

Results on irrigation system through mini sprinkler irrigation system showed that 5.73 and 5.36tha^{-1} grain yield was obtained in DSR with reduce tillage (RTDSR) and RTDSR with 33% wheat residue incorporation (RTDSR+RI) during*kharif*2022 (Fig 51). During 2022, 0.52 and 6.94% lower yield of DSR was reported in RTDSR and RTDSR+RI, respectively under mini sprinkler irrigation system as compared to PTR (5.76 t ha^{-1}). Higher grain yield of direct seeded rice under mini-sprinkler irrigation was recorded in comparison to DSR in surface irrigation method (SIS-RTDSR; 5.17 t ha^{-1}), which was about 10.83 and 3.67 % higher in MSIS-RTDSR and MSIS-RTDSR+RI treatments, respectively.

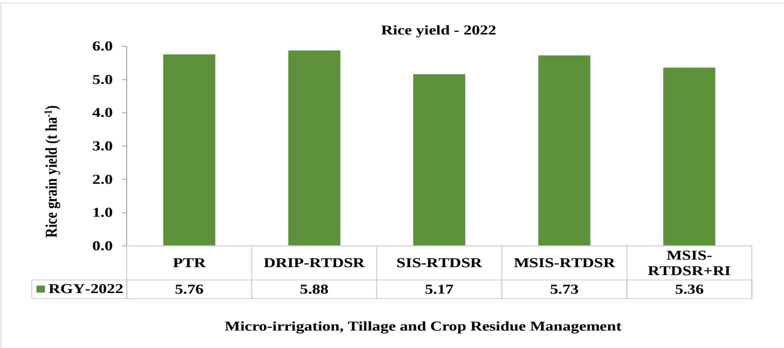


Fig 51: Effects of different micro-irrigation methods, tillage and crop residue management on rice grain yield during kharif 2022.

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

Plate 9. Zero tilled wheat sowing using happy seeder in rice residue under mini sprinkler irrigation method

Wheat crop during *rabi 2021*-22

The results of micro-irrigation systems (drip and mini sprinkler) in zero tilled wheat with rice residue mulch (ZTW+RM) during 2021-22is given in Fig. 52 as given below:

a) **Drip irrigation system in wheat**

The grain yield of zero tilled wheat under drip irrigation (DRIP-ZTW+RM) was 5.25 t ha^{-1}, which was almost similar to CTW (5.22 t ha^{-1}) (Fig 52).

b) **Surface irrigation system in wheat**

Surface irrigation system in wheat with 100% rice residue mulch (SIS-ZTW+RM) produced grain yield of 5.05 t ha^{-1}. Grain yield in SIS-ZTW+RM was similar to that of CTW (5.05 t ha^{-1}), whereas lowest among the different micro irrigation applied (2.72-3.87 %). 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 sown is feasible as rice residue is hassle free which is good for plant stand, higher crop growth and yield.

c) **Mini sprinkler irrigation system in wheat**

Zero tilled wheat with 100% rice straw mulch under mini sprinkler irrigation system (MSIS-ZTW+RM) produced grain yield of 5.19 t ha^{-1} (T9) to 5.22 t ha^{-1} (T10) which was almost similar to conventional tilled wheat (CTW; 5.22 t ha^{-1}). Thus, the mini-sprinkler method may be feasible for wheat production. During 2021-2022, 0.57 and 1.14% lower yield of wheat recorded under zero tilled wheat with 100% rice straw mulch under mini sprinkler irrigation system (MSIS-ZTW+RM) i.e., T9 and T10, respectively as compared to DRIP-ZTW+RM (5.25 t ha^{-1}). Higher grain yield of under 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;5.05 t ha^{-1}), which was about 2.77and3.36% higher, respectively.

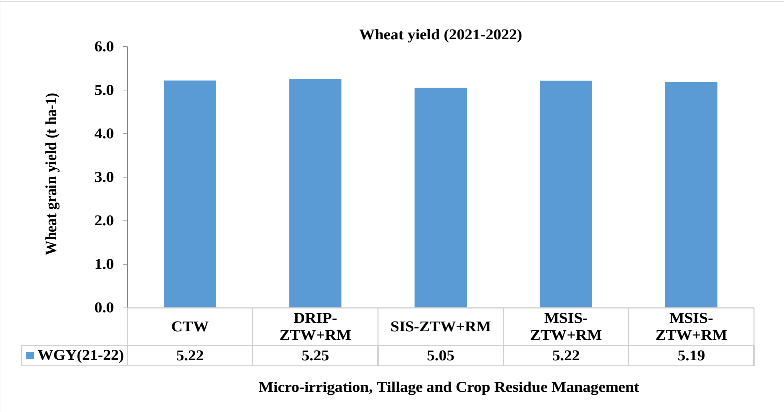


Fig 52: Effects of different micro-irrigation methods,tillage and crop residue management on wheat grain yield during rabi 2021-2022.

(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 2022-23

a) DRIP-RTDSR/ZTW+RM

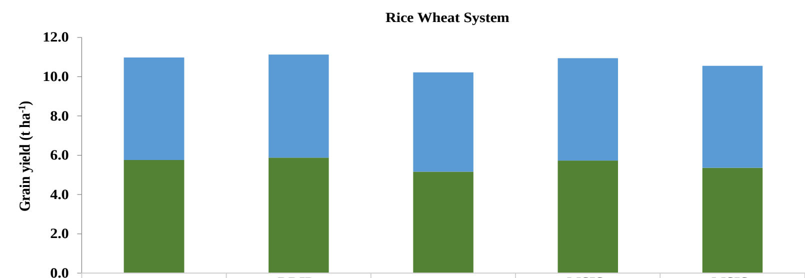
Higher grain yield (11.13 tha^{-1}) was recorded under drip irrigation system with DSR in reduced tillage/zero tilled wheat under drip irrigation (DRIP-RTDSR/ZTW+RM) than PTR/CTW (10.98 t ha^{-1}) (Fig 53). So, the drip irrigation system leads to 1.36 % increase in the grain yield of rice and wheat during 2022-2023.

b) SIS-RTDSR/ZTW+RM

DSR with reduced tillage under surface irrigation method/Surface irrigation system in wheat with 100% rice residue mulch (SIS-RTDSR/SIS-ZTW+RM) produced grain yield of 10.22t ha^{-1}(Fig 53). Grain yield in SIS-RTDSR/SIS-ZTW+RM was lowest among conventional PTR/CTW and different micro irrigation applied (3.22-8.90 %).

c) MSIS-RTDSR+RI/ZTW+RM

Results on irrigation system through mini sprinkler irrigation system showed that 10.95 and 10.55 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) during 2021-2022. During 2022-23, 0.27 and 3.91% lower yield was reported in MSIS-RTDSR/MSIS-ZTW+RM and MSIS-RTDSR+RI/MSIS-ZTW+RM, respectively as compared to PTR/CTW (10.98 t ha^{-1}). Moreover, highergrain yield of mini-sprinkler irrigation was recorded in comparison toSIS-RTDSR/SIS-ZTW+ RM(10.22 t ha^{-1}), which was about 7.14 and 3.22% higher in MSIS-RTDSR/MSIS-ZTW+RM and MSIS-RTDSR+RI/MSIS-ZTW+RM treatments, respectively. However, So, DRIP-RTDSR/ZTW+RM system leads to 1.64 to 5.49 % increase in the grain yield of rice and wheat during 2022-2023 in comparison to MSIS-RTDSR/ MSIS-ZTW+RM and MSIS-RTDSR+RI/ MSIS-ZTW+RM treatments, respectively.The result shows that grain yield of wheat increased under different irrigation methods with *in-situ* management of rice residue. ZTW with rice residue mulch was relatively better than CTW method of wheat sowing. It may be due to optimum soil moisture and favorable temperature regulation under residue management to facilitate better seed germination and crop growth as compared to non-residue practice.



	PTR/CTW	DRIP-RTDSR/DRIP-ZTW+RM	SIS-RTDSR/SIS-ZTW+RM	MSIS-RTDSR/MSIS-ZTW+RM	MSIS-RTDSR+RI/MSIS-ZTW+RM
Wheat	5.22	5.25	5.05	5.22	5.19
Rice	5.76	5.88	5.17	5.73	5.36

Fig 53: Effects of micro-irrigation methods, tillage and crop residue management on rice-wheat cropping system grain yield during 2022-23.

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

Long term impact for micro-irrigation methods

A five-years (2016-17 to 2020-21) field experiment was conducted in RWS with hypothesis that pressurized irrigation systems [drip (DRIP) and mini-sprinkler (MSIS) in conservation tillage [reduced (RT)/zero (ZT)] and crop residue management [incorporation (RI)/mulch (RM) might result in higher resource use efficiency with lesser carbon footprint compared to conventional system. Experiment consisted five treatments namely (1) puddled transplanted rice followed by conventionally tilled wheat (PTR/CTW), (2) DRIP irrigated reduced till direct seeded rice (RTDSR) followed by zero-till wheat with 100% rice residue mulching (ZTW+RM) (DRIP-RTDSR/ZTW+RM), (3) surface irrigated RTDSR followed by ZTW+RM (SIS-RTDSR/ZTW+RM), (4) MSIS irrigated RTDSR followed by ZTW+RM (MSIS-RTDSR/ZTW+RM), and (5) MSIS irrigated RTDSR with 1/3rd wheat residue incorporation followed by ZTW+RM (MSIS-RTDSR+RI/ZTW+RM). The pressurized irrigation system in RWS established under conservational tillage and residue management (DRIP-RTDSR/ZTW+RM and MSIS-DSR+RI/ZTW+RM) produced at par system productivity compared to PTR/CTW. Substantial nitrogen (79-114 ka ha^{-1}) and irrigation water (536-680 mm) savings under pressurized irrigation systems resulted in 41-64% higher partial factor productivity of nitrogen with 48-

61% lower water footprint. These systems had lower energy consumption attaining 15-21% higher net energy, 44-61% higher energy use efficiency, and 31-38% lower specific energy. Efficient utilization of farm inputs caused lower greenhouse gas emission (39-44%) and enhanced carbon sequestration (35-62%) resulting 63-76% lower carbon footprint over PTR/CTW.

a) Grain yield and partial factor productivity (N) of rice, wheat system

The annual grain yield (productivity) of rice, wheat and rice wheat system is given in Table 54. The annual productivity of rice and wheat were significantly different under different treatments. However, the system productivity was non-significant over the years except during 2018-19 (Table 6). In rice crop, the grain yield during first two years (2016-17 and 2017-18) was the highest in PTR/CTW treatment and was at par with MSIS-RTDSR+RI/ZTW+RM treatment. However, during third year (2018-19) it was the highest in DRIP-RTDSR/ZTW+RM treatment and was at par with SIS-RTDSR/ZTW+RM treatment. During fourth year (2019-20), PTR/CTW treatment had significantly the highest grain yield while all other treatments had similar grain yield. During fifth year (2020-21), it was non-significant under all the treatment. The five-year average rice grain yield was significantly the highest in PTR/CTW treatment (6.76 Mg ha^{-1}) followed by DRIP-RTDSR/ZTW+RM treatment (6.38 Mg ha^{-1}) while the lowest in MSIS-RTDSR/ZTW+RM treatment (6.17 Mg ha^{-1}). The PTR/CTW treatment had 5.6-8.8% higher grain yield than rest of the treatments.

In wheat crop, the grain yield during first year (2016-17) was the highest in MSIS-RTDSR+RI/ZTW+RM treatment (5.77 Mg ha^{-1}) followed by MSIS-RTDSR/ZTW+RM treatment (5.58 Mg ha^{-1}). During third year (2018-19), the highest yield was in SIS-RTDSR/ZTW+RM treatment (6.54 Mg ha^{-1}) followed by MSIS-RTDSR+RI/ZTW+RM treatment (6.50 Mg ha^{-1}). During second, fourth and fifth year (2017-18, 2019-20 and 2020-21), it was the highest in DRIP-RTDSR/ZTW+RM treatment at par with SIS-RTDSR/ZTW+RM treatment. The lowest grain yield during five years' period was in PTR/CTW treatment. The five-year average wheat grain yield was the highest in SIS-RTDSR/ZTW+RM treatment (5.92 Mg ha^{-1}) followed with DRIP-RTDSR/ZTW+RM treatment (5.90 Mg ha^{-1}) and significantly higher than PTR/CTW treatment (5.23 Mg ha^{-1}). The grain yield in SIS-RTDSR/ZTW+RM and DRIP-RTDSR/ZTW+RM treatments were 13.2 and 12.7%, respectively, higher than PTR/CTW treatment.

The system productivity was not significantly different under different treatments over the years except during 2018-19 (Table 56). During 2018-19, it was the highest in SIS-RTDSR/ZTW+RM (13.61 Mg ha^{-1}) followed by DRIP-RTDSR/ZTW+RM (13.49 Mg ha^{-1}) while the lowest in DRIP-RTDSR/ZTW+RM (12.40 Mg ha^{-1}). The five-year average system productivity was similar under all the treatments.

Significant differences were observed for partial factor productivity of nitrogen (PFP_N) in response to different treatments; variations being 42 to 56% in rice, 35 to 80% in wheat, and 41 to 68% in RWS. The highest PFP_N was recorded in MSIS treatments (MSIS-RTDSR/ZTW+RM and MSIS-RTDSR+RI/ZTW+RM) followed by DRIP-RTDSR/ZTW+RM, SIS-RTDSR/ZTW+RM and PTR/CTW. Rice and wheat crops irrigated with MSIS in system perspective attained 22-24%, 128-130% and 62-64% higher PFP_N for rice, wheat and RWS, respectively than PTR/CTW. The corresponding increase was 17%, 75% and 40% for rice, wheat and RWS, respectively in case of DRIP-RTDSR/ZTW+RM than PTR/CTW.

Table 54 :Annual mean grain yield (Mg ha^{-1}) of rice, wheat, and rice-wheat system.

Treatments	2016-17	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**Pooled average 2016-21**
Rice						
PTR/CTW	7.16^{a}	7.01^{a}	6.66^{ab}	6.53^{a}	6.46*	6.76^{a}
DRIP-RTDSR/ZTW+RM	6.84^{ab}	6.30^{b}	7.17^{a}	5.54^{b}	6.08	6.38^{b}
SIS-RTDSR/ZTW+RM	6.59^{b}	6.53^{ab}	6.81^{a}	5.53^{b}	6.11	6.31^{b}
MSIS-RTDSR/ZTW+RM	6.51^{b}	6.56^{ab}	5.96^{c}	5.61^{b}	6.22	6.17^{c}
MSIS-RTDSR+RI/ZTW+RM	6.68^{ab}	6.66^{ab}	6.11^{bc}	5.71^{b}	6.25	6.28^{bc}
Wheat						
PTR/CTW	5.24^{b}	5.16^{b}	5.52^{b}	5.14^{b}	5.10^{b}	5.23^{b}
DRIP-RTDSR/ZTW+RM	5.24^{b}	5.95^{a}	6.08^{ab}	6.54^{a}	5.68^{a}	5.90^{a}

SIS-RTDSR/ZTW+RM	5.46[ab]	5.52[ab]	6.54[a]	6.53[a]	5.55[a]	5.92[a]
MSIS-RTDSR/ZTW+RM	5.58[ab]	5.38[ab]	6.46[a]	6.10[a]	5.67[a]	5.84[a]
MSIS-RTDSR+RI/ZTW+RM	5.77[a]	5.32[b]	6.50[a]	6.29[a]	5.54[ab]	5.88[a]
Rice-wheat system						
PTR/CTW	12.80*	12.64*	12.40[c]	11.92*	11.79*	12.31*
DRIP-RTDSR/ZTW+RM	12.48	12.80	13.49[ab]	12.40	12.02	12.64
SIS-RTDSR/ZTW+RM	12.47	12.55	13.61[a]	12.38	11.92	12.59
MSIS-RTDSR/ZTW+RM	12.51	12.43	12.68[bc]	12.00	12.15	12.35
MSIS-RTDSR+RI/ZTW+RM	12.89	12.46	12.86[abc]	12.31	12.05	12.51

Table 55: Effect of irrigation systems, tillage and residue management treatments on applied nitrogen and partial factor productivity of nitrogen in rice-wheat system (data are pooled average of five cropping cycles from 2016-17 to 2020-21).

Treatments	N applied (kg ha^{-1})			PFP_N (kg grain kg^{-1} N)		
	Rice	Wheat	Rice-wheat system	Rice	Wheat	Rice-wheat system
PTR/CTW	150±0.00	150±0.00	300±0.00	45.1±0.68[c]	34.9±0.53[d]	41.0±0.53[d]
DRIP-RTDSR/ZTW+RM	122±2.38	99±7.76	221±8.12	52.7±1.48[b]	60.9±2.08[b]	57.6±1.25[b]
SIS-RTDSR/ZTW+RM	149±1.07	134±7.40	283±6.95	42.4±0.75[d]	44.8±1.37[c]	44.7±0.83[c]
MSIS-RTDSR/ZTW+RM	112±2.45	74±3.85	186±4.49	55.1±0.89[a]	79.6±1.80[a]	66.6±1.01[a]
MSIS-RTDSR+RI/ZTW+RM	112±2.45	74±3.85	186±4.49	56.1±0.92[a]	80.3±2.14[a]	67.5±1.20[a]
p-value				<.0001	<.0001	<.0001

Note: PFP_N: Partial factor productivity of nitrogen; *PTR/CTW* (farmers' practice): Puddle transplanted rice (PTR)/conventional tilled wheat; *DRIP-RTDSR/ZTW+RM*: Drip irrigation in reduce tilled direct seeded rice (RTDSR)/zero tilled wheat (ZTW) with 100% rice residue mulch (RM); *SIS-RTDSR/ZTW+RM*: Surface irrigation in RTDSR/ZTW+RM; *MSIS-RTDSR/ZTW+RM*: Mini-sprinkler irrigation in RTDSR/ZTW+RM; *MSIS-RTDSR+RI/ZTW+RM*: Mini-sprinkler irrigation in RTDSR with 1/3rd wheat residue incorporation/ZTW+RM

b) Energy input and output relationship

Among different treatments, maximum energy input or consumption was recorded in PTR/CTW (57.01 GJ ha^{-1}) while minimum was in DRIP-RTDSR/ZTW+RM (36.43 GJ ha^{-1}) (Table 56). Compared to PTR/CTW, the energy inputs in DRIP-RTDSR/ZTW+RM, MSIS-RTDSR/ZTW+RM, MSIS-RTDSR+RI/ZTW+RM and SIS-RTDSR/ZTW+RM treatments were lowered by 36, 30, 30 and 19%, respectively. Irrespective of treatments, energy usage through fertilizers was highest among different farm inputs; being 33.8% in MSIS-RTDSR+RI/ZTW+RM and 42.6% in DRIP-RTDSR/ZTW+RM. Electricity had the next major share in energy consumption which varied from 21.0% in SIS-RTDSR/ZTW+RM to 29.8% in MSIS-RTDSR/ZTW+RM and MSIS-RTDSR+RI/ZTW+RM treatments. Similarly, PTR/CTW had maximum energy usage through irrigation water use (11571 MJ ha^{-1}) while minimum was found in DRIP-RTDSR/ZTW+RM (4631 MJ ha^{-1}). In comparison, PTR/CTW had 251-376 MJ ha^{-1} higher energy inputs through engaging human labour for different farm operations. Similarly, the energy consumption through machinery and diesel in PTR/CTW remained 40.0 and 45.2% higher, respectively than all other treatments (Fig 55). The energy output among different treatments was statistically at par with each other (Table 56) and ranged from 181.0 GJ ha^{-1} in PTR/ CTW to 185.7 GJ ha^{-1} in DRIP-RTDSR/ZTW+RM.

The data on energy budgeting and efficiency showed that rice established as DSR (irrespective of irrigation treatments) had lower energy consumption and higher energy output than PTR/CTW; thereby culminating in significantly higher values of net energy (NE), energy use efficiency (EUE) and energy productivity (EP) (Table 56). Compared to PTR/CTW, the DRIP-RTDSR/ZTW+RM and MSIS-RTDSR+RI/ZTW+RM had 20.5 and 16.4 % higher net energy, respectively. The treatment DRIP-RTDSR/ZTW+RM had the highest EUE (5.10) and EP (0.35 kg MJ^{-1}) followed by MSIS-RTDSR+RI/ZTW+RM. Both these treatments were the most energy-efficient saving 37.8 and 31.7% specific energy respectively, over PTR/CTW.

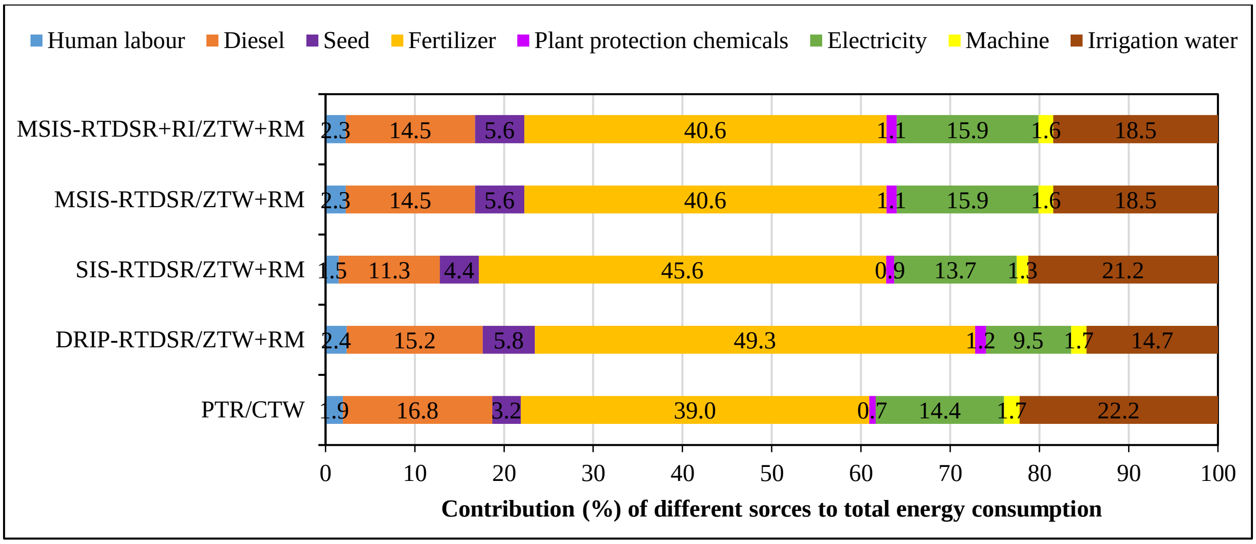


Fig 54: Per cent contribution of different sources to total energy consumption (input-wise energy utilization pattern) in rice-wheat system as influenced by the various irrigation systems under tillage and residue management treatments (data are pooled average of five cropping cycles from 2016-17 to 2020-21).

Note: *PTR/CTW* (farmers' practice): Puddle transplanted rice (PTR)/conventional tilled wheat; *DRIP-RTDSR/ZTW+RM*: Drip irrigation in reduce tilled direct seeded rice (RTDSR)/zero tilled wheat (ZTW) with 100% rice residue mulch (RM); *SIS-RTDSR/ZTW+RM*: Surface irrigation in RTDSR/ZTW+RM; *MSIS-RTDSR/ZTW+RM*: Mini-sprinkler irrigation in RTDSR/ZTW+RM; *MSIS-RTDSR+RI/ZTW+RM*: Mini-sprinkler irrigation in RTDSR with 1/3rd wheat residue incorporation/ZTW+RM

Table 56: Treatment-wise energy consumption through different sources in rice-wheat system (data are pooled average of five cropping cycles from 2016-17 to 2020-21).

Energy inputs	Energy consumption (MJ ha^{-1})				
	PTR/CTW	**DRIP-RTDSR/ZTW+RM**	**SIS-RTDSR/ZTW+RM**	**MSIS-RTDSR/ZTW+RM**	**MSIS-RTDSR+RI/ZTW+RM**
Human labour	1004	753	627	753	753
Machine	907	544	544	544	544
Diesel	8728	4786	4786	4786	4786
Seed	1654	1838	1838	1838	1838
Fertilizers	20316	15516	19274	13420	13420
Plant protection chemicals	366	379	379	379	379
Electricity	12464	7981	9665	11839	11839
Irrigation water	11571	4631	8972	6106	6106
Total	57009	36428	46084	39664	39664

Note: *PTR/CTW* (farmers' practice): Puddle transplanted rice (PTR)/conventional tilled wheat; *DRIP-RTDSR/ZTW+RM*: Drip irrigation in reduce tilled direct seeded rice (RTDSR)/zero tilled wheat (ZTW) with 100% rice residue mulch (RM); *SIS-RTDSR/ZTW+RM*: Surface irrigation in RTDSR/ZTW+RM; *MSIS-RTDSR/ZTW+RM*: Mini-sprinkler irrigation in RTDSR/ZTW+RM; *MSIS-RTDSR+RI/ZTW+RM*: Mini-sprinkler irrigation in RTDSR with 1/3rd wheat residue incorporation/ZTW+RM

Table 57: Energy input-output relationship under different treatments in rice-wheat system (data are pooled average of five cropping cycles from 2016-17 to 2020-21).

Treatments	Energy indices

	Energy output (GJ ha^{-1})	**Net energy (GJ ha^{-1})**	**Energy use efficiency**	**Energy productivity (kg MJ^{-1})**	**Specific energy (MJ kg^{-1})**
PTR/CTW	181.0±2.34	124.0±2.34^{d}	3.17±0.05^{d}	0.22±0.003^{d}	4.65±0.06^{a}
DRIP-RTDSR/ZTW+RM	185.7±2.01	149.3±2.01^{a}	5.10±0.06^{a}	0.35±0.004^{a}	2.89±0.03^{d}
SIS-RTDSR/ZTW+RM	185.0±2.15	138.9±2.15^{c}	4.01±0.05^{c}	0.27±0.003^{c}	3.67±0.04^{b}
MSIS-RTDSR/ZTW+RM	181.6±1.23	141.9±1.23^{bc}	4.58±0.03^{b}	0.31±0.002^{b}	3.21±0.02^{c}
MSIS-RTDSR+RI/ZTW+RM	184.0±1.51	144.3±1.51^{b}	4.64±0.04^{b}	0.32±0.003^{b}	3.17±0.03^{c}
p-value	0.1235	<.0001	<.0001	<.0001	<.0001

PTR/CTW (farmers' practice): Puddle transplanted rice (PTR)/conventional tilled wheat; *DRIP-RTDSR/ZTW+RM*: Drip irrigation in reduce tilled direct seeded rice (RTDSR)/zero tilled wheat (ZTW) with 100% rice residue mulch (RM); *SIS-RTDSR/ZTW+RM*: Surface irrigation in RTDSR/ZTW+RM; *MSIS-RTDSR/ZTW+RM*: Mini-sprinkler irrigation in RTDSR/ZTW+RM; *MSIS-RTDSR+RI/ZTW+RM*: Mini-sprinkler irrigation in RTDSR with 1/3rd wheat residue incorporation/ZTW+RM

NIASM

Ratoon Sugarcane Cropping System

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

In year 2022, field experiment was repeated to optimize the effect of zigzag paired row planting, subsurface drip irrigation and intercropping (groundnut-fenugreek) with aim of enhancing productivity of ratoon sugarcane (Co-86032) cropping system. The main plot treatments included, M1: Zigzag Paired Row (ZPR) with (60 cm-plant spacing ,150 cm-row spacing) + Sub-Surface Drip Irrigation (SSDI); M2: ZPR (75 cm, 150 cm) + SSDI; M3: ZPR (60 cm, 210 cm) + SSDI; M4: ZPR (75 cm, 210 cm) + SSDI; M5: ZPR (60 cm, 225 cm) + SSDI; M6: ZPR (75 cm, 225 cm) + SSDI; M7: ZPR (60 cm,180 cm) + SSDI; M8: ZPR (75 cm,180 cm) + SSDI. Two soil cover treatments included S1: Groundnut residue + sugarcane trash and S2: without residue were accommodated in sub-plots. An absolute control surface irrigation management practices was also maintained to compare the treatment effects. The first year results showed 39.5, 51.3 and 28% improvement in yields of groundnut, fenugreek and sugarcane in M5S1 treatments in comparison to M3S2, respectively indicating possibility of improving productivity sugarcane cropping system.

E. Effect of Machinery in Conservation Agriculture

CIAE

Validation of location specific CA machinery for wheat crop

Wheat crop (HI-1544) was sown in the experimental field on first December, 2021with different machines. The seed rate applied was 120 kg.ha^{-1}and depth of sowing was 50 mm (Figure-2). Basal dose of fertilizer at the rate of di-ammonium phosphate(130kg ha^{-1}) and muriate of potash (67kg.ha^{-1}) was applied during sowing. As per recommendation remaining of nitrogen was applied by two dressing of urea, each at the rate of 208kg.ha^{-1}.Four irrigations were applied during different growth stage of the wheat crop.

Slit-till drill | Mulcher-cum-seeder | Inclined plate planter with herbicide applicator | Turbo happy seeder

Plate 10. Field experiment with Four Machine

The observation of crop parameters (germination, number of effective tillers, plant height, grain and biomass yield) were recorded for all the equipment as given in Table 58 Seed germination counts were taken at 15days after sowing. The number of tillers per plant was counted 45 days after sowing. Plant counts and number of tillers were taken by marking one m^2 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.

Table 58: Crop parameters and crop yield for wheat crop.

Equipment	Germination per m^2,no's	Number of tillers per plant	Plant height at maturity, mm	Grain yield, tha^{-1}	Total biomass yield, $t.ha^{-1}$
Slit-till drill	83	15.85	885.83	5.41	7.11
Mulcher-cum-seeder	97	15.90	862.50	4.65	6.99
Inclined plate planter with herbicide applicator	96	18.15	840.83	4.62	6.35
Turbo happy seeder	94	17.65	802.50	3.77	5.36

The wheat crop was harvested with combine harvester. The height of cut of wheat crop was adjusted by adjusting the cutter bar of combine harvester. These four heights of cut of wheat crops were just above theground (C1-0%); 30% height(C2), 60% height(C3),90%height as below grain head (C4).The aim of cutting of crop from different height is to identify the suitability of machine in full straw condition (loose and standing height).

Validation of location specific CA machinery for Moong crop

Moong crop (Varity PDM- 139) was sown on 21/04/2022 in D_2 plot of institute research farm after harvesting of wheat crop. Total wheat straw, cut from different heights such as just above the ground (C1), 30% height (C2), 60% height (C3), 90% height as below grain head (C4), was available in field. The seed rate applied was 25kg 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 10kg ha^{-1}. Five irrigations were applied during different growth stage of the wheat crop.

Slit-till drill

Mulcher-cum-seeder

Inclined plate planter with herbicide applicator

Turbo happy seeder

Plate 11. Field experiment with four machines

The observation of crop parameters (germination, number of effective tillers, plant height, grain and biomass yield) were recorded for all the equipment as given in Table 1.58. 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 m^2 wooden square frame. The plants were cut and thresh separately.

Table 58: Crop parameters and crop yield for Moong crop

Equipment	Germination per m^2,no's	Number of tillers per plant	Plant height at maturity,mm	Grain yield, $t.ha^{-1}$	Total biomass yield, $t.ha^{-1}$
Slit till drill	82.08	8.08	462.50	0.486	2.09
Mulcher cum seeder	82.50	7.75	464.17	0.485	2.20
Inclined plate planter with herbicide applicator	77.17	7.67	455.83	0.561	1.90
Turbo happy seeder	61.75	6.75	485.00	0.523	1.86

Rainfed Ecosystem / Dryland Ecosystem

A . Tillage and Residue management in Conservation Agriculture

IISS

Soybean-Wheat Cropping Systems

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

In the *kharif* season, soybean yield varied between 17.61-19.31 q/ha. Among the *rabi* season crops, wheat yield varied between 52.98 and 55.62 q/ha under different tillage treatments (Table 59). Barring soybean yield, tillage treatments did not show significant effect on yields of both the *kharif* and *rabi* seasons crops in 2021-22. Higher (balanced) nutrient application through 100%RDF and STCR dose recorded significantly higher grain yield under soybean-wheat cropping systems compared to N75% RDF.

Soybean yield was relatively higher under no tillage (T2) which was on par with reduced tillage +residue retention (T3, T4 and T5). However, nutrient doses showed significant effect of soybean yield. STCR based fertilizer application recorded significantly higher yield compared to N2 (100% RDF) and N1 (75% RDF) (Table 59).

Table 59: Effect of different tillage and nutrient doses on yield of different crops during 2021-22

Treatment	Grain Yield	
	Soybean*	Wheat
	(q/ha)	(q/ha)
Tillage		
T1 – NT with 30cm height residue	17.97	53.81
T2 – NT with 60cm height residue	19.12	53.69
T3 – RT with 30cm height residue	18.98	52.98
T4 – RT with 60cm height residue	17.61	55.62
T5 – CT (Conventional Tillage)	18.52	53.38

Mean	18.37	53.90
Nutrient levels		
N1- 75% RDF	16.32	48.11
N2-100% RDF	19.01	54.51
N3- STCR dose	19.96	59.07
Mean	18.37	53.90
C.D. (P< 0.05)		
Tillage System (TS)	0.806	NS
Nutrient Dose (ND)	0.839	0.647

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

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

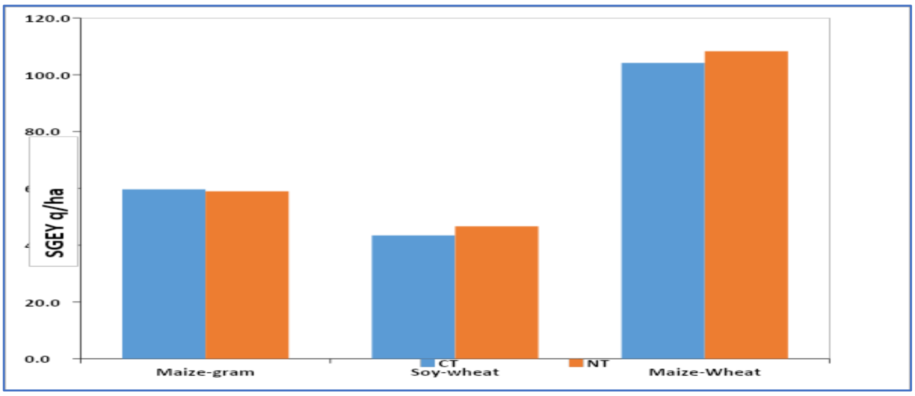


Fig 58: Effect of conservation agricultural practices on soybean grain equivalent yield (q ha^{-1}) after 11 crop cycles (2021-22) (MSP/Q; Soybean Rs 3950, Maize Rs 1870, Wheat Rs 1975; Gram Rs 5230)

Maize-Chickpea Cropping Systems

This field experiment was initiated during *kharif* 2015 in maize-chickpea cropping systems with five different tillage treatments, viz. T1: No Tillage (NT) with 30cm height of crop residue retention, T2: No Tillage (NT) with 60cm height of crop residue retention;, T3: Reduced Tillage with 30cm height of crop residue retention, T4: Reduced Tillage with 60cm height residue and T5: Conventional Tillage (CT)/Farmers practices with three nutrient doses namely N1:75% of the recommended dose of fertilizer (RDF), N2:100% RDF, N3: Soil test based recommendation. The experiment was taken in split plot design with three replications. Test crops (maize, chick pea) were sown using happy seeder during rainy and winter seasons by adopting standard package of practices. Biometric observations and yield parameters were recorded. Following cultivars were used - maize cultivar: Nath Samrat, Gram cultivar: JS 13.
In the *kharif* season, maize yield ranged between 48.57-49.83 q/ha (Table 59). Among the *rabi* season crops, chickpea yield varied between 16.76 and 17.53 q/ha (Table 59). Higher (balanced) nutrient application through 100%RDF and STCR dose recorded significantly higher grain yield under maize-gram cropping systems compared to N75% RDF.

Table 59: Effect of different tillage and nutrient doses on yield of different crops during 2021-22

Treatment	Grain Yield

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

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

This long-term experiment is continuing at the experimental farm of the Institute for the last ten years with two tillage treatments namely conventional tillage (CT) with residue removed and no tillage (NT) with residue retained along with cropping systems namely Maize- Gram. During *kharif* season, tillage system did not have significant effect on crop yield but cropping system had significant effect on crop yield. During Rabi season, tillage and cropping system had significant effect on gram yield after 11 crop cycles (Fig 59).

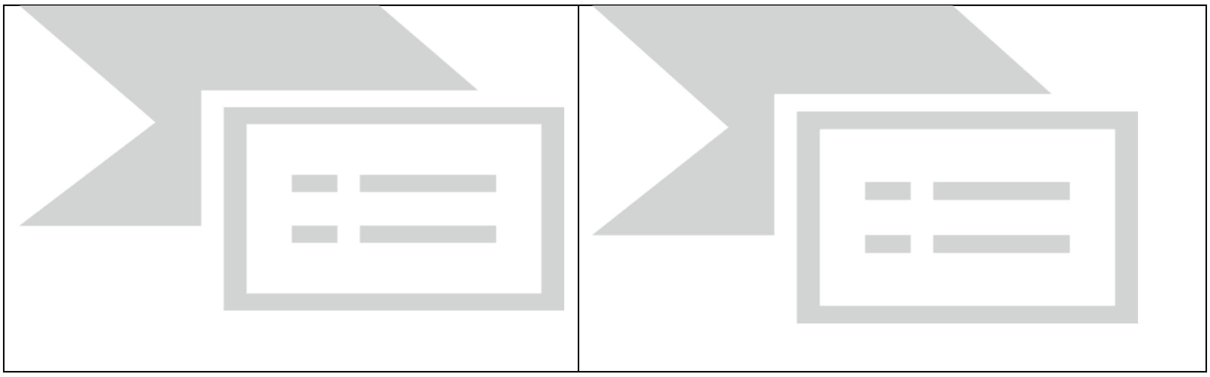


Plate 12. Experimental plots under different tillage system

CRIDA

1. Pigeonpea + Setaria – Maize + cowpea system

The experiment was initiated in 2009 with pigeon pea - castor rotation system. The experiment was laid out in split plot design with tillage treatments as main plots and harvesting heights as sub plots. In 2013 dhaincha a green manure crop was introduced between pigeonpea and castor crops as live mulch. In 2021 without changing the lay out the cropping system was changed to Pigeonpea+setaria – Maize+cowpea rotation. This year Maize +cowpea intercropping system was evaluated on different levels of pigeonpea and kora residues with different tillage practices like conventional tillage (Disc ploughing in off season, Cultivator, disc harrow and sowing of crop), Reduced tillage (Ploughing once with cultivator and disc harrow), Zero tillage (direct sowing in residues) and different residue levels by harvesting pigeonpea crop and Foxtail millet at different heights (0 cm, 10 cm and 30 cm) to increase the residue contribution to the field. In the subplots the intercrop cowpea was introduced in 10 and 30 cm. The germination of both the crops maize and cowpea were good. The crop suffered from moisture stress during the initial stages. Zero tillage and reduced tillage recorded 19 and 4 % higher maize equivalent yields as compared to conventional respectively. The maize equivalent yields in 10 and 30 cm anchored residues recorded significantly higher yield as compared to no residues. 10 and 30 cm height crop residues recorded 23 and 20 % higher yield as compared to no residue. ((Fig 59)

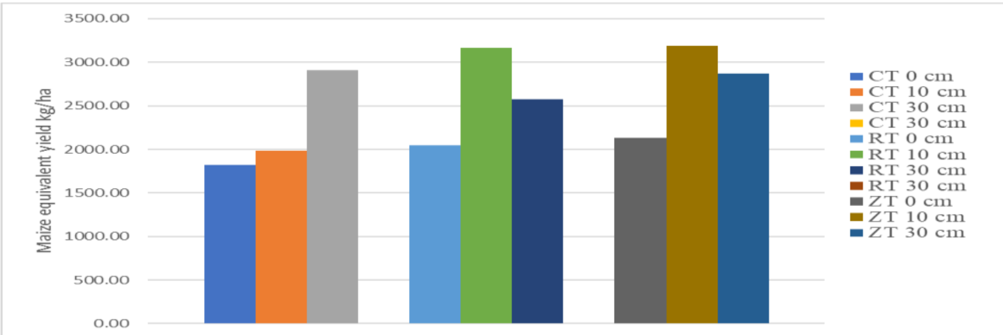


Fig 59: Influence of tillage and residue levels on maize equivalent yield


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

Plate 13.Strategies for enhancing residue retention in Rainfed region

CRIDA

2. Pigeonpea - Finger millet

The experiment was initiated in 2021 with in pigeonpea - finger millet sequence cropping in rainfed ecosystem at Bangalore (plate 3). Among different tillage practices, conventional tillage recorded significantly higher finger millet grain and straw yield (2486 & 3679 kg ha^{-1}) compared to zero tillage (2085 & 3086 kg ha^{-1}) but was on par with reduced tillage (2367 & 3503 kg ha^{-1}). Higher net returns (Rs.6021 ha^{-1}), and rain water use efficiency (2.98 kg ha-mm^{-1}) were recorded with conventional tillage as compared to reduced tillage (Rs.58141& 2.73 kg ha-mm^{-1}) and zero tillage (Rs.51802, & 2.73 kg ha-mm^{-1}) (Table 60).

Sunhemp

Horsegram

Finger millet under conventional tillage

Finger millet under reduced tillage

Plate 14. Performance of Finger millet in different treatments

Table 60: Biomass yield of cover crop under conservation agriculture

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

Table 61: Yield, economics and water use efficiency influenced by conservation agriculture practices in finger millet under pigeonpea - finger millet sequence cropping system

Treatments	Finger millet Yield (kg ha^{-1})	CoC (Rs. ha^{1})	Net Returns	B: C ratio	RWUE

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

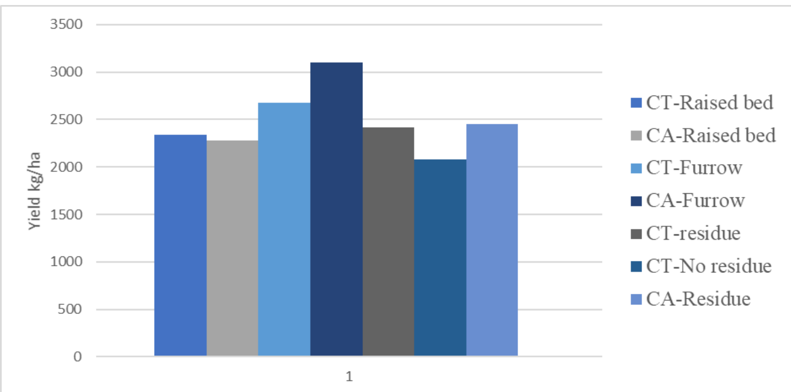
M_1: Conventional tillage M_2: Reduced tillage M_3: Zero tillage
C_1: Control C_2: Sun hemp C_3: Horsegram

Growing horse gram as cover crop recorded significantly higher finger millet grain and straw yield, (2414 & 3573 kg ha-1) compared to control (2192 & 3244 kg ha-1) but was on par with sun hemp (2331, 2959, 168 & 3450 kg ha-1) (Table 61). Similar trend was observed with respect to net returns (Rs.59122 ha-1), benefit cost ratio (3.73) and rain water use efficiency (3.04 kg ha-mm-1). However, the interaction between tillage and cover crops was non-significant.

3. Maize –Pigeonpea System

CRIDA

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



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

Plate 15. Reshaping of a) Bed and furrow in Zero tillage b) Conservation furrow

4. Sorghum-Black gram system

CRIDA

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

Blackgram (variety PU 31) was grown in the year 2022. In the 10th year of the study, despite high yields, there were no significant differences in seed yield of blackgram with either tillage or residue retention (Table 62).

Plate 16. Blackgram (PU 31) crop with CT - conventional tillage (left) and MT - minimum tillage (right) under maximum residue retention (S2)

Table 62: Effect of tillage and residue management on grain yield of blackgram

Tillage	Residue	Seed yield (kg/ha)
Minimum tillage	S0: No residue application	1,407
	S1: Cutting at 35 cm height (1/3rd height)	1,424
	S2: Cutting at 60 cm height	1,338

Conventional tillage	S0: No residue application	1,082
	S1: Cutting at 35 cm height (1/3rd height)	1,085
	S2: Cutting at 60 cm height	1,126
CD (P=0.05)		
Tillage		NS
Residues		NS
T X R		NS

5. Soybean-Chickpea

CRIDA

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

The growth and yield attributes differed significantly among different crops (Table 63). Soybean yield, was significantly superior in T3 over other treatments however T1 and T3 were on par with each other. Whereas straw yield of soybean, were non-significant. The rainwater use efficiency was observed to be higher in the treatments T_3 and T_1 as compared to other treatments (Table 64).

Table 63: Growth, yield attributes and productivity of soybean as influenced by different treatment combinations during 2022

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

Table 64: Productivity and Rain water use efficiency as influenced by different treatments in soybean crop during 2022

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Rain water use efficiency (kg ha^{-1}mm^{-1})
T_1	1728	2006	1.86
T_2	1582	1968	1.71
T_3	1863	2107	2.01
T_4	1369	1841	1.48
T_5	1453	1927	1.57

6. *Rabi* Chickpea

Chickpea grain and straw yield were significant among different treatments (Table 65). Chickpea yields were higher in T_3 and was significantly superior over T_4 and T_5 and were on par with T_1 and T_2. Whereas the straw yields were higher in T3 and were significantly superior over T_2, T_4, T_5 and was found at par with treatment T_1.

Table 65: Yield of chickpea as influenced by different treatment combinations 2022-23

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

Sowing with BBF planter

Soybean crop in CT with crop residue mulch

Soybean crop in CT without crop residue mulch

Soybean in Reduced tillage with crop residue mulch

Soybean in Zero tillage + crop residue mulch

Permanent BBF, furrow after every 4 rows + crop residue mulch

Plate 17. Performance of Soybean in different treatments

CRIDA

7. Foxtail millet- Greengram

A field experiment was started in Gunegal Research Farm of Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad during 2022. The experiment was laid out in split plot design with four tillage treatments: T_1- Conventional tillage (CT) and T_2- Minimum tillage (MT), T_3- Zero tillage (ZT) and T_4- Zero tillage with ridge and furrow (soil and moisture conservation practice) and three residue retention treatments viz; Farmers' practice of harvesting close to the ground without any residue retention (S_1), Harvesting kharif and rabi crop at 20 cm height (S_2) and leaving the residues, harvesting only pods/panicles and retaining the entire residue (S_3). Setaria variety SiA 3222 was sown on 28thJune, 2022 and was harvested on 5thSeptember, 2022. WGG 42 Greengram crop was sown on 14thSeptember, 2022 and was harvested on 15thDecember, 2022. Zero tillage with ridge and furrow (T4) and Minimum tillage (T2) recorded 24 % and 19% higher yields respectively as compared to conventional tillage. Among different residue levels retention of entire residue (S3) has improved the system productivity by 27% (Fig 60).

Conventional tillage with complete residue

Zero tillage with ridge and furrow with complete residue

Minimum tillage with complete residue

Zero tillage with ridge and furrow with complete residue

Plate 18. Crop growth in various treatments

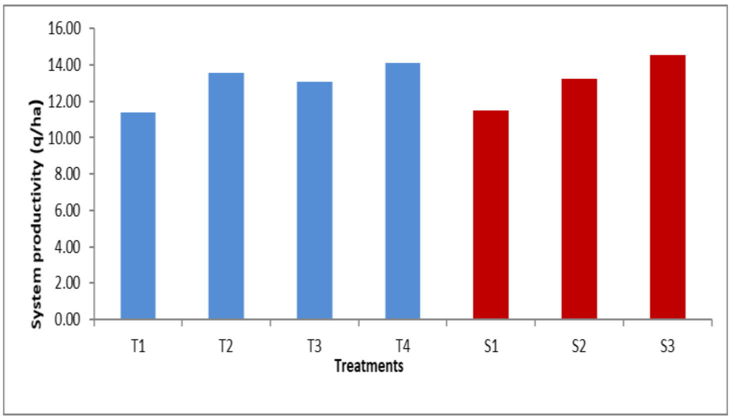


Fig 60: Effect of tillage practices and residue retention level on system productivity (q/ha)

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

IISS

The experiment was conducted in a factorial randomized design to study the effect of different levels of crop residue retention and herbicide application in maize-chickpea cropping system. The treatments comprised of four levels of residue retention and four weed control treatments (table 66)

Table 66: Details of residue and nutrient level treatment

Factor. A↓/ Factor B→ Residue levels	**Herbicide treatment**	
	Chickpea	**Maize**
A_1(90%) Crop residue	B_1. Imazethapyr @ 50 g a.i. ha^{-1} (as pre-em)	B_1.Tembotrione@120g a.i. ha^{-1}+Atrazin @ 1 kg a.i. ha^{-1} (as pre-em)
A_2(60%) Crop residue	B_2. Imazethapyr @ 50 g a.i. ha^{-1} (as pre-em) fb HW (50 DAS)	B_2.Tembotrione@120g a.i. ha^{-1}+Atrazin @ 625 g a.i. ha^{-1} (30 DAS)
A_3(30%) Crop residue	B_3. Imazethapyr @ 25 g a.i. ha^{-1}+Clodinafop @ 60 g a.i. ha^{-1} (30 DAS)	B_3.Tembotrione@180g a.i. ha^{-1}+Atrazin @1kg a.i. ha^{-1} (30 DAS)
A_4(0%) without Crop residue	B_4. Imazethapyr @ 25g a.i. ha^{-1}+ Clodinafop @ 60g a.i. ha^{-1} (30 DAS) fb HW (50 DAS)	B_4.Tembotrione@120g a.i. ha^{1}+Atrazin @ 625g a.i. ha^{-1} (30 DAS) fb HW (50 DAS)

Response of different residue levels and herbicide treatments on chickpea crop

Weed species;

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

Table 67: Dominant weed species observed in the experimental field

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

The data pertaining to weed density at 30 DAS presented in table 22 depicts significant effect on weed density as a result of different levels of crop residue retention. Maximum weed density (77.50 m^{-2}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (61.67 m^{-2}) ,60% crop residue retention (57.03 m^{-2}) and 90% crop residue retention treatment (52.69 m^{-2}). Different herbicidal weed control treatments showed significant influence on weed density. Under all residue levels, better weed control was observed in B1 (Imazethapyr) and B2 (Imazethapyr followed by hand weeding at 50 DAS) treatments. The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments varied but was not significant.

Table 68: Effect of different levels of crop residue retention and herbicidal weed control treatments on Weed density in chickpea at 30 DAS (m^{-2}).

	B1	B2	B3	B4	Mean of A
A1	38.67	39.00	66.22	66.89	52.69
A2	44.44	42.33	71.44	69.89	57.03
A3	48.00	49.44	75.00	74.22	61.67
A4	64.22	63.11	91.56	91.11	77.50
MEAN OF B	48.83	48.47	76.06	75.53	
CD <0.05					
A	2.034	** 1%			
B	2.034	** 1%			
AB	4.067	NS			

Table69: Effect of different levels of crop residue retention and herbicidal weed control tments on Weed density in chickpea at harvest (m^{-2})

	B1	B2	B3	B4	Mean of A
A1	67.00	27.22	45.67	29.33	42.31
A2	71.44	29.67	49.44	31.56	45.53
A3	74.67	33.11	53.33	36.56	49.42
A4	89.78	44.22	66.78	47.89	62.17
MEAN OF B	75.72	33.56	53.81	36.33	
CD 0.05					
A	2.246	** 1%			
B	2.246	** 1%			
AB	4.492	NS			

The data pertaining to weed density at harvest presented in table 23 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (62.17 m^{-2}) was recorded in no-residue treatment and significantly higher over 30% crop residue retention (49.42 m^{-2}),60% crop residue retention (45.53 m^{-2}) and 90% crop residue retention treatments (42.31 m^{-2}). Among the weed control treatments, B_2 treatment (Imazethapyr followed by HW at 50 DAS) showed the best weed control efficacy. The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments varied but the interaction effect was not significant.

Table 70: Effect of different levels of crop residue retention and herbicidal weed control treatments on Weed biomass (kg ha^{-1}) in chickpea crop

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

The data pertaining to weed biomass presented in table 24 depicts significant effect on weed biomass as a result of different levels of crop residue retention. Maximum weed biomass (746.80 $kgha^{-1}$) was recorded in no-residue treatment and significant reduction in weed biomass was observed under 30%

crop residue retention (601.39 kg ha^{-1}), 60% crop residue retention (553.30 kgha^{-1}) and 90% crop residue retention treatments (514.38 kgha^{-1}). At all residue levels, significantly lower weed biomass was observed under B2 treatment. The weed biomass as a result of interaction effect between residue levels and herbicidal weed control treatments varied significantly.

Table 71: Effect of different levels of crop residue retention and herbicidal weed control treatments on Grain yield on chickpea crop

	B1	B2	B3	B4	Mean of A
A1	1263.83	1459.33	987.00	1093.83	1201.00
A2	1231.50	1431.50	971.00	1044.50	1169.63
A3	1209.00	1396.67	939.33	1026.00	1142.75
A4	943.33	1025.00	817.33	854.00	909.92
MEAN OF B	1161.92	1328.13	928.67	1004.58	
CD 0.05					
A	54.006	** 1%			
B	54.006	** 1%			
AB	108.012	* 5%			

The data pertaining to grain yield presented in table 25 depicts significant effect on grain yield as a result of different levels of crop residue retention. The maximum grain yield (1201.00 kgha^{-1}) was recorded in 90% crop residue retention level which was at par with 60% crop residue retention (1169.63 kgha^{-1}) and 30% crop residue retention (1142.75 kgha^{-1}) and significantly superior over without residue retention treatment (909.92 kgha^{-1}). In case of different herbicidal weed control treatments shows non-significant effect on the grain yield. The grain yield as a result of interaction effect between residue levels and herbicidal weed control treatments also varied significantly.

Plate 19. Response of different residue levels and herbicide treatments on maize crop

Weed species

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

Table 72: Dominant weed species present in the experimental field

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

Table 73: Effect of different levels of crop residue retention and herbicidal weed control treatments on weed density at 30 DAS in maize (m^{-2}) in maize crop.

	B1	B2	B3	B4	Mean of A
A1	27.56	53.33	54.67	55.00	47.64
A2	32.22	57.11	58.00	58.11	51.36
A3	37.78	61.78	62.78	62.44	56.19
A4	50.89	76.33	76.89	79.78	70.97
MEAN OF B	37.11	62.14	63.08	63.83	
CD 0.05					
A	2.406	** 1%			
B	2.406	** 1%			
AB	4.812	NS			

The data pertaining to weed density at 30 DAS presented in table 27 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (70.97 m^{-2}) was recorded in without residue retention level and significantly higher over 30% crop residue retention (56.19 m^{-2}), 60% crop residue retention (51.36 m^{-2}) and 90% crop residue retention treatment (47.64 m^{-2}). Different herbicidal weed control treatments showed significant influence on weed density. Lowest weed density was observed under B1 treatment across residue treatment levels.

Table 74: Effect of different levels of crop residue retention and herbicidal weed control treatments on weed density at harvest in maize (number m^{-2}) in maize crop.

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

The data pertaining to weed density at harvest presented in table 28 depicts significant effect on weed density as a result of different levels of crop residue retention. The maximum weed density (44.00 m^{-2}) was recorded in without residue retention level and which was at par with 30% crop residue retention (34.03 m^{-2}) and significantly higher over 60% crop residue retention (30.30 m^{-2}) and 90% crop residue retention treatment (26.22 m^{-2}). Maximum weed control was observed under B4 treatment (Tembotrione@120g a.i. ha^{1}+Atrazin @ 625g a.i. ha^{-1} (30 DAS) fb HW at 50 DAS)across all residue retention levels. The weed density as a result of interaction effect between residue levels and herbicidal weed control treatments also varied significantly.

Table 75: Effect of different levels of crop residue retention and herbicidal weed control treatments on total weed biomass (kgha^{-1}) in maize crop.

	B1	B2	B3	B4	Mean of A
A1	822.00	392.93	343.17	96.26	413.59
A2	896.10	418.03	372.82	119.29	451.56
A3	974.67	449.09	408.08	141.27	493.28
A4	1110.73	554.24	506.54	185.61	589.28
MEAN OF B	950.88	453.58	407.65	135.61	
CD 0.05					
A	14.227	** 1%			
B	14.227	** 1%			
AB	28.454	** 1%			

The data pertaining to weed biomass presented in table 29 depicts significant effect on weed biomass as a result of different levels of crop residue retention. The maximum weed biomass (589.28 kg ha^{-1}) was recorded in no-residue treatment, which was significantly higher as compared to 30% crop residue retention (493.28 kg ha^{-1}), 60% crop residue retention (451.56 kg ha^{-1}) and 90% crop residue retention treatment (413.59 kg ha^{-1}). Lowest weed biomass was observed under B4 treatment. The weed biomass as a result of interaction effect between residue levels and herbicidal weed control treatments also varied significantly.

Table 76: Effect of different levels of crop residue retention and herbicidal weed control treatments on grain yield in maize crop (kg ha^{-1}).

	B1	B2	B3	B4	Mean of A
A1	4456.00	5315.67	5389.33	6021.00	5295.50
A2	4358.67	5203.00	5266.33	5436.33	5066.08
A3	4139.50	4837.00	4964.67	5364.00	4826.29
A4	3915.00	4071.83	4179.83	4530.33	4174.25
MEAN OF B	4217.29	4856.88	4950.04	5337.92	
CD 0.05					
A	252.440	** 1%			
B	252.440	** 1%			
AB	504.881	NS			

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

Table 77: Effect of different levels of crop residue retention and herbicidal weed control treatments on stover yield in maize crop (kg ha^{-1}).

	B1	B2	B3	B4	Mean of A
A1	7107.32	8252.48	8288.95	8899.82	8137.14
A2	7021.02	8249.06	8219.48	8249.17	7934.68
A3	6792.43	7634.37	7788.15	8361.04	7644.00
A4	6700.57	6667.84	6852.26	7317.04	6884.43
MEAN OF B	6905.33	7700.94	7787.21	8206.77	
CD 0.05					
A	402.550	** 1%			
B	402.550	** 1%			
AB	805.099	NS			

The data pertaining to stover yield presented in table 31 depicts significant effect on stover yield as a result of different levels of crop residue retention. The maximum stover yield (8137.14 kg ha^{-1}) was recorded in 90% crop residue retention level and significantly superior over 60% crop residue retention (7934.68 kg ha^{-1}), 30% crop residue retention (7644.00 kg ha^{-1}) and without residue retention treatment (6884.43 kg ha^{-1}). Stover yield was highest under B4 treatment across all residue retention levels. The interaction effect of residue level and herbicidal weed control was not significant.

Plate 20. Effect of different levels of crop residue retention and herbicidal weed control treatments on maize crop

C. Water Management in Conservation Agriculture
Soybean-Wheat Cropping Systems
IISS
Wheat crop 2021-2022

During the winter season, wheat (cv. HI 1544) was grown with three methods of irrigation (flood, sprinkler and drip irrigation), three tillage management treatments (CT, RT and NT) and four levels of fertilizer treatments (100% RDF, 75% RDF, STCR and Leaf colour chart-based fertilizer management, LCC). Measured amount of irrigation water was applied in each of the irrigation treatment plots. Flood irrigated plots in wheat received 5 post sowing irrigations and a seasonal total of 416 mm water was applied. In sprinkler irrigation plots a measured total amount of 355 mm water (about 80% of the flood irrigation) was applied through micro sprinklers at twice a week interval, while in drip irrigation treatment a seasonal total of 290 mm of irrigation water (about 60% of the flood irrigation water) was applied through drip system at alternate day interval throughout the season. Better temporal distribution of irrigation water and consequently better profile moisture distribution could be attained in sprinkler and drip systems with less but more frequent irrigation water application to wheat. Data showed that grain and straw yield of wheat did not vary significantly among the irrigation method, tillage system and different nutrient doses.

Table 78: Effect of tillage systems and different nutrients doses under different irrigation systems on wheat grain yield, straw yield, harvest index and water use efficiency of wheat crop

Treatment	Grain yield (Kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest Index (%)
Irrigation methods			
Flood	5256	5179	0.50
Sprinkler	5155	5230	0.50

Drip	4745	4923	0.49
LSD (0.05)	NS	NS	NS
Tillage systems			
CT	4933	5059	0.49
RT	5058	5085	0.50
NT	5156	5188	0.50
LSD (0.05)	NS	NS	NS
Nutrients Doses			
100% RDF	5092	5106	0.50
75% RDF	4747	4902	0.49
STCR dose	5307	5358	0.50
LCC dose	5063	5076	0.50
LSD (0.05)	279.8	337.98	NS

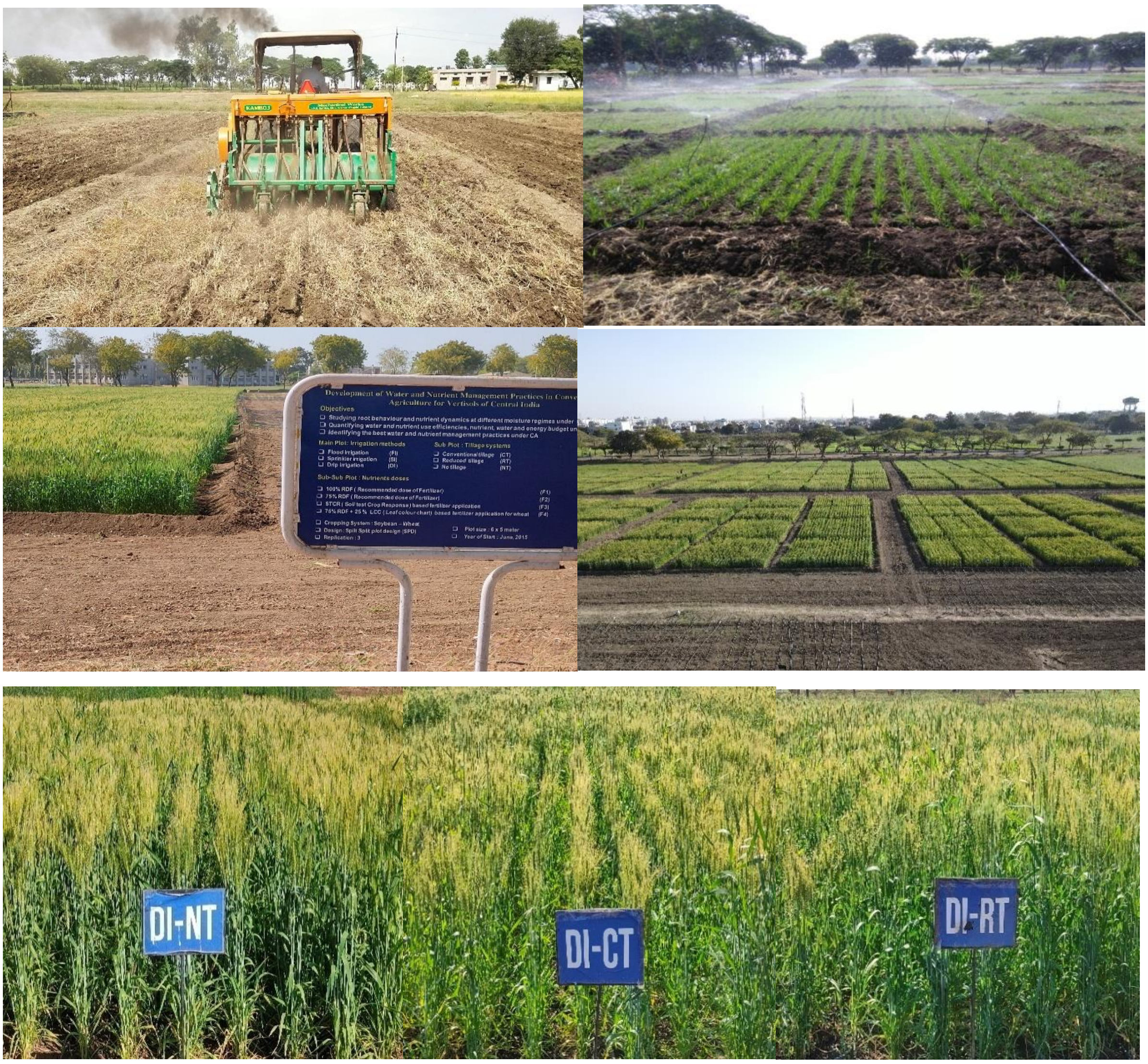


Plate 21. Field experiment view of development of Water and Nutrient Management Practices in rabi season 2021-2022

Soybean Crop 2022

The field experiment conducted on soybean crop in kharif season in year 2022. There were three levels of fertilizer treatments (F_1=100 % RDF, F_2=75% DRF, F_3=STCR and three levels of tillage treatment (CT-Conventional tillage, RT-Reduced tillage and NT- No tillage) were tested. The soybean variety of RVS 2001-4 was sown on22 June, 2022 and harvested in the month of October, 2022. The grain and straw yield of soybean (1098 and 3350 kg ha^{-1}) was slightly higher under reduced tillage system as compared conventional tillage. The lowest grain and straw yield were recorded under no tillage (1036 and 3060 kg ha^{-1}) but all the tillage systems were significantly at par. Similarly, in case of fertilizer treatments, the STCR dose recorder slightly higher grain yield of soybean (1080 and 3260 kg ha^{-1}) followed by 100% RDF and less yield was in 75% RDF (1039 and 3020 kg ha^{-1}). However, all the fertilizer treatments were also significantly at par. The interaction effect of tillage systems and different nutrient doses was found non-significant (Table 79). Conservation agriculture system maintained yield level on par with the conventional agricultural practices with concomitant savings of time, labour and input cost and improvement in soil health parameters and sustainability of yield.

Table 79: Effect of tillage systems and nutrients doses on grain and straw yield of soybean

	Soybean grain yield (kg ha^{-1})				Soybean straw yield (kg ha^{-1})			
	F1	F2	F3	Mean	F1	F2	F3	Mean
CT	1085	1013	1056	1051	3130	3010	3160	3100
RT	1103	1055	1136	1098	3540	3030	3490	3350
NT	1011	1049	1048	1036	3030	3030	3130	3060
Mean	1067	1039	1080		3230	3020	3260	
	Tillage: NS, Nutrient Dose: NS, Tillage x Fertilizer dose: NS				Tillage: NS, Nutrient Dose: NS, Tillage x Fertilizer dose: NS			

Plate 22. View of soybean sowing and crop performance in 2022

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

The experiment was conducted in a factorial randomized design to study the effect of different levels of crop residue retention and optimum doses of nutrient application in soybean-wheat cropping system. The treatments comprised of four levels of residue retention and optimized doses of nitrogen, phosphorus and potassium application as compared to 100% nutrient application (table 80)

Table 80: Details of residue and nutrient level treatment

Factor. A↓/ Factor B→ Residue levels	Nutrient level treatment	
	Soybean	Wheat
A_1(90%) Crop residue	B_1. 25:60:40 kg ha^{-1} N, P_2O_5, K_2O	B_1. 120:60:40 kg ha^{-1} N, P_2O_5, K_2O

A_2(60%) Crop residue	B_2. 15:60:40 kg ha^{-1} N, P_2O_5, K_2O	B_2. 90:60:40 kg ha^{-1} N, P_2O_5, K_2O
A_3(30%) Crop residue	B_3. 25:45:40 kg ha^{-1} N, P_2O_5, K_2O	B_3. 120:45:40 kg ha^{-1} N, P_2O_5, K_2O
A_4(0%) without Crop residue	B_4. 25:60:30 kg ha^{-1} N, P_2O_5, K_2O	B_4. 120:60:30 kg ha^{-1} N, P_2O_5, K_2O

Grain yield of Wheat crop

The data pertaining to grain yield of wheat crop (table 81) shows significant differences in grain yield as a result of different levels of crop residue retention. The maximum yield (6215.67kg ha^{-1}) was recorded in 90% residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 5772.22, 5368.92, 5158.19 kg ha^{-1}, respectively and the lowest grain yield (5158.19 kg ha^{-1}) was observed in without residue treatment. In case of various levels of nutrient applications there was nonsignificant effect of nutrient doses on grain yield and the grain yield varied between (5554.44 to 5766.53 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant effect on grain yield (Table 81). The highest grain yield (6600 kg ha^{-1}) in 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (5077.78 kg ha^{-1}) was observed in without residue with 75% N, 100% P, K doses.

Table 81: Effect of different levels of crop residue retention and nutrient doses on grain yield (kg ha^{-1}) on wheat crop

	100% RDF (120:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	6600.00	5989.22	6029.00	6244.44	6215.67
60% R	5733.33	5911.11	5777.78	5666.67	5772.22
30% R	5500.01	5275.78	5277.67	5422.22	5368.92
WR	5232.78	5077.78	5133.33	5188.89	5158.19
Mean	5766.53	5563.47	5554.44	5630.56	
CD 0.05					
Residue	363.004	** 1%			
Nutrient	363.004	NS			
Residue x Nutrient	726.008	NS			

Straw yield

The data pertaining to straw yield of wheat crop (table 82) shows significant differences in straw yield as a result of different levels of crop residue retention. The maximum straw yield (9738.94 kg ha^{-1}) was recorded in 90 % residue retention treatment which was significantly superior to 60%, 30% and without residue retention with the mean value 9356.75, 8801.75, 8265.75kg ha^{-1} respectively and the lowest straw yield (8265.75 kg ha^{-1}) was observed in without residue. In case of various levels of nutrient applications there was non-significant effect of nutrient doses on straw yield and the straw yield varied between (8872.05 to 9293.69 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on straw yield as a result of different residue levels and nutrient doses (Table 82). The highest straw yield (10025kg ha^{-1}) recorded from 90% crop residue with 100%RDF treatment, was statistically at par with other residue levels. The lowest straw yield (8872 kg ha^{-1}) was observed in no-residue treatment with 75% N, 100% P, K doses.

Table 82: Effect of different levels of crop residue and nutrient doses on straw yield (kg ha^{-1}) on wheat crop

	100% RDF (120:60:40)	75% N, 100% P, K	75% P, 100% N, K	75% K, 100% N, P	Mean
90% R	10024.61	9565.67	9676.42	9689.07	9738.94
60% R	9390.80	9405.21	9328.00	9303.00	9356.75
30% R	9087.33	8599.00	8728.00	8792.67	8801.75
WR	8672.00	7918.33	8021.00	8451.67	8265.75
Mean	9293.69	8872.05	8938.35	9059.10	
CD 0.05					
Residue	159.250	** 1%			
Nutrient	159.250	** 1%			
Residue x Nutrient	318.501	NS			

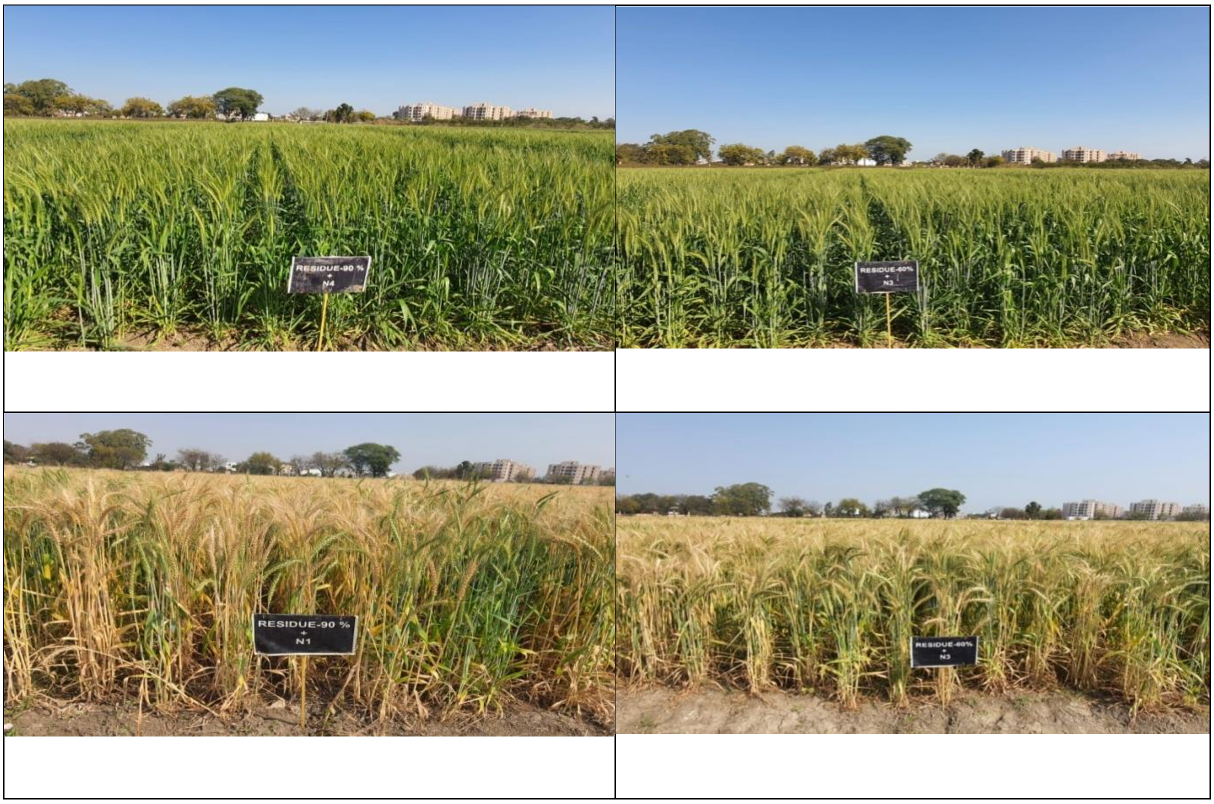


Plate 23. Effect of different levels of crop residue and nutrient doses on wheat crop

Soybean crop

Seed yield

The data on grain yield of soybean crop (table 83) shows significant differences in grain yield as a result of different levels of crop residue retention. The maximum yield (1276 kg ha^{-1}) was recorded in 90% residue retention treatment which was significantly superior to 60%, 30% and no-residue treatment with the mean value of 1197.38, 1128.83, 1054.50 kg ha^{-1}, respectively and the lowest grain yield (1054.50 kg ha^{-1}) was observed in no-residue treatment. In case of various levels of nutrient applications there was non-significant effect of nutrient doses on grain yield and the grain yield varied between (1132.08

to1195.58 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on grain yield as a result of different residue levels and nutrient doses (Table 83). The highest grain yield (1332.67 kg ha^{-1}) was obtained from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (1017 kg ha^{-1}) was observed in no-residue treatment with 75% N, 100% P, K doses.

Table 83: Effect of different levels of crop residue retention and nutrient doses on grain yield kg ha^{-1} on soybean crop

	100% RDF (25:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	1332.67	1234.33	1258.33	1280.00	1276.33
60% R	1227.33	1164.67	1190.83	1206.67	1197.38
30% R	1140.67	1112.33	1125.00	1137.33	1128.83
WR	1081.67	1017.00	1055.33	1064.00	1054.50
Mean	1195.58	1132.08	1157.38	1172.00	
CD 0.05					
Residue	19.626	** 1%			
Nutrient	19.626	** 1%			
Residue x Nutrient	39.251	NS			

Straw yield

The data pertaining from straw yield of soybean crop (table 84) shows no significant differences in straw yield as a result of different levels of crop residue retention. The maximum straw yield (2493.21 kg ha^{-1}) was recorded in 90 % residue retention treatment which was at par with rest of the residue levels and he lowest straw yield (1991.21 kg ha^{-1}) was observed in without residue. In case of various levels of nutrient applications there was also non-significant effect of nutrient doses on straw yield and the straw yield varied between (2195.21 to 2286.71 kg ha^{-1}). The interaction effect between residue levels and nutrient doses not show any significant difference effect on straw yield as a result of different residue levels and nutrient doses (Table 84). The highest straw yield (2608.50 kg ha^{-1}) recorded from 90% crop residue and treatment with 100% RDF which was statistically at par with other residue levels. The lowest grain yield (1950.00 kg ha^{-1}) was observed in without crop residue with 75% N, 100% P, K doses.

Table 84: Effect of different levels of crop residue retention and nutrient doses on straw yield kg ha^{-1} on soybean crop

	100% RDF (25:60:40)	**75% N, 100% P, K**	**75% P, 100% N, K**	**75% K, 100% N, P**	**Mean**
90% R	2608.50	2430.17	2466.67	2467.50	2493.21
60% R	2315.00	2300.67	2394.17	2250.83	2315.17
30% R	2144.17	2100.00	2093.17	2104.33	2110.42
WR	2079.17	1950.00	1964.00	1971.67	1991.21
Mean	2286.71	2195.21	2229.50	2198.58	
CD 0.05					
Residue	45.063	** 1%			
Nutrient	45.063	** 1%			
Residue x Nutrient	90.125	* 5%			

Plate 24. Effect of different levels of crop residue retention and nutrient doses on soybean crop

CRIDA

Maize –Pigeonpea system

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

This year maize crop was sown. Results revealed that both tillage practices and nitrogen management did not influence the seed germination of maize. NT and RT recorded 20.7 and 10.5% higher mean maize grain yield respectively as compared to CT. NT recorded 9.2 % higher seed yield over RT. The increase in the nitrogen levels enhanced the seed yield significantly. Due to continuous omission of the nitrogen in control plot (N-0) since last 10 years the yield very low as compared to the other nitrogen levels. The maize grain yield in N-0, N-75, N-100 and N-125 were 231.2, 2668.1, 3326.3 and 3639.9 kg ha^{-1}, respectively. The interactive effect of tillage practices and nitrogen levels found to be non-significant (Fig 61).

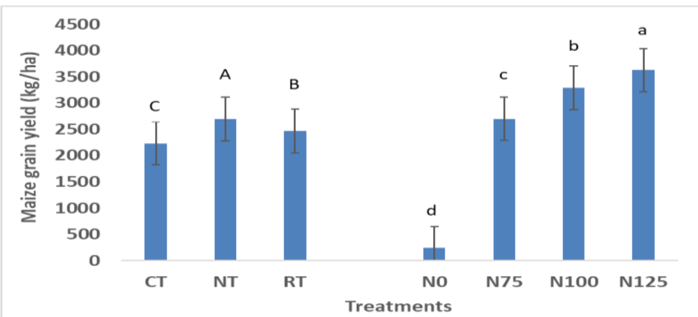


Fig 61: Mean effect of tillage practices and nitrogen levels on maize grain yield (kg/ha).

Plate 25.Maize crop growth in the no-tillage plot along with N125% RDN.

2. Pearlmillet – Horsegram/ Pigeonpea

A field experiment was conducted since 2016 in sandy loam soil of Gunegal Research Farm at ICAR-Central Research Institute for Dryland Agriculture (ICAR-CRIDA), Hyderabad with different treatments: zero tillage (ZT- no till, direct seeded with residue retention), minimum tillage (MT- One ploughing, sowing with residue retention) and conventional tillage (CT- two ploughing with disk plough, one harrowing and sowing) as main plots and 75% RDF, 100% RDF (Pearl millet: 80-40-30 kg N, P_2O_5, K_2O ha^{-1}), Horsegram on residual fertility, Pigeon pea: 20-50-0 kg N, P_2O_5, K_2O ha^{-1}) and 125% RDF as subplots, to study the effect of tillage practices and different doses of fertilizers on performance of pearlmillet (MP MH21) and horsegram (CRHG 4). Short duration (75-80 days) pearlmillet (MP MH21) was selected to take the advantage of early sowing of horsegram and increase cropping intensity. In pearlmillet (PM)-horsegram (HG) sequence-pigeonpea (PP) rotation: Significantly higher yield was obtained in ZT (1100 kg/ha) as compared to CT (831 kg/ha) in 2022.

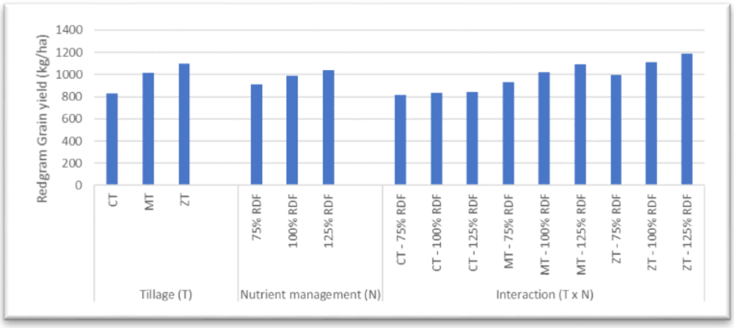


Fig 62: Effect of tillage and different fertilizer doses on pigeon pea yield

Plate 26.Effect of tillage and nutrient management in pigeon pea

3. Cotton – Pigeonpea system

In cotton- pigeonpea system, theRDF of 120-60-60 kg N, P_2O_5, K_2O ha^{-1} was applied.(plate 9). Significantly higher seed cotton yield was observed in ZT (2686 kg/ha) followed by MT (2420 kg/ha) and CT (2339 kg/ha), Whereas in nutrient management 125% RDF reported significantly higher seed cotton yield (2571 kg/ha) which was on par with 100% RDF (2523 kg/ha) followed by 75% RDF (2352 kg/ha) (Fig 63).

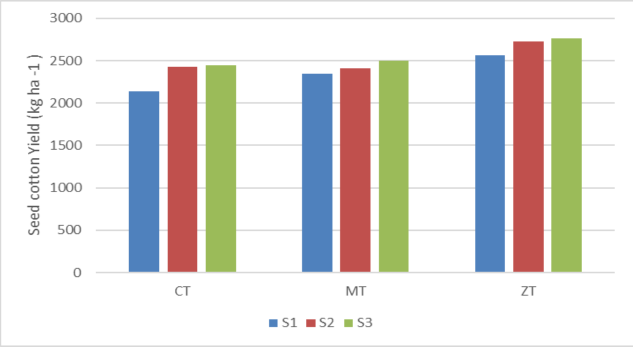


Fig 63: Effect of tillage and different fertilizer doses on seed cotton yield


Plate 27.Effect of tillage and nutrient management in cotton

CRIDA

Pigeonpea Crop

An experiment was initiated at CRIDA with integration of in situ moisture conservation and weed control along with CA practices as complimentary practices. Pigeonpea was the test crop. This year integration of in situ moisture conservation practices through permanent bed and furrow, permanent conservation furrow recorded 15 and 40 % higher pigeonpea yields as compared to conventional tillage without moisture conservation. Among the weed control treatments pre-emergence + post emergence herbicide application recorded higher yields as compared to other weed management practices. Reduction in crop yield in un weeded treatment in ZT normal sowing was higher than in conventional tillage and Zero tillage with in situ moisture conservation. It was observed that ZTF recorded higher yield in control since dhaincha is grown as intercrop. (Fig. 64)

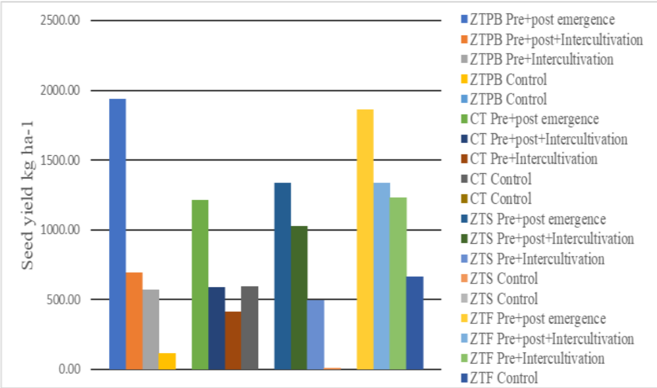


Fig 64: Influence of different treatments on pigeonpea seed yield

NIASM

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

A new experiment to study the interaction effects plant growth regulators (PGRs) and deficit irrigation (DI) was established in sugarcane (Variety: Co–86032) cropping system during year 2022. The CA practices of crop residue management and tillage were imposed in recently harvest crop. The main treatments included three DIlevels i.e. 50% ETc; 75% ETc and 100% ETc (full irrigation) were applied using subsurface drip irrigation system. Two soil surface cover (mulching) practices *viz.*, S1: crop residue covering and S2: no residue was accommodated in subplots. Four PGRs namely thio-urea (TU, 1800 ppm), irradiated chitosan (IC, 5 ml/L), nano-urea (NU, 4 ml/L), salicylic acid (SA, 25 µM) and no PGRs (control) were applied exogenously with interval of one month after crop establishment (60 DAT) for alleviating water stress as sub-sub plot treatments. The real time crop-soil-water parameters were measured with interval of 30-45 days interval. The preliminary results of IC and NU at 75% ETc seems to promising for enhancing the growth attributes and cane yields of plant sugarcane.

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

In year 2022, field experiment was repeated to optimize the effect of zigzag paired row planting, subsurface drip irrigation and intercropping (groundnut-fenugreek) with aim of enhancing productivity of ratoon sugarcane (Co-86032) cropping system. The main plot treatments included, M1: Zigzag Paired Row (ZPR) with (60 cm-plant spacing ,150 cm-row spacing) + Sub-Surface Drip Irrigation (SSDI); M2: ZPR (75 cm, 150 cm) + SSDI; M3: ZPR (60 cm, 210 cm) + SSDI; M4: ZPR (75 cm, 210 cm) + SSDI; M5: ZPR (60 cm, 225 cm) + SSDI; M6: ZPR (75 cm, 225 cm) + SSDI; M7: ZPR (60 cm,180 cm) + SSDI; M8: ZPR (75 cm,180 cm) + SSDI. Two soil cover treatments included S1: Groundnut residue + sugarcane trash and S2: without residue were accommodated in sub-plots. An absolute control surface irrigation management practices was also maintained to compare the treatment effects. The first year results showed 39.5, 51.3 and 28% improvement in yields of groundnut, fenugreek and sugarcane in M5S1 treatments in comparison to M3S2, respectively indicating possibility of improving productivity sugarcane cropping system.

Objective 2: Quantification of tangible and non-tangible effects

1. Physical Property
A. Mean Weight Diameter (MWD)
Rice-Wheat Cropping System
IARI

The triple zero-tillage system with the residue of three crops (CA5) had a higher MWD (Table 85) at 0–5cm, 5–15cm, and 15–30 cm soil depths than conventional tillage (CT) (i.e., PTR-CTW) and double ZT with or with out residue retention (CA1, CA2, CA3, and CA4). The CT system observed the lowest MWD (0.60-1.00 mm) across the studied depths. The MWD was decreased with increasing soil depth (i.e., 0–5cm>5–15cm >15–30cm).

Contrast analysis of MWD showed a significant variation between CA versus (Vs) CT, residue Vs no-residue, triple zero-tillage with residue (TZT+R) Vs double zero-tillage with residue (DZT+R), triple zero-tillage without residue (TZT-R)Vs doublezero-tillage without residue (DZT-R), and zero tillage without residue (ZT-R) Vs CT. The MWD were higher for CA (141%, 71%, and 49%), residue retention (13%, 26%, and 26%), TZT+R (24%, 98%, and 50%), TZT-R (15%, 97%, and 10%), and ZT-R (113%, 112%, and 17%) treatments compared to CT, no-residue, DZT+R, DZT-R and CT at 0–5, 5–15 and 15–30cm soil depth respectively.

Table;-85 Mean weight diameter (MWD) (mm) of soil aggregatesat different soil depths after 10 years of CA-based rice-wheat system

Treatment	MWDofaggregates(mm) Soildepths(cm)		
	0-5	5-15	15-30
CA1	1.98±0.08[b†]	0.91±0.10[d]	0.72±0.03[bc]
CA2	2.19±0.04[b]	1.21±0.02[c]	0.79±0.03[b]
CA3	2.27±0.07[b]	1.37±0.07[c]	0.85±0.06[b]
CA4	2.28±0.19[b]	1.80±0.16[b]	0.78±0.01[b]
CA5	2.77±0.15[a]	2.55±0.11[a]	1.23±0.04[a]
CT	1.00±0.02[c]	0.64±0.02[e]	0.60±0.04[c]

[†]Treatment means followed by same lower case letters do not differ by Fisher's least significant difference (LSD) test at P≤0.05. CA1=Zero-till direct-seeded rice (ZTDSR)-zero till wheat (ZTW); CA2=ZT DSR+ wheat residue (WR)-ZTW+ rice residue (RR); CA3=ZTD SR+WR+ brown manuring (BM)- ZTW+RR; CA4=ZTDSR– ZTW – ZTmungbean (ZTMB); CA5=ZTDSR+ mungbean residue (MR) - ZTW+ RR - ZTMB+WR; CT=Puddled transplanted rice (PTR)-conventional till wheat(CTW).

Maize-Chickpea Cropping System

IISS

Tillage along with residue retention significantly (P <0.05) influenced the MWD and WSA in maize-chickpea rotation (Table 86). The highest MWD of 1.39 mm was recorded in 90% of residue retained plot, which is almost 100% higher in comparison to CT treatment. Even retention of 60% of residue significantly improved MWD of soil. However, no significant impact of no till on MWD was recorded in 10-20 cm of soil depth.

Retention of 90% of residue significantly improved water stable aggregates in comparison to conventionally tilled plot. The same trend was recorded in case of 30 and 60% of residue retained plot. However, no significant impact of no till on WSA and MWD was recorded in 10-20 cm of soil depth.

Table 86: Mean weight diameter and water stable aggregates under conventional and no till system in maize-chickpea cropping system

	MWD (mm)	WSA (%)	MWD (mm)	WSA (%)
	0-10 cm	0-10cm	10-20 cm	10-20 cm
CTR0	0.70c	65.37c	0.88a	69.21a
NTR0	1.17b	73.57b	0.90a	74.36a
NTR30	1.16b	72.27b	0.89a	68.61a
NTR60	1.27ab	76.62b	1.02a	76.41a
NTR90	1.39a	81.97a	0.93a	73.22a

Cotton-wheatsystem

IARI

After tenth year of cotton-wheat system, results indicated a considerable improvement in the mean weightdiameter (MWD) of soil at 0-5 and 5-15 cm soil depth by 13.9, 58%, respectively. CA system compared to the conventional tillage system in(Table 87). Among the CA systems retention of crop residues could improve the MWD at 0-5 and 5-15 cm soildepth by 16.7 and 2.6%, respectively. Among the landform treatments, Broad bed system registered higher MWDthan Narrow bed system at 0-5 cm soil depth. Among the CA practices i.e. zero tilled flatbed withresidueretention registered highestMWDat0-5and5-15cmsoil depth.

Table 87: Mean weight diameter (mm) of water stable aggregates under conservation and conventional agriculturepractices

Treatment	**Meanweightdiameter**		
Zerotillage(ZT)	0-5cm	5-15cm	15-30cm
ZT+Residue	0.98^{B}	0.77^{A}	0.78^{AB}
BB+Residue	1.19^{A}	0.81^{A}	0.71^{BC}
Broadbed(BB)	0.97^{B}	0.78^{A}	0.62^{C}
NB+Residue	0.76^{D}	0.76^{A}	0.65^{C}
Narrowbed(NB)	0.78^{D}	0.77^{A}	0.62^{C}
Flatbed	0.77^{D}	0.79^{A}	0.73^{BC}
Mean	0.86^{C}	0.50^{B}	0.88^{A}
PValue	0.90	0.74	0.71
	<.0001	<.0001	<.0001
ContrastCAvsCT			
CA	0.98	0.79	0.65
CT	0.86	0.50	0.88
PValue	<.0001	<.0001	<.0001
ContrastRvsR0			
R+	0.98	0.79	0.65
R0	0.84	0.77	0.72
PValue	<.0001	0.4980	0.0029
ContrastBBvsNB			
BB	0.87	0.77	0.64
NB	0.78	0.78	0.68
PValue	<.0001	0.2761	0.1084

B. Water Stable Aggregate Percentage (WSA)

Maize-Chickpea Cropping System

IISS

Tillage along with residue retention significantly (P <0.05) influenced the WSA in maize-chickpea rotation (Table 88). Retention of 90% of residue significantly improved water stable aggregates in comparison to conventionally tilled plot. The same trend was recorded in case of 30 and 60% of residue retained plot. However, no significant impact of no till on WSA was recorded in 10-20 cm of soil depth.

Table 88 Water stable aggregates under conventional and no till system in maize-chickpea cropping system

	WSA (%)	WSA (%)
	0-10cm	10-20 cm
CTR0	65.37c	69.21a
NTR0	73.57b	74.36a
NTR30	72.27b	68.61a
NTR60	76.62b	76.41a
NTR90	81.97a	73.22a

D. Bulk Density (BD)

IARI

Rice-Wheat Cropping System

A lower bulk density (BD) was observed for CA5 over CT and superior to other CA treatments having no residueretention (Table89).Contrary to MWD,the soil BD was lowerforCA5 (1.28, 1.50, and 1.62Mg m^{-3} at 0–5, 5–15, and 15–30 cm depth respectively) and higher for CT system (1.42, 1.64 and 1.72 Mg m^{-3} at 0–5, 5–15 and15–30 cm depth respectively). Likewise, BD values also increased with an increase in soil depth but it was contrary to the MWD.

Contrast analysiss howed the BD values were lower for CA (8.45%, 7.31%, and 5.23%), residue retention (4.41%, 3.79%, and 2.39%), TZT+R (2.29%, 1.96%, and 1.21%), TZT-R (0.73%, 0.63%, and 1.19%), and ZT-R (4.22%, 3.65%, and 2.90%) treatments compared to CT, no residue, DZT+R, DZT-R and CT respectively, at soil depth of 0–5, 5–15 and 15–30 cm.

Table 89;- BD (Mgm^{-3}) of soil aggregates at different soil depths after 10 years of CA-based rice-wheat system

Treatment	BD(Mgm^{-3})		
	Soil depths(cm)		
	0-5	5-15	15-30
CA1	$1.36±0.01^{b}$	$1.58±0.03^{b}$	$1.68±0.01^{ab}$
CA2	$1.31±0.02^{cd}$	$1.53±0.02^{cd}$	$1.65±02^{bcd}$
CA3	$1.30±0.01^{cd}$	$1.52±0.02^{d}$	$1.63±0.02^{cd}$
CA4	$1.35±0.02^{bc}$	$1.57±0.02^{bc}$	$1.66±0.01^{bc}$
CA5	$1.28±0.01^{d}$	$1.50±0.02^{d}$	$1.62±0.02^{d}$
CT	$1.42±0.03^{a}$	$1.64±0.04^{a}$	$1.72±0.02^{a}$

[†]Treatment means followed by same lower case letters do not differ by Fisher's least significant difference (LSD) test at P≤0.05. CA 1=Zero- till direct-seeded rice (ZTDSR) –zero till wheat (ZTW); CA2=ZT DSR+ wheat residue (WR) -ZTW+ rice residue (RR); CA3=ZTDSR+WR+ brown manuring (BM)- ZTW+RR; CA 4=ZTD SR– ZTW – ZT mung bean (ZTMB); CA5=ZTDSR+ mung bean residue (MR) - ZTW+ RR - ZTMB+WR; CT= Puddled transplanted rice ([†]Treatment means followed by same lower case letters do not differ by Fisher's least significant difference (LSD) test at P≤0.05. Values inparen theses a repercent increase or decrease over the respective counter treatment in each pair of contrast. CA (conservation agriculture); CT (conventional tillage); TZT+R (triple zero-tillage with residue); DZT+R (double zero-tillage with residue); TZT-R (triple zero-tillage with out residue); DZT-R (double zero-tillage with out residue); ZT-R (zero-tillage without residue)

DZT+R *P*-value	2.23^{b} 0.0011	1.29^{b} <.0001	0.82^{b} <.0001	1.31^{a} 0.1376	1.53^{a} 0.1930	1.64^{a} 0.2527
Triple zero-tillage without residue (TZT-R) vs double zero-tillage without residue (DZT-R)						
TZT-R	2.28^{a}(15)	1.80^{a}(97)	0.79^{a}(10)	1.35^{a}(1)	1.57^{a}(1)	1.66^{a}(1)
DZT-R	1.98^{a}	0.91^{b}	0.72^{a}	1.36^{a}	1.58^{a}	1.68^{a}
P-value	0.0502	<.0001	0.2835	0.6366	0.6416	0.4815
Zero-tillage without residue (ZT-R) vs conventional tillage (CT)						
ZT-R	2.13^{a}(113)	1.36^{a}(112)	0.76^{a}(17)	1.36^{b}(4)	1.58^{b}(4)	1.67^{b}(3)
CT	1.00^{b}	0.64^{b}	0.65^{a}	1.42^{a}	1.64^{a}	1.72^{a}
P-value	<.0001	<.0001	0.0509	0.0030	0.0031	0.0140

DZT+R *P*-value	2.23^{b} 0.0011	1.29^{b} <.0001	0.82^{b} <.0001	1.31^{a} 0.1376	1.53^{a} 0.1930	1.64^{a} 0.2527
Triple zero-tillage without residue (TZT-R) vs double zero-tillage without residue (DZT-R)						
TZT-R	2.28^{a}(15)	1.80^{a}(97)	0.79^{a}(10)	1.35^{a}(1)	1.57^{a}(1)	1.66^{a}(1)
DZT-R	1.98^{a}	0.91^{b}	0.72^{a}	1.36^{a}	1.58^{a}	1.68^{a}
P-value	0.0502	<.0001	0.2835	0.6366	0.6416	0.4815
Zero-tillage without residue (ZT-R) vs conventional tillage (CT)						
ZT-R	2.13^{a}(113)	1.36^{a}(112)	0.76^{a}(17)	1.36^{b}(4)	1.58^{b}(4)	1.67^{b}(3)
CT	1.00^{b}	0.64^{b}	0.65^{a}	1.42^{a}	1.64^{a}	1.72^{a}
P-value	<.0001	<.0001	0.0509	0.0030	0.0031	0.0140

CRIDA

In Pigeonpea - castor cropping system, zero tillage with residues recorded 39% higher infiltration over conventional tillage without residues. Whereas zero tillage without residues recorded 18% lower infiltration as compared to conventional tillage. Slight increase in bulk density was observed in zero tillage (6%) as compared to conventional tillage.

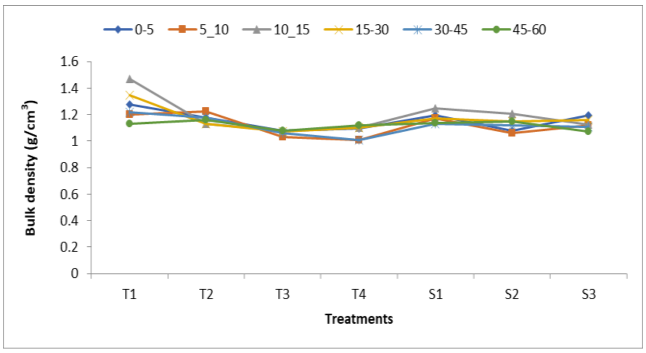


Fig 65 Effect of tillage practices and residue retention levels on bulk density (g/cm^3)

E. Soil Penetration Resistance

Rice-Wheat Cropping System

IARI

The tillage, cropping system, and residue retention highly influenced the soil penetration resistance after10 years of experimentation (Fig 2.2). Among the treatments, the penetration resistance value was significantly lower in CT (1052±68 kPa) and CA5 (1122±126 kPa) over other treatments at 0-5 cm soil depths. However, the CA 5 treatment had significantly lower penetration resistance at 5-15cm (1236±35kPa) and15-30cm (1694±50kPa) compared to other treatments. In the CT system, the penetration resistance values were increased by 22.36% at5–15 cm and 51.78% at 15–30 cm over 0–5 cm soil depth, which was considerably higher compared to CAsystems. The significantly highest penetration resistance was noticed in CT at a soil depth of 15–30 cm. Similarresults were also reflected in the continuous measurement of penetration resistance using a cone penetrometeracross thedepth of soil from 0–45 cm. In the CA-based system, penetration resistance did not exceed 2000 kPaat any depth whereas in the CT system the penetration resistance attained the value of 2400 kPa at 20–25 cm depth in dicating hard pan there.

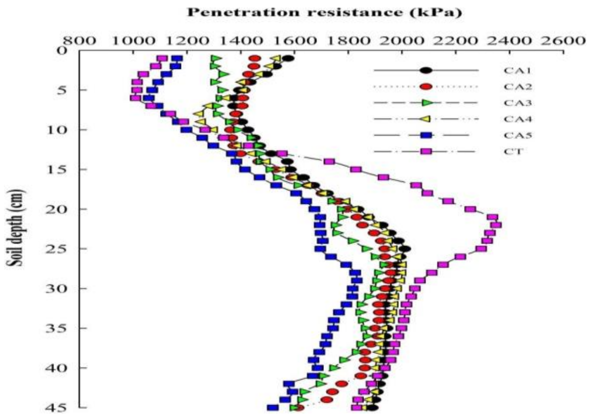


Fig 66: Soil penetration resistance profile under the conservation agriculture (CA) and conventional tillage(CT) practices across soil depth (Continuous measurement).

CA1=Zero-till direct-seeded rice (ZTDSR) –zero till wheat (ZTW) ; CA2=ZTDSR+wheat residue (WR)-ZTW+rice residue (RR); CA3=ZT DSR+WR+ brown manuring (BM)-ZTW+RR; CA4=ZTD SR–ZTW–ZT mung bean (ZTMBCA5=ZTDSR+mung bean residue (MR)-ZTW+RR-ZTMB+WR;CT=Puddled transplanted rice (PTR)-conventional till wheat (CTW).

Water Use efficiency

Soybean-Wheat Cropping Systems
Wheat crop 2021-2022

Water Use efficiency (WUE) was significantly higher under drip irrigation than the sprinkler and flood irrigation. The WUE was lowest under flood irrigation, which was significantly lower than that under sprinkler irrigation (Table 90). 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. 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.

Table 90: Effect of tillage systems and different nutrients doses under different irrigation systems on water use efficiency of wheat crop.

Treatment	**Water Use efficiency (Grain kg ha^{-1} mm^{-1})**	**SMC (%)**
	Irrigation methods	
Flood	12.6	15.8
Sprinkler	14.4	20.7

Drip	16.3	21.0
LSD (0.05)	2.034	
	Tillage systems	
CT	14.2	18.4
RT	14.4	19.7
NT	14.8	19.3
LSD (0.05)	NS	
	Nutrients Doses	
100% RDF	14.4	18.8
75% RDF	13.6	19.2
STCR dose	15.2	18.9
LCC dose	14.5	19.6
LSD (0.05)	NS	

Plate 28. Field experiment view of development of Water and Nutrient Management Practices in rabi season 2021-2022

Plate 29. Field visit at CA Experiment

H. Aggregate Size Distribution

Size distribution of water-stable soil aggregates and aggregate stability

Tillage along with residue retention significantly (P <0.05) influenced the distribution of aggregates in large macro-aggregates (>2 mm size) (Table 2.7a). The proportion of large macroaggregates (>2 mm) was significantly higher in the NT treatment than that in CT. In contrast, the proportion of small macro-aggregates (1-0.25 mm) was higher in the CT than that in NT. A similar trend was also observed for micro–aggregate (0.25- 0.053 mm) fractions, but the difference was not significant. The proportion of large macro-aggregate fraction in the NTR90 treatment was significantly higher than that in NTR0 (P < 0.05), while the proportion of micro-aggregates was higher in the CT and NT without residue retention treatments than for R90 although the difference was not significant in the other size fractions (P > 0.05).No significant impact of tillage and residue retention on aggregate size distribution was recorded in 10-20 cm of soil depth (Table 91).

Table 91: Aggregate size distributions under different levels of residue retention (0-10 cm)

Treatments	**Large macro-aggregates (>2 mm)**	**Small macro-aggregates (2–0.25 mm)**	**Micro-aggregates (0.25–0.053 mm)**	**Silt+clay fraction (<0.053 mm)**
CT	13.73b	56.68a	11.78a	17.6a
NTR0	13.83b	54.58a	11.63a	19.83a
NTR30	26.50ab	43.73a	8.54a	20.60a
NTR60	28.67ab	45.46a	6.53a	18.60a
NTR90	36.13a	45.06a	5.81a	12.57a

Note: Values followed by a letter not in common within a column, are significantly different based on Duncan's multiple range test at $P = 0{\cdot}05$.

Table 92: *Size distribution of water-stable soil aggregates and aggregate stability (10-20 cm)*

	Lmacro (%)	Smacro (%)	Micro (%)	Silt+clay (%)
CTR0	26.69a	56.82a	5.86a	9.40a
NTR0	8.83a	55.54a	8.20a	10.54a
NTR30	11.87a	62.33a	10.36a	13.8a
NTR60	24.47a	41.96a	4.85a	11.7a
NTR90	15.46a	41.67a	6.45a	18.4a

Note: Values followed by a letter not in common within a column, are significantly different based on Duncan's multiple range test at $P = 0{\cdot}05$

Maize-Chickpea Cropping System

Tillage along with residue retention significantly (P <0.05) influenced the distribution of aggregates in large macro-aggregates (>2 mm size) (Table 93 & 94). The proportion of large macro-aggregates (>2 mm) was significantly higher in the NT treatment than that in conventionally tilled plot. In contrast, the proportion of small macro-aggregates (2-0.25) was higher in the CT than that in NT. The proportion of large macro-aggregate fraction in the NTR90 treatment was significantly higher (Table 2.8) than that in CT (P < 0.05), while the proportion of micro-aggregates was higher in the CT and NT without residue retention treatments than for NTR90 (P > 0.05).

No significant impact of tillage and residue retention on aggregate size distribution was recorded in 10-20 cm of soil depth.

Table 93: Aggregate size class distribution under conventional and no till system in maize-chickpea cropping system

Treatments	Large macro-aggregates (>2 mm)	Small macro-aggregates (2–0.25 mm)	Micro-aggregates (0.25–0.053 mm)	Silt+clay fraction (<0.053 mm)
CT	4.38c	61.15a	12.47a	21.65a
NTR0	22.67b	47.90b	9.58ab	10.61b
NTR30	22.53b	50.01b	10.00ab	11.65b
NTR60	23.65ab	53.44ab	9.93ab	12.33b
NTR90	29.35a	52.64ab	6.97b	11.00b

Table 94: Tillage and residue retention impact on organic C concentration (%) in aggregate and silt + clay fractions from the top 0.2 m soil depth.

	Lmacro (%)	Smacro (%)	Micro (%)	Silt+clay (%)
CTR0	10.30a	47.84a	10.05a	16.55a
NTR0	9.36a	60.11a	9.66a	11.93a
NTR30	12.12a	51.23a	9.85a	18.55a
NTR60	14.81a	56.59a	8.40a	12.16a
NTR90	10.73a	52.34a	6.74a	14.37a

Treatment effects on the MWD of soil aggregates and the WSA are summarized in table 95. No significant impact of no till system with residue retention was observed on WSA. Although increased rate of residue retention under no till system resulted in improvement in WSA, however the effect was not significant. Retention of residue to the extent of 90% resulted in 20% improvement in WSA in comparison to CT system. The effect of no till system along with residue retention significantly impacted soil MWD. There was 5.5-77% improvement in soil MWD in no till system with different levels of residue retention in comparison to CT system. The highest improvement of 77% was recorded under no till system with 90% of residue retention. MWD of soil increased from 0.91 mm in CT system to 1.61 mm in no till system with 90% of residue retention. Retention of 30 and 60% residues of previous crops resulted in 32 and 55% improvement in MWD of soil.

Table 95 Mean weight diameter and water stable aggregates (0-10 cm) as affected by different levels of residue retention in no-till system under soybean-wheat cropping system

Treatments	MWD (mm)	WSA (%)
CTR0	0.91c	67.70a
NTR0	0.96bc	70.36a
NTR30	1.20abc	69.96a
NTR60	1.41ab	73.96a
NTR90	1.61a	81.06a

Table 96: Mean weight diameter and water stable aggregates (10-20 cm) as affected by different levels of residue retention in no-till system under soybean-wheat cropping system

Treatments	TC (%)	WSA(%)	MWD (mm)
CTR0	0.78a	83.33a	1.37a
NTR0	0.79a	75.64abc	0.90a
NTR30	0.78a	73.7bc	0.93a
NTR60	0.73a	79.64ab	1.38a
NTR90	0.79a	68.50c	0.99a

Tillage and residue retention impact on organic C concentration (%) in aggregate size class are summarised in table 97. The highest concentration of soil carbon was recorded in 2mm size class and the concentration decreased as the size of aggregate decreased. Here also, the highest concentration of soil carbon was recorded in 90% of residue retained treatment in different aggregate size class. In general, in all aggregate size class, concentration of carbon was higher in residue retained treatments in comparison to conventionally tilled plot. Although increased rate of residue retention under no till system resulted in improvement in carbon concentration, however the effect was not significant.

Table 97: Tillage and residue retention impact on organic C concentration (%) in aggregate and silt + clay fractions from the top 0.1 m soil depth.

Treatments	2 mm	1 mm	0.5 mm	0.25 mm	0.125 mm	0.053mm
CT	1.05b	1.09a	0.91b	0.79b	0.73b	0.62b
NT-0R	1.43ab	1.27a	1.06ab	0.96ab	0.89ab	0.74ab
NT-30R	1.60a	1.30a	1.14a	1.03a	0.88ab	0.80a
NT-60R	1.38ab	1.15a	0.96ab	0.92ab	0.89ab	0.77ab
NT-90R	1.45a	1.30a	1.13a	1.02a	0.97a	0.71ab

Note: Values followed by a letter not in common within a column, are significantly different based on Duncan's multiple range test at P = 0·05

Table;- 98 Tillage and residue retention impact on organic C concentration (%) in aggregate and silt + clay fractions from the top 0.2 m soil depth. **Aggregate associated carbon (%) under soybean-wheat cropping system in 0-20cm of soil depth**

	2 mm	1 mm	0.5 mm	0.25 mm	0.125mm
CTR0	0.96a	0.97a	0.75a	0.65a	0.61a
NTR0	1.06a	0.90a	0.76a	0.68a	0.64a
NTR30	0.92a	0.83a	0.71a	0.63a	0.60a
NTR60	0.84a	0.81a	0.67a	0.59a	0.55a
NTR90	0.89a	0.81a	0.72a	0.65a	0.59a

Note: Values followed by a letter not in common within a column, are significantly different based on Duncan's multiple range test at P = 0·05

2. Soil Chemical Properties

A. Soil total carbon

Tillage and residue retention significantly affected soil total carbon in 0-10 cm of soil depth (Table 99) No till system without residue retention enhanced soil total carbon by 6% in comparison to CT, although the difference was insignificant. Retention of residue to the tune of 90% resulted in 47% improvement in soil total carbon in comparison to C. The trend was similar for Walkley and Black carbon also. The highest concentration of 1.22% of WBC was recorded in 90% of residue retained treatment, which was 56% higher than the conventionally tilled plot. No significant difference in WBC was recorded between

60 and 60% of residue-retained treatments. No significant impact of tillage and residue retention on soil carbon was recorded in 10-20 cm of soil depth (Table 2.15).

Table 99: Carbon concentration under different treatments of conservation agriculture (0-10 cm)

	WBC (%)	***TC (%)***
CTR0	0.78b	1.15b
NTR0	0.81b	1.22b
NTR30	0.92b	1.33ab
NTR60	0.92b	1.31b
NTR90	1.22a	1.63a

Table 100: Carbon concentration under different treatments of conservation agriculture (10-20 cm)

	TC (%)	**WSA(%)**
CTR0	0.78a	83.33a
NTR0	0.79a	75.64abc
NTR30	0.78a	73.7bc
NTR60	0.73a	79.64ab
NTR90	0.79a	68.50c

Maize-chickpea cropping system

Tillage and residue retention significantly affected soil total carbon in 0-10 cm of soil depth (Table 101). No significant impact of tillage and residue retention on soil carbon was recorded in 10-20 cm of soil depth (Table 101). Under maize-chickpea system, no-till system without residue retention could not make any change in soil total concentration in comparison to CT. Retention of residue to the tune of 90% resulted 23% improvement in WBC in comparison to conventional tilled plot. The highest concentration of 1.30% of TC was recorded in 90% of residue retained treatment, which was 14% higher than the conventionally tilled plot. No significant difference in WBC and TC was recorded in 10-20 cm of soil depth.

Table 101: Carbon concentration under different treatments of conservation agriculture in maize-chickpea cropping system

	WBC (%)	**TC (%)**	**WBC (%)**	**TC (%)**
	0-10 cm	0-10cm	10-20 cm	10-20 cm
CTR0	0.89bc	1.14ab	0.53a	0.81a
NTR0	0.75c	1.13b	0.51a	0.76a
NTR30	0.84c	1.10b	0.48a	0.78a
NTR60	1.01ab	1.23ab	0.52a	0.79a
NTR90	1.10a	1.30a	0.54a	0.84a

Cotton-WheatSystem

IARI

There was an improvement in the total organic carbon (TOC) concentration at 0-5 (by 19.2%) and 5-15 cm(2.2%) soil depth under CA, respectively, compared to CT (Table 102). The carbon stratification ratio also higher under CA (1.56) than that of CT. Among the CA practices, CA with residue retention improved TOC concentration by 21.7 and 7.5% at 0-5 and 5-15cm soil depth, respectively than that of residue removal. Among the CA practices maximum carbon sequestration was registered in ZT flat bed with residue retention (Fig 67).Therefore, conservation agriculture practices have a great potential for improving carbon sequestration in cotton-wheat system under sandy loam soil.

Table102:Totalorganiccarbonconcentrationandcarbonstratificationratioincotton-wheatsystemasinfluencedbytillageandresiduemanagement

Treatment	TOC(g/kg)			Carbonstratificationratio
	0-5cm	5-15cm	15-30cm	
Zerotillage(ZT)	12.18^{AB}	8.29^{A}	7.52^{BC}	1.62^{AB*}
ZT+Residue	14.72^{A}	9.29^{A}	7.03^{C}	2.09^{A}
BB+Residue	10.90^{BC}	8.94^{A}	7.86^{ABC}	1.39^{BC}
Broadbed(BB)	8.00^{C}	8.00^{A}	7.75^{ABC}	1.03^{C}
NB+Residue	9.89^{BC}	9.29^{A}	8.31^{ABC}	1.19^{BC}
Narrowbed(NB)	9.01^{C}	9.31^{A}	9.22^{A}	0.98^{C}
Flatbed	9.93^{BC}	8.97^{A}	9.01^{AB}	1.10^{BC}
Mean	10.66	8.87	8.10	1.34
PValue	0.0003	0.0586	0.0040	0.0001
ContrastCAvsCT				
CA	11.84	9.17	7.73	1.56
CT	9.93	8.97	9.01	1.10
PValue	0.0304	0.5825	0.0050	0.0040
ContrastRvsR0				
R+	11.84	9.17	7.73	1.56
R0	9.73	8.53	8.16	1.21
PValue	0.0024	0.0272	0.1280	0.0026
ContrastBBvsNB				
BB	9.45	8.47	7.81	1.21
NB	9.45	9.30	8.77	1.09
PValue	1.0000	0.0207	0.0115	0.3197

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

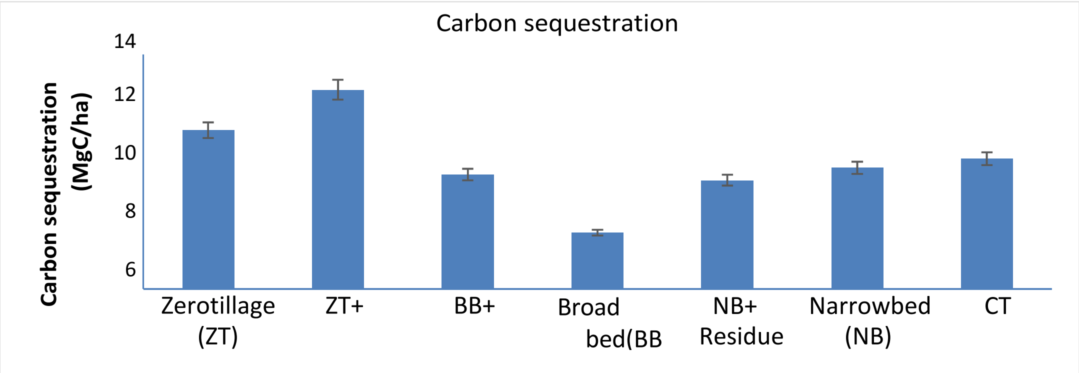


Fig67: Carbon sequestrationunder cotton-wheat system at 0-15 cm soil depth as influenced by conservation agriculture practice

Maize-MustardSystem

Conservation agriculture (CA) practices that retain crop residue and use minimal tillage with diversified cropping system store more C as organic matter.The long-term conservation agricultural practices on carbon stabilization within soil aggregates was undertaken in a maize-mustard system under CA practices in an Inceptisol. Results revealed that the mean weight diameter (MWD) and proportion of macro and micro aggregates were significantly higher for ZT(R) treatments than in CT.The ZTplots had higher macro aggregate associated C than CT plots in the 0–5 and 5–15 cm soil layers, respectively. At both depths, the ZTMz+R–ZTM+R–ZTMB+R had significantly higher macro-aggregate associated C (27.10 and 29.49%) than the CTMz–CTM treatment. ZTMz+R–ZTM+R–ZTMB+R treatment had 70 and 34% higher coarse particulate organic matter (cPOM_M) and micro-aggregates within the macro-aggregates (mM) fractions than the conventional treatment, respectively, in the top soil (Table103). Similar results were obtained in the case of intra-aggregate particulate organic matter (iPOM_mM).The ZT(R) plots had a higher light fraction within microagggregates (LF_m) than the CT plots (Table 2.19 and 2.20).Interestingly, irrespective of the treatments, the total C stock in iPOM_mM was higher than that in iPOM_m. In general, within the free micro aggregates, the highest concentration of total C was in the iPOM_m, followed by s+c_m and m_LF fraction fractions, respectively.Thus, adoption of CA has great potential in enhancing soil C content and C stability of soil aggregates to sustain soil health and crop production. Finally, this study suggested that treatment with ZTMZ (+R)-ZTM (+R)-ZTSMB (+R) (T5) is so far the most effective treatment in carbon sequestration point of view.

Table 103: Percentage distribution of coarse particulate organic matter (cPOM_M), micro-aggregates inside macro-aggregates (mM) and siltand clay (s+c_M) present with in macro-aggregates as affected by 11-years of conservation agriculture under amaize-mustard system in an Inceptisol

Treatment	cPOM_M(g100 g^{-1}ofbulksoil)	mM(g100g^{-1}ofbulksoil)	s+cM(g100g^{-1}ofbulksoil)
T1:ZTMz(-R)–ZTM(-R)	4.79[cd]	38.8[d]	8.84[de]
T2:ZTMz+R–ZTM+R	5.29[bc]	39.8[cd]	9.31[cd]
T3:ZTMz+R+BM–ZTM+R	5.44[b]	41.4[b]	8.84[de]
T4:ZTMz(-R)–ZTM(-R)–ZTMB(-R)	5.32[b]	40.9[bc]	10.4[bc]
T5:ZTMz+R–ZTM+R–ZTMB+R	6.12[a]	45.3[a]	8.12[e]
T6:CTMz(-R)–ZTM(-R)	4.33[d]	35.3[e]	10.5[b]
T7:CTMz–CTM	3.59[e]	33.2[f]	12.2[a]
LSD(<0.05)	0.53	1.55	1.17

For each column, different letters indicate that the treatment means are significantly differentat P<0.05 according toTukey’s HSDTest for separation of means

Table104: Percentage distribution of light fraction (LF_mM), intra-aggregate particular teorganic matter (iPOM_mM) and silt and clay (s+c_mM) insidemicro-aggregates within macro-aggregatea saffected by 11-years of conservation agriculture under amaize-mustard system in an Inceptisol

Treatment	LF_mM(g100g^{-1}ofbulksoil)	iPOM mM(g 100g^{-1}ofbulksoil)	s+c_mM(g100g^{-1}ofbulksoil)
T1:ZTMz(-R)–ZTM(-R)	5.95[b]	21.1[d]	11.8[b]
T2:ZTMz+R–ZTM+R	8.64[a]	23.3[c]	7.78[d]
T3:ZTMz+R+BM–ZTM+R	4.21[bc]	24.1[c]	13.2[a]
T4:ZTMz(-R)–ZTM(-R)–ZTMB(-R)	5.98[b]	26.9[b]	8.06[cd]
T5:ZTMz+R–ZTM+R–ZTMB+R	2.60[c]	33.6[a]	9.07[c]
T6:CTMz(-R)–ZTM(-R)	5.82[b]	18.8[e]	10.7[b]
T7:CTMz–CTM	5.38[b]	16.4[f]	11.4[b]
LSD(<0.05)	1.89	2.05	1.28

For each column, different letters indicatethat the treatment means are significantly differentat P <0.05 accordingtoTukey’sHSDTest for separation of means

Table 105: Percentage distribution of light fraction (m_LF), intra-aggregate POM (iPOM_m) and silt and clay(s+c_m) with infreemicro-aggregates as affected by 11-years of conservation agriculture under amaize-mustard system in an Inceptisol in the 0-5cm soil layer

Treatment	LF_m (g100g^{-1}ofbulksoil)	iPOM_m (g100$g^{-1}$of bulksoil)	s+c_m (g100g^{-1}ofbulksoil)
T1:ZTMz(-R)–ZTM(-R)	4.84[c]	24.8[ab]	8.55[b]
T2:ZTMz+R–ZTM+R	5.58[b]	24.2[bc]	9.38[a]

T3:ZTMz+R+BM–ZTM+R	5.78[b]	20.9[d]	5.98[e]
T4:ZTMz(-R)–ZTM(-R)–ZTMB(-R)	4.73[c]	19.7[e]	6.56[d]
T5:ZTMz+R–ZTM+R–ZTMB+R	8.00[a]	21.5[d]	7.46[c]
T6:CTMz(-R)–ZTM(-R)	3.80[d]	23.5[c]	7.55[c]
T7:CTMz–CTM	4.01[d]	25.3[a]	9.55[a]
LSD(<0.05)	0.43	0.88	0.30

For each column, different letters indicatethat the treatmentmeans are significantly differentat P<0.05 according toTukey'sHSDTest for separation ofmeans

Table 106: Effect of different tillage and nutrient doses on SOC in 2021-22

Treatments	SOC Soybean (%)			SOC Maize (%)		
	Soil depth			Soil depth		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
T1	0.88	0.49	0.41	0.83	0.56	0.46
T2	0.99	0.51	0.46	0.86	0.57	0.49
T3	0.84	0.51	0.41	0.76	0.56	0.43
T4	0.96	0.54	0.46	0.80	0.59	0.46
T5	0.70	0.46	0.38	0.70	0.53	0.48
CD	**0.141**	**0.016**	**0.033**	**0.024**	**NS**	**0.019**
100 %	0.88	0.51	0.43	0.80	0.57	0.46
75%	0.82	0.47	0.41	0.74	0.51	0.45
STCR	0.93	0.53	0.45	0.83	0.61	0.48
CD	**0.037**	**0.016**	**NS**	**0.023**	**0.026**	**NS**

IISS

B. Active or $KMnO_4$ oxidizable carbon
CRIDA

In Sorghum-Blackgram system, Labile (permanganate oxidizable) carbon in 0-7.5 cm and 7.5-15 cm soil at 35 days after sowing was not influenced by tillage or residue retention (Table 107).

Table 107: Effect of tillage and residue management on labile carbon (mg/kg) in 0-7.5 and 7.5-15 cm soil at 35 days after sowing

Tillage	Residue	0-7.5 cm	7.5-15 cm
Minimum tillage	S0: No residue application	221.4	235.8
	S1: Cutting at 35 cm height (1/3rd height)	233.6	232.2
	S2: Cutting at 60 cm height	205.7	244.7
Conventional tillage	S0: No residue application	234.0	238.3
	S1: Cutting at 35 cm height (1/3rd height)	237.9	227.6
	S2: Cutting at 60 cm height	230.1	237.7
CD (P=0.05)			
Tillage		NS	NS
Residues		NS	NS
T X R		NS	NS

C. Cumulative Carbon Input, Carbon and N Stocks and CN Ratio

CarbonSequestrationInCotton-WheatSystem

There was an improvement in the total organic carbon (TOC) concentration at 0-5 (by 19.2%) and and 5-15 cm (2.2%) soil depth under CA, respectively, compared to CT (Table 109). The carbon stratification ratio also higher under CA (1.56) than that of CT. Among the CA practices, CA with residue retention improved TOC concentration by 21.7 and 7.5% at 0-5 and 5-15 cm soil depth, respectively than that of residue removal. Among the CA practices maximum carbon sequestration was registered in ZT flat bed with residue retention. Therefore conservation agriculture practices have a great potential for improving carbon sequestration in cotton-wheat system under sandyloam soil.

Table109: Total organic carbon concentration and carbons tratification ratioin cotton-wheat system as influenced by tillage and residue management

Treatment	**TOC(g/kg)**			**Carbonstratificationratio**
	0-5cm	5-15cm	15-30cm	
Zerotillage(ZT)	12.18^{AB}	8.29^{A}	7.52^{BC}	1.62^{AB*}
ZT+Residue	14.72^{A}	9.29^{A}	7.03^{C}	2.09^{A}
BB+Residue	10.90^{BC}	8.94^{A}	7.86^{ABC}	1.39^{BC}
Broadbed(BB)	8.00^{C}	8.00^{A}	7.75^{ABC}	1.03^{C}
NB+Residue	9.89^{BC}	9.29^{A}	8.31^{ABC}	1.19^{BC}
Narrowbed(NB)	9.01^{C}	9.31^{A}	9.22^{A}	0.98^{C}
Flatbed	9.93^{BC}	8.97^{A}	9.01^{AB}	1.10^{BC}
Mean	10.66	8.87	8.10	1.34
PValue	0.0003	0.0586	0.0040	0.0001
ContrastCAvsCT				
CA	11.84	9.17	7.73	1.56
CT	9.93	8.97	9.01	1.10
PValue	0.0304	0.5825	0.0050	0.0040
ContrastRvsR0				
R+	11.84	9.17	7.73	1.56
R0	9.73	8.53	8.16	1.21
PValue	0.0024	0.0272	0.1280	0.0026
ContrastBBvsNB				
BB	9.45	8.47	7.81	1.21
NB	9.45	9.30	8.77	1.09
PValue	1.0000	0.0207	0.0115	0.3197

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

Carbon Sequestration in Maize-Mustard System

Conservation agriculture (CA) practices that retain crop residue and use minimal tillage with diversified cropping system store more C as organic matter. The long-term conservation agricultural practices on carbons tabilization with in soil aggregates was under taken in a maize-mustard system under CA practices in an Inceptisol. Results revealed that the mean weight diameter (MWD) and proportion of macro and micro aggregates were significantly higher for ZT (R) treatments than in CT. The ZT plots had higher macro aggregate associated C than CT plots in the 0–5 and 5–15 cm soil layers, respectively. At both depths, the ZTMz+R–ZTM+R–ZTMB+R had significantly higher macro-aggregate associated C (27.10 and 29.49%) than the CTMz–CTM treatment. ZTMz+R–ZTM+R–ZTMB+R treatment had 70 and 34% higher coar separticulate organic matter (cPOM_M) and micro-aggregates within the macro-aggregates (mM) fractions than the conventional treatment, respectively, in the top soil (Table 2.24). Similar results were obtained in the case of intra-aggregate particulate organic matter (iPOM_mM). TheZT(R) plots had a higher light fraction within micro agggregates (LF_m) than the CT plots (Table 110 & 111). Interestingly, irrespective of the treatments, the total C stock in iPOM_mM was higher than that in iPOM_m. Ingeneral, within the free micro aggregates, the highest concentration of total C was in the iPOM_m, followed bys+c_mandm_LF fraction fractions, respectively. Thus, adoption of CA has great potential in enhancing soil C content and C stability of soil aggregates to sustain soil health and crop production. Finally, this studysuggested that treatment with ZTMZ (+R)-ZTM (+R)-ZTSMB (+R) (T5) is so far the most effective treatment in carbon sequestration point of view.

Table 110: Percentage distribution of coarse particulate organic matter (cPOM_M), micro-aggregates inside macro-aggregates (mM) and silt and clay (s+c_M) present with in macro-aggregates as affected by 11-years of conservation agriculture under amaize-mustard system in an Inceptisol

Treatment	cPOM_M(g100 g^{-1}ofbulksoil)	mM(g100g^{-1}ofbulksoil)	s+cM(g100g^{-1}ofbulksoil)
T1:ZTMz(-R)–ZTM(-R)	4.79^{cd}	38.8^{d}	8.84^{de}
T2:ZTMz+R–ZTM+R	5.29^{bc}	39.8^{cd}	9.31^{cd}
T3:ZTMz+R+BM–ZTM+R	5.44^{b}	41.4^{b}	8.84^{de}
T4:ZTMz(-R)–ZTM(-R)–ZTMB(-R)	5.32^{b}	40.9^{bc}	10.4^{bc}
T5:ZTMz+R–ZTM+R–ZTMB+R	6.12^{a}	45.3^{a}	8.12^{e}
T6:CTMz(-R)–ZTM(-R)	4.33^{d}	35.3^{e}	10.5^{b}
T7:CTMz–CTM	3.59^{e}	33.2^{f}	12.2^{a}
LSD(<0.05)	0.53	1.55	1.17

For each column, different letters indicate that the treatment means are significantly differentat P<0.05 according toTukey's HSDTest for separation of means

Table111: Percentage distribution of light fraction (LF_mM), intra-aggregate particular teorganic matter (iPOM_mM) and silt and clay (s+c_mM) inside micro-aggregates within macro-aggregate as affected by 11-years of conservation agriculture under amaize-mustard system in an Inceptisol

Treatment	LF_mM(g100g^{-1}ofbulksoil)	iPOM_mM(g 100g^{-1}ofbulksoil)	s+c_mM(g100g^{-1}ofbulksoil)
T1:ZTMz(-R)–ZTM(-R)	5.95^{b}	21.1^{d}	11.8^{b}
T2:ZTMz+R–ZTM+R	8.64^{a}	23.3^{c}	7.78^{d}
T3:ZTMz+R+BM–ZTM+R	4.21^{bc}	24.1^{c}	13.2^{a}
T4:ZTMz(-R)–ZTM(-R)–ZTMB(-R)	5.98^{b}	26.9^{b}	8.06^{cd}
T5:ZTMz+R–ZTM+R–ZTMB+R	2.60^{c}	33.6^{a}	9.07^{c}
T6:CTMz(-R)–ZTM(-R)	5.82^{b}	18.8^{e}	10.7^{b}
T7:CTMz–CTM	5.38^{b}	16.4^{f}	11.4^{b}
LSD(<0.05)	1.89	2.05	1.28

For each column, different letters indicate that the treatment means are significantly differentat P<0.05 according toTukey's HSDTest for separation of means

Table 112: Percentage distribution of light fraction (m_LF), intra-aggregate POM (iPOM_m) and silt and clay (s+c_m) with in free micro-aggregates as affected by 11-years of conservation agriculture under maize-mustard system in an Inceptisol in the 0-5cm soil layer

Treatment	LF_ m(g100g^{-1}ofbulksoil)	iPOM_m(g100$g^{-1}$of bulksoil)	s+c_m(g100g^{-1}ofbulksoil)
T1:ZTMz(-R)–ZTM(-R)	4.84^{c}	24.8^{ab}	8.55^{b}
T2:ZTMz+R–ZTM+R	5.58^{b}	24.2^{bc}	9.38^{a}
T3:ZTMz+R+BM–ZTM+R	5.78^{b}	20.9^{d}	5.98^{e}
T4:ZTMz(-R)–ZTM(-R)–ZTMB(-R)	4.73^{c}	19.7^{e}	6.56^{d}
T5:ZTMz+R–ZTM+R–ZTMB+R	8.00^{a}	21.5^{d}	7.46^{c}
T6:CTMz(-R)–ZTM(-R)	3.80^{d}	23.5^{c}	7.55^{c}
T7:CTMz–CTM	4.01^{d}	25.3^{a}	9.55^{a}
LSD(<0.05)	0.43	0.88	0.30

D. Carbon equivalente mission in rice-wheat and cotton-wheat cropping system under CA

A field experiment was carried out to quantify the mitigation in carbon equivalent emissions when the conventionalrice-wheat crop rotation is substituted with the alternative cotton-wheat crop rotation under conventional and zero tillagewith and without residue retention, and reduced N fertilizer application. The treatments in *kharif* season in rice were: conventionally transplanted puddled rice (CTPR), zero till direct seeded rice (ZTDSR), zero till direct seeded rice with wheat residue + 100%N (ZTDSR +WR-100), zero till direct seeded rice with wheat residue + 75% N (ZTDSR+WR-75). During the *rabi* season the treatments were: conventionally tilled wheat (CTW), zero tilled wheat (ZTW), zerotilled wheat with rice residue + 100%N (ZTW+RR-100) and zero tilled wheat with rice residue + 75%N (ZTW+RR-75). The GWP in rice ranged from 2183 to 3112 kg CO_2 equiv. ha^{-1}, whereas the GWP in wheat ranged from 2560 to2951 kg CO_2 kg CO_2 equiv. ha^{-1} under the different treatments. The change of practice from CTPR-CTW to ZTDSR-ZTW in rice-wheat reduced the GWP by 21.8%. The carbon equivalent emission reduced by 9.4 under CT cotton-wheatsystem and by 28.6 % under ZT cotton-wheat system as compared to conventional rice-wheat system (Table 113; Table114). The system productivity was significantly higher under all the cotton-wheat treatments. Thus, the greenhouse gasintensity (kg CO_2 equiv. ha^{-1}/kg grain yield) was significantly lower in C-W treatments ranging from 0.34 to 0.47 than the rice-wheat crop rotation (0.48to0.58)

Table113: Carbon equivalen temissions from rice-wheat system

Treatments	Rice			Wheat		R-WSystem
	CH4 kgha^{-1}	**N2O** kgha^{-1}	**CO2** kgha^{-1}	**N2O** kgha^{-1}	**CO2** kgha^{-1}	**GWP**kgCO_2 eq.ha^{-1}
CTPR–CTW	34.56a	0.92b	2100a	1.08b	2617a	6063c
ZTDSR-ZTW	3.20c	1.12a	1770b	1.15a	2204b	4743a
ZTDSR+WR-100-ZTW+RR-100	5.62b	1.26a	1921a	1.18a	2390c	5186b
ZTDSR+WR-75-ZTW +RR-75	4.95bc	0.89b	1898a	1.02c	2332bc	4926ab

Table 114: Carbon equivalen temissions from cotton-wheat system

Treatments	Cotton		Wheat		C-WSystem
	N2O kgha^{-1}	**CO2** kgha^{-1}	**N2O** kgha^{-1}	**CO2** kgha^{-1}	**GWP**kgCO_2 equi.ha^{-1}
CTC–CTW	1.14b	2555a	1.03b	2266a	5494d
ZTPBBC-ZTPBBW	1.20a	1929b	1.06b	1701b	4329a
ZTPBBC+WR-100-ZTPBBW+CR-100	1.22a	2075b	1.11a	1977a	4873c
ZTPBBC+WR-75-ZTPBBW+CR-75	0.96c	2018b	0.85c	1921b	4599b

CRIDA

In pigeonpea- castor system, zero tillage recorded 10% higher organic carbon than conventional tillage in 0-7.5 cm where as in deeper depths CT and ZT are on par with each other. ZT recorded 40% higher carbon sequestration than CT. The residue increased the carbon sequestration in all the tillage treatments.

In Maize-pigeonpea cropping system in situ moisture conservation system along with conservation agriculture practices increased the soil organic carbon. Permanent conservation furrow and permanent bed and furrow recorded 6% and 11% higher OC as compared to conventional tillage in 0-7.5 cm where as in deeper depths CT and ZT are on par with each other.

In Pearlmillet – Horsegram/ Pigeonpea system, significantly higher SOC was observed in ZT and MT (5.6 g/kg) as compared to CT. Significantly higher very labile and non-labile C was observed in ZT, higher labile C was observed in MT.

In Foxtail millet- Greengram System, Among the tillage practices, zero tillage with soil and moisture conservation practices (T4) recorded significantly higher organic carbon as compared to other treatments. Among the residue retention levels, harvesting only pods/panicles and retaining the entire residue as such (S3) recorded higher organic carbon over S2 and S1(Fig 68).

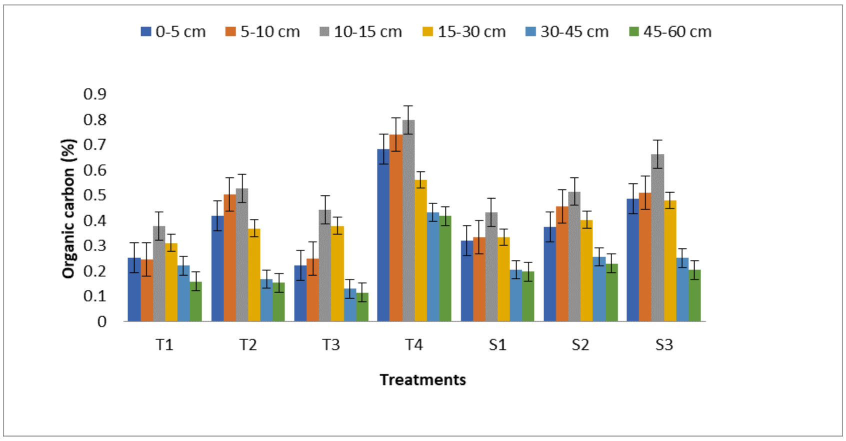


Fig 68: Effect of tillage practices and residue retention levels on organic carbon (%)

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

IIFSR

A conservation agriculture (CA) based field experiment is continuing since 2015 with diversified cropping systems under the umbrella of Consortium Research Platform on Conservation Agriculture (CRP on CA). A total number of eight cropping sequences i.e. rice-wheat (R-W-CP); rice-wheat-green gram (R-W-GG-CA); rice-wheat-sesbania (R-W-S-CP); maize-wheat-green gram (M-W-GG-CA); maize(cob)-mustard-green gram (M-M-GG-CA); rice-wheat-sesbania (CA); sugarcane-ratoon-wheat (CP); sugarcane+greengram-ratoon-wheat (CA) are grown under both conservation (CA) and Conventional agricultural (CP) practices.

The perusal of data reveals that surface retention of crop residues followed by zero tillage in conservation agriculture practices (CA) significantly enhanced the different soil physico-chemical properties both in surface and sub-surface soils over the conventional practices (CP). CA+ inclusion of pulses in maize-wheat and maize-mustard cropping sequences recorded highest Walkley Black carbon (WBC) (6.62 and 6.72 g/kg, respectively) and available nitrogen (205.9 and 224.8 kg/ha, respectively) over the other treatments. Surface retention of sugarcane trash and inclusion of legume in sugarcane + green gram-ratoon-wheat in CA practices significantly improved the available phosphorus (74.95 kg/ha), potassium (278.4 kg/ha) and sulphur (27.87 mg/kg) content over the other treatments.

Table 115: Effect of resource conservation techniques and crop diversification on various soil chemical properties.

	pH	**EC (dS/m)**	**WBC (g/kg)**	**Avail. N (kg/ha)**	**Avail P (kg/ha)**	**Avail. K (kg/ha)**	**Avail. S (mg/kg)**
ropping Systems							
R-W (CP)	8.11	0.288	5.68	154.7	55.81	146.9	14.94
R-W-GG (CA)	7.87	0.220	5.55	205.9	57.16	165.0	16.56
R-W-S (CP)	8.09	0.268	5.81	171.4	81.81	153.5	15.51
M-W-GG (CA)	7.98	0.241	6.62	210.1	66.96	235.8	17.44
M-M-GG (CA)	7.93	0.243	6.72	224.8	53.23	181.9	30.58

R-W-S (CA)	7.90	0.237	6.12	193.4	51.63	174.8	13.86
S-R-W (CP)	8.03	0.257	4.04	176.7	54.54	231.1	16.84
S+GG-R-W (CA)	8.00	0.244	4.50	186.1	74.95	278.4	27.87
Sem (±)	0.053	0.008	0.400	13.69	1.523	3.58	1.113
C.D. (p<5%)	0.155	0.023	1.161	39.73	4.42	10.38	3.229
Soil Depth							
0-15 cm	7.93	0.235	5.14	197.0	70.12	237.9	20.68
15-30 cm	8.14	0.264	4.77	183.7	53.90	156.5	15.72
Sem (±)	0.027	0.004	0.200	6.845	0.762	1.79	0.556
C.D. (p<5%)	NS	0.011	NS	19.87	2.21	5.19	1.614

Pigeonpea- Castor System

CRIDA

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

Maize-Pigeonpea Cropping System

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

Pearlmillet – Horsegram/ Pigeonpea System

In Pearlmillet – Horsegram/ Pigeonpea system, there was a slight buildup of available N and K (kg/ha) in surface soil in ZT. Significantly higher water-soluble K and exchangeable K was observed in ZT compared to MT and CT, but Non-exchangeable K was at par in MT and ZT.

Cotton-Pigeonpea System

In cotton-pigeonpea system, significantly higher available N after harvest of cotton was observed in MT (128 kg/ha) and ZT (124 kg/ha) compared to the CT (103 kg/ha). Whereas in nutrient management higher available N was observed in 125% RDF (134 kg/ha) and 100% RDF (114 kg/ha) compared to the 75% RDF (107 kg/ha). With increasing depth either increases or decreases. Significantly higher available K after harvest of cotton was observed in MT (226 kg/ha) and ZT (226 kg/ha) as compared to CT (193 kg/ha). Whereas in nutrient management higher available K was observed in 125% RDF (244 kg/ha) and 100% RDF (219 kg/ha) compared to the 75% RDF (182 kg/ha). With increasing depth either increases or decreases.

Foxtail Millet- Greengram System

In Foxtail millet- Greengram System, zero tillage with soil and moisture conservation practices (T4) recorded significantly higher available nitrogen compared to Zero tillage (T3) and Conventional tillage

(T1) and it is on par with Minimum tillage (T2). Among the residue retention levels, harvesting only pods/panicles and retaining the entire residue as such (S_3) treatment recorded higher available nitrogen over S2 and S_1 (Fig 69).

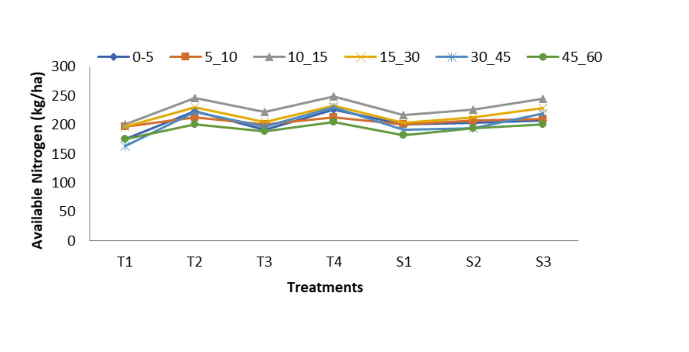


Fig 69: Effect of tillage practices and residue retention levels on available Nitrogen (kg/ha

F. Micronutrients in Conservation Agriculture
IIFSR

Table 116: Impact of resource conservation techniques and crop diversification on DTPA Extractable micronutrients and system productivity

Treatments	Iron (Fe) (mg/kg)	Copper (Cu) (mg/kg)	Zinc (Zn) (mg/kg)	Manganese (Mn) (mg/kg)
Cropping systems				
R-W (CP)	13.55	2.544	4.273	13.34
R-W-GG (CA)	17.84	2.256	5.732	15.62
R-W-S (CP)	14.54	2.336	4.789	14.67
M-W-GG (CA)	18.48	3.063	5.513	16.47
M-M-GG (CA)	18.89	2.842	6.473	17.24
R-W-S (CA)	20.31	2.572	7.273	19.34
S-R-W (CP)	17.72	2.685	5.526	12.19
S+GG-R-W (CA)	17.94	3.085	6.249	19.64
Sem (±)	0.840	0.264	0.441	0.758
C.D. (p<5%)	2.439	NS	1.281	2.199
Soil Depth				
0-15 cm	17.41	2.922	5.617	14.55
15-30 cm	9.31	2.419	3.400	11.08
Sem (±)	0.421	0.132	0.221	0.379
C.D. (p<5%)	1.219	NS	0.641	1.099

3. Soil Biological Properties
IARI
ResistanceandresilienceoffluoresceindiacetatehydrolaseactivityunderCA-basedrice-wheatsystem

Soil samples were collected after harvesting of wet season rice from eight treatments to assess resistance and resilience of FDA hydrolase activity. The treatments were ZTDSR-ZTW (T1), ZT DSR+WR–ZTW+RR (T2), ZT DSR+WR+CBM–ZTW+RR (T3), ZTDSR+WR+SBM–ZTW+RR (T4), ZTDSR-ZTW–ZTMB (T5), ZTDSR+MR–ZTW+RR–ZTMB+WR (T6), TPR-ZTW (T7) and TPR–CTW (T8). Soil samples were provided with heat stress @ 48°±2 and 72 hours of air drying. After providing stress, moisture content wasmaintained at one-third of field capacity. Incubation was done at 28°±2 for 45 days. Interval of study was 1, 15,30 and 45 DAS. The method based on the determination of fluorescein released after the incubation of soil with fluoresce in diacetate substrate for 3 hours at 37˚C was used to assess FDA hydrolase activity. Result showed that triple zero tillage with triple residueretention was most resistant where aspartly conventional and fully conventional treatments were least resistant to heat stress.Value of resistance index in dicated that triple ZT with triple residue retention was most resistant to moisture stress and fully conventional treatment was least resistant with RS value of 0.40.The high estresistance and resilience of FDA hydrolase activity was foundunder triple zero tillage with triple residue retention treatment after heat and moisturestress in conservation agricultural based rice wheat cropping system. Therefore, this practice may be recommended under CA based rice- wheat system in Indo-Gangeticplain.

NRRI

Enzymatic activity under different establishment methods in CA

Microbial biomass carbon was notably higher in ZT-DSR-ZT-GG followed by CT-DSR-CT-GG and ZT-TPR-ZT-GG (Fig 70). Among green gram varieties, there were no significant differences recorded. The enzymatic activities (DHA, FDA, Urease, Phosphatase, and ß-glucosidase) were higher in ZT-DSR-ZT-GG followed by ZT-TPR-ZT-GG. In ZT-DSR-ZT-GG, the recorded values of MBC, DHA, FDA, acid phosphatase and alkaline phosphatase were 2.7, 1.9, 1.4, 1.03 and 1.07 fold higher over CT-DSR-CT-GG. Higher abundance of substrates owing to residue retention in addition to a significant reduction in physical disturbance under zero tillage improves soil biological health.

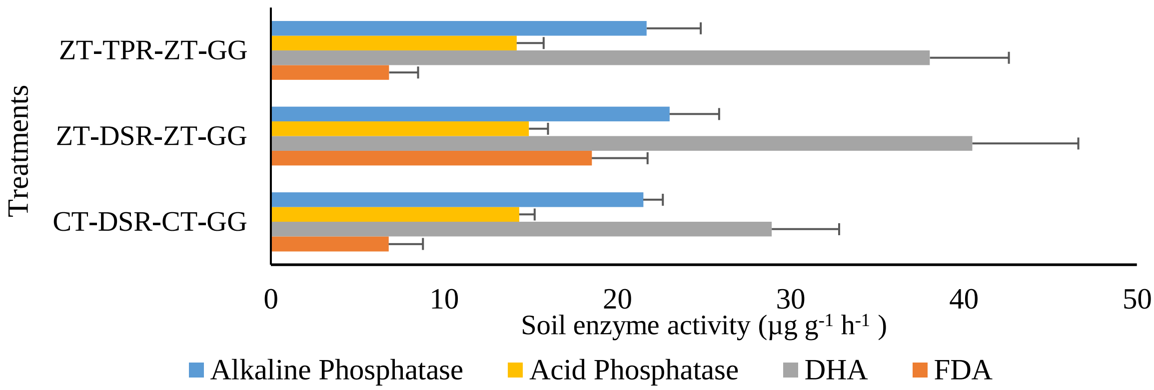


Fig 70: Soil enzyme activity as affected by different management practises after 5 years of experiment

IIFSR

The collected soil samples were also analysed for different soil biological indicators including extracellular enzymes and microbial biomass carbon (MBC). The data presented in table 2.31 showed that all the enzymatic activities were significantly influenced due to both resource conservation techniques and crop diversification. Overall, treatment comprised of resource conservation techniques along with inclusion of pulses and crop diversification recorded higher microbiological diversity over the treatments of conventional practices. The dehydrogenase (DHA) which is the respiratory enzyme in the soil varied 188.1µg TPF g^{-1} soil 24 h^{-1} to 283.8 µg TPF g^{-1} soil 24 h^{-1} among the different cropping systems. At the same time, it was found superior in the surface soil (0-15cm) layer as compared to the sub-surface soil layer (Table 117). Phosphatases enzymes plays a crucial role in mineralization of organic phosphate compounds and release inorganic phosphorus in soil. The acid phosphatases enzyme was found superior (150.3 µg pNP g^{-1} soil h^{-1}) in S-R-W (CP) cropping system among all the adopted cropping systems followed by M-W-GG (CA) and R-W-S (CP) cropping systems.At the same time, the highest alkaline phosphatase enzyme activity (379.2µg pNP g^{-1} soil h^{-1}) was found in M-M-GG (CA) followed by S+GG-R-W (CA) (343.5 µg pNP g^{-1} soil h^{-1}) and maize-wheat-green gram (CA) (343.0 µg pNP g^{-1} soil h^{-1}) cropping systems (Table 117). Microbial biomass carbon (MBC) is a key soil indicator to measure the management induces changes in soil quality. In the present research investigation, the impact of resources conservation technologies in collaboration with crop diversification with pulses on soil MBC was studied and it was found that M-W-GG (CA) cropping sequence recorded significantly highest MBC (272.7 mg/kg) among all the treatments followed by R-W-GG (CA) and R-W-S (CP) cropping sequences.

Table 117: Effect of different resource conservation techniques and crop diversification on soil carbon, nitrogen and phosphorus cycling enzymes

	DHA (µg TPF g^{-1} soil 24 h^{-1})	ACP (µg pNP g^{-1} soil h^{-1})	ALP (µg pNP g^{-1} soil h^{-1})	MBC (mg kg^{-1})	Total Glomalin(mgkg^{-1})	FDA(µg F g^{-1} dry soil h^{-1})
Cropping Systems (CS)						
R-W (CP)	188.1	109.3	306.8	261.1	317.9	242.7
R-W-GG (CA)	248.3	128.6	335.6	268.2	302.9	230.8
R-W-S (CP)	224.6	128.7	327.8	262.5	284.3	273.3
M-W-GG (CA)	269.9	135.2	343.0	272.7	306.0	243.1
M-M-GG (CA)	283.8	117.4	379.2	254.3	373.4	276.7
R-W-S (CA)	249.9	122.5	379.1	252.9	315.0	270.9
S-R-W (CP)	207.3	150.3	292.2	239.7	292.7	244.8
S+GG-R-W (CA)	252.5	109.3	343.5	261.8	311.3	204.7
Sem (±)	12.75	6.50	17.05	9.864	23.06	11.62
C.D.	37.05	18.86	50.79	28.62	NS	33.74
Soil Depth						
0-15 cm	288.9	148.9	374.4	256.9	316.5	301.0
15-30 cm	192.2	110.6	281.7	161.4	309.3	195.8
Sem(±)	6.375	3.25	8.75	4.932	11.53	5.812
C.D.	18.503	9.433	NS	NS	NS	16.87

Glomalin is the glycoprotein produced by the hyphae of arbuscular mycorrhizal (AMF). Glomalin is hypothesized to improve soil aggregate stability and decrease soil erosion. Both the surface (0-15 cm) and sub-surface (15-30 cm) soil samples were analysed for total glomalin content. Among all the treatments M-M-GG (CA) cropping sequence recorded highest total glomalin content (373.4 mg/kg) followed by R-W (CP) and R-W-S (CA) treatments. Fluorescein diacetate activity (FDA) is an accurate and simple parameter to measure the total microbial activity in any soil. Many free and membrane bound enzyme i.e. lipase, protease and esterase etc. are included as synonyms of FDA activity in soil. In the present research investigation, the FDA activity ranges from 204.7 (µg F g^{-1} dry soil h^{-1}) in S+GG-R-W (CA) to as high 276.7 (µg F g^{-1} dry soil h^{-1}) in M-M-GG (CA) (Table 117). Among all the cropping systems under study, the maized based cropping systems produced significant highest FDA activity over the other cropping systems both in surface and sub-surface soil layers.

Soil microbial population

Fresh soil samples were analysed for different microbial population diversity in the treatments. The main principles of conservation agriculture i.e. minimum soil disturbance, crop diversification and permanent soil cover aim to increase and sustain the soil organic matter (SOM). This increased SOM have an advantageous effect on soil physico-chemical and biological attributes. Table 118 contains the effect of different conservation of agricultural practices on soil microbial population under diversified cropping systems.

Table 118: Impacts of conservation agriculture practices on soil microbial population under diversified cropping systems

Treatments	Microbial population on different growth media (CFU/g dry soil)						
	Bacteria	Fungi	Actinomycetes	Pseudomonas	Free living N fixers	Trichoderma	Rhizobium
R-W (CP)	1.8×10^{7}	2.3×10^{4}	2.5×10^{5}	5.3×10^{6}	1.2×10^{5}	9.3×10^{4}	2.7×10^{4}
R-W-GG (CA)	4.4×10^{7}	5.5×10^{4}	4.1×10^{5}	6.3×10^{6}	1.5×10^{5}	25.7×10^{4}	3.5×10^{4}
R-W-S (CP)	3.4×10^{7}	3.0×10^{4}	2.9×10^{5}	8.0×10^{6}	1.5×10^{5}	7.3×10^{4}	2.9×10^{4}
M-W-GG (CA)	2.0×10^{7}	4.7×10^{4}	2.6×10^{5}	5.6×10^{6}	1.3×10^{5}	12.7×10^{4}	3.7×10^{4}

M-M-GG (CA)	2.6×10^{7}	4.6×10^{4}	4.1×10^{5}	6.7×10^{6}	1.7×10^{5}	27.7×10^{4}	4.7×10^{4}
R-W-S (CA)	7.7×10^{7}	3.8×10^{4}	5.3×10^{5}	10.2×10^{6}	1.8×10^{5}	28.3×10^{4}	5.4×10^{4}
S-R-W (CP)	3.2×10^{7}	3.5×10^{4}	2.1×10^{5}	6.4×10^{6}	1.1×10^{5}	6.0×10^{4}	3.2×10^{4}
S+GG-R-W (CA)	3.3×10^{7}	3.8×10^{4}	3.0×10^{5}	7.9×10^{6}	1.5×10^{5}	15.7×10^{4}	3.4×10^{4}

The data presented in table 118 recorded that among the tillage practices conservation agriculture recorded higher microbial population over the conventional practices due to minimum soil disturbance and residue retention. At the same time, crop diversification with legumes (Sesbania and green gram) resulted in higher microbial population as compared to the non-legume cropping sequences. Among the treatment having legume component, cropping sequences comprised of sesbania resulted in higher microbial population over the treatments containing green gram which was probably due to higher biomass incorporation by sesbania. Similar results were also found for the various carbon, nitrogen, phosphorus and sulphur cycling enzymes studied along with the microbial population.

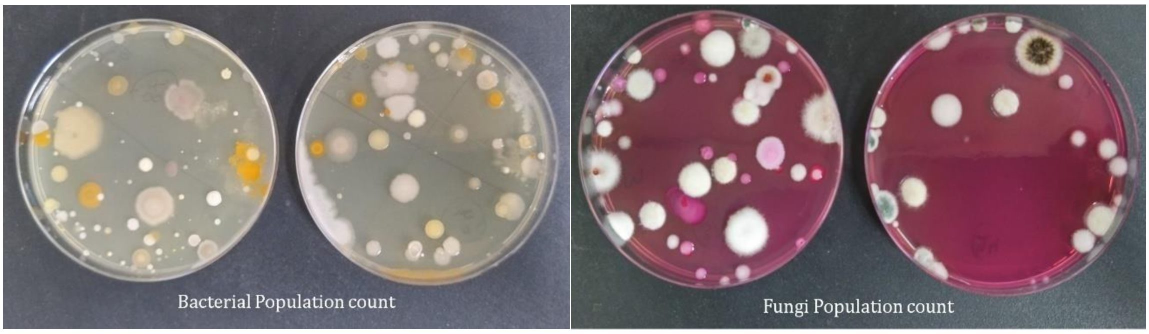


Fig 71: Soil microbial population as influenced by conservation agricultural practices and crop diversification

CRIDA

In Sorghum-Blackgram system, Microbial biomass C (MBC) in 0-7.5 cm and 7.5-15 cm soil at 35 days after sowing did not differ with either tillage or residue retention (Table 119).

Table 119: Effect of tillage and residue management on microbial biomass carbon (MBC, mg/kg) in 0-7.5 and 7.5-15 cm soil at 35 days after sowing

Tillage	**Residue**	**0-7.5 cm**	**7.5-15 cm**
Minimum tillage	S0: No residue application	179.3	122.4
	S1: Cutting at 35 cm height (1/3rd height)	159.0	150.3
	S2: Cutting at 60 cm height	157.6	150.0
Conventional tillage	S0: No residue application	157.8	128.9
	S1: Cutting at 35 cm height (1/3rd height)	104.4	196.4
	S2: Cutting at 60 cm height	115.0	142.6
CD (P=0.05)			
Tillage		NS	NS
Residues		NS	NS
T X R		NS	NS

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

IARI , New Delhi

The success of the CA based rice-wheat system was validated on farmers' fields in two districts of the north-western Indo-Gangetic plain *viz.* Bareilly and Karnal. The fields of ten farmers (five from each district) wereplanted with direct-seeded rice, transplanted rice, zero-till wheat, conventional-till wheat. The results on crop yields, system productivity (wheat equivalent yield, WEY), and netreturns were compared (Table 120). Inallthedistricts, the zero till wheat exhibited higher yield than the conventional tilled wheat while DSR yield was littlelower but comparable to TPR yield. The DSR-ZTW system performed slightly better in terms of system productivity (wheat equivalent yield, WEY) with TPR-CTW. With respecttonet returns, CA based system gave approximately 18.3% higher net returns at Karnal and 16.4% higher net returns at Bareilly as compared to conventional system. The DSR-ZTW also performed better than TPR-CTW. These successful field demonstrations not only proved the superiority of CA based systems in terms of yield but also established its importance as ahighly sustainable and an economically viable alternative to conventional agriculture systems.

Table 120: Crop and system productivity (t/ha) and netreturns (Rs./ha) at farmer sat karnal (Haryana) and Bareilly (U.P.)

Farmer(No.)	District	Conservationagriculture(CA)practices				Conventionaltillage(CT)practices			
		Ricegrainyield(t/ha)	Wheatgrainyield (t/ha)	RW systemproductivity(WEY) (t/ha)	Netreturns(Rs./ha)	Rice grain yield (t/ha)	Wheat grain yield(t/ha)	RW systemproductivity(WEY) (t/ha)	Netreturns(Rs./ha)
5	Karnal	4.94	5.56	10.36	176478	5.01	5.27	10.1	149216
5	Bareilly	4.67	5.64	10.16	173603	4.76	5.33	9.93	149198

CRIDA, Hyderabad

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.

Demonstration on minimum tillage Begalgram in Setaria + Redgram Intercropping

The results indicated that highest net returns was obtained with minimum tillage Bengalgram in Korra+ Redgram intercropping (Rs 71,892/ha) than Korra+ Redgram intercropping (Rs 50, 310ha).The additional net income of the farmers was also increased in minimum tillage Bengalgram in Korra+ Redgram intercropping which is calculated as Rs. 21,672/- more than the in Setaria+ Redgram Intercropping.

Plate 30.Demonstration on minimum tillage Begalgram in Setaria + Redgram Intercropping

Demonstration on Setaria- Blackgram and Setaria- Bengalgram cropping sequence with minimum Tillage

Table 121: Demonstration on Setaria- Blackgram and Setaria- Bengalgram cropping sequence with minimum Tillage

Particulars	**Yield Kg/ha**	**Cost of cultivation**	**Gross returns Rs/ha**	**Net returns Rs/ha**	**Addl Returns (Rs/ha)**
Redgram + Setaria-Bengalgram (Minimum tillage)	1690 637 617	46375	118267	71982	**21672**
Redgram + Setaria (FP)	1690 637	35256	85566	50310	

The results indicated that highest net returns was obtained with Korra-Blackgram sequence (Rs. 102870/ha) than fallow –Blackgram (Rs. 90918/ha). The additional net income of the farmers was also increased in Korra- Blackgram sequence which is calculated as Rs. 11952/- more than the Fallow-Blackgram. Similarly, Setaria-Bengalgram sequence has recorded 15887 additional returns over sole crop of Bengalgram. This shows the increased profitability through Korra- Blackgram and 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.

Plate 31. Setaria - Blackgram sequence with Minimum tillage

Particulars	Yield Kg/ha	Cost of cultivation	Gross returns Rs/ha	Net returns Rs/ha	Addl Returnns(Rs/ha)
Setaria-Bengalgram	1827-1755	65653	139690	74037	15887
Bengalgram	2050	50500	50500	58150	
Setaria-Blackgram	1862-1940	75600	178470	102870	11952
Blackgram	- 2201	58750	149688	90918	

Demonstration of Soyabean- Bengalgram cropping sequence with minimum Tillage

The results indicated that highest net returns was obtained with Soyabean- Bengalgram sequence (Rs. 92198/ha) than fallow –Bengalgram (Rs. 58150 /ha). The additional net income of the farmers was also increased in Soyabean- Bengalgram sequence which is calculated as Rs. 34048 more than the Fallow-Bengalgram.

Plate 32.Soyabean- 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)
Soybean-Bengalgram	1682-1845	89687	181885	92198	34048
Bengalgram	2050	50500	108650	58150	

IIWBR, Karnal

Field demonstrations on *in-situ* rice residue management in wheat under rice-wheat system were conducted at farmers' field in Taroari and Hajwana village of Karnal and Kaithal district, respectively. Paddy was harvested using straw management system (SMS) fitted combine harvester. Wheat was sown using a seed rate of 125 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 (58.9 q/ha) and CT (58.7 q/ha) system. The use of such resource conserving technologies can reduce the input cost as well as provide the yield advantage to crop due to timely completion of sowing operation. The reduced tillage cost in CA has resulted in economics in favour of CA system.

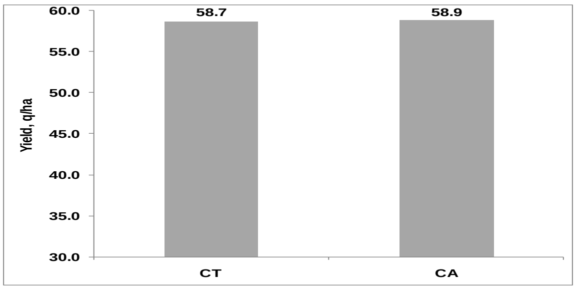


Plate 33. Wheat sowing with Turbo Happy Seeder

Fig 72: Performance of wheat under CA and CT in rice-wheat system

DWR, Jabalpur

Wheat (*Rabi* 2021-22)

In wheat crop, ten on-farm research trials cum demonstrations on weed management were undertaken at villages *viz*. Guleda, Purena, Singhaldeep, Lakhna and Raipura of Patan and Mankhedi, Saliwada, Riwa, Nayagaon, Chullaghat and Sahajpuri of Bargi locality under conservation agriculture during *Rabi* 2021-22. The major weed flora observed in the field were *Avena ludoviciana*, *Chenopodium album*, *Cynodon dactylon*, *Cyperus rotundus*, *Medicago polymorpha*, *Phalaris minor*, *Lathyrus aphaca* and *Vicia sativa* in Patan and *Anagallis arvensis*, *Lathyrus aphaca*, *Chenopodiumalbum*, *Eclipta alba*, *Cyperus* spp., *Vicia sativa*, *Sonchus* spp., *Asphodelus tenuifolius*, *Medicago* spp.,*Convolvulus arvensis*, *etc*. in Bargi locality. Under conservation agriculture, excellent germination and establishment was observed. Application of clodinafop propargyl + metsulfuron methyl 60+4 g/ha as post-emergence at 30 DAS and practicing of recommended fertilizer dose (RDF) (120:60:40 N, P_2O_5, K_2O kg/ha) under conservation agriculture resulted in lowest weed density and biomass, with 82.4% weed control efficiency, further, a highest grain yield of 4.78 t/ha was also observed. Thus, it recorded highest net returns of Rs. 65982/ha and higher B: C of 3.17 compared to farmers' practice (grain yield 4.05 t/ha, net returns Rs. 48536/ha and B:C 2.49) (Table 122).

Table 122: Weed management, productivity and economics of OFR treatments in wheat during *Rabi*, 2021-22 (values are average of ten farmers)

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Grain yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C
RDF+CA+WM	24.4	10.8	82.4	4.78	86468	65982	3.17
FP	47.2	26.8	56.3	4.05	81407	48536	2.49
RDF+CA+Weedy	107.8	61.9		3.04	63841	34028	2.14

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

Plate 34.Weed management on wheat during Rabi, 2021-22

Chickpea (*Rabi*, 2021-22)

In chickpea crop, eight OFR cum demonstrations were conducted on weed management under conservation agriculture at Patan and Bargi locality of Jabalpur under conservation agriculture during *Rabi* 2021-22. The major weed flora observed was *Avena ludoviciana*, *Cyperus rotundus*, *Rumex dentatus*, *Vicia sativa*, *Lathyrus aphaca*, *Chenopodium album* and *Phalaris minor* in Patan and *Medicago* spp., *Chenopodium* spp., *Sonchus* spp., *Convolvulus arvensis*, *Mecardonia* spp., *Anagllis arvensis*, *Cyperus rotundus*, *Cyperus iria*, *Melilotus* spp., *Vicia sativa* and*Asphodelus tenuifolius* in Bargi. In chickpea grown with recommended fertilizer (20:60:40 N, P_2O_5, K_2O kg/ha) and herbicide (pendimethalin 678 g/ha as PE) under CA, weed density and biomass were lower than farmers' practice (Table 123). The seed yield of chickpea was obtained to the tune of 2.56 t/ha in this practice. The higher B:C of 3.88 was also recorded with the same treatment, whereas it was only 2.78 in case of farmer's practice.

Table 123: Weed management, productivity and economics of OFR treatments of chickpea during *Rabi*, 2021-22 (values are average of eight farmers)

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Seed yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C
RDF+CA+WM	25.5	15.3	78.2	2.56	132218	98343	3.88
FP	58.9	32.5	52.6	2.00	102128	65558	2.78
RDF+CA+Weedy	123.0	69.1		1.35	68818	41830	2.10

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

Plate 35. Weed management on chickpea during Rabi, 2021-22

Greengram (Summer 2022)

During summer 2022, total fifteen OFR cum demonstrations were conducted on weed management in greengram under conservation agriculture at farmers' fields in Patan and Bargi locality. The major weed flora observed was *Alternanthera sessilis, Cyperus rotundus, Cynodon dactylon, Echinochloa colona,Euphorbia geniculata,* and *Sporobolus* sp. in Patan and *Phyllanthus* spp., *Cyperus rotundus, Eclipta alba, Echinochloa colona, Sonchus* spp., *Dinebra* spp., *Alternanthera sessilis, Commelina* spp., *Digitaria* spp., *Oldenlandia* spp. and *Euphorbia geniculate* in Bargi locality. Results obtained from OFR trials revealed that RDF (20:60:40 N, P_2O_5, K_2O kg/ha) + CA + imazethapyr 100 g/ha as post-emergence was effective and provided broad spectrum weed control and seed yield of 1.51 t/ha, as compared to 1.18 t/ha under FP (conventional tillage + hand weeding); and provided a net returns of Rs. 80305/ha with higher B:C of 3.77 over farmers practice (Table 124). The cultivation of crop under CA by using Happy seeder facilitated early sowing of crop by utilizing the residual soil moisture content in addition of effective management of crop residue and reduction on excessive tillage operation and operational cost.

Table 124: Weed management, productivity and economics of OFR treatments of greengram during summer, 2022

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Seed yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C
RDF+CA+WM	13.6	7.5	80.3	1.51	108702	80305	3.77
FP	21.2	18.3	52.0	1.18	84923	51810	2.49
RDF+CA+Weedy	40.6	37.7		0.76	54401	26710	1.98
SEm±	0.98	1.42	3.39	0.03	2295	2294	0.07
LSD (p=0.05)	2.93	4.21	10.06	0.09	6820	6815	0.20

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

Plate 36. Weed management on greengram during summer, 2022

Rice (Direct-seeded) (*Kharif*, 2022)

In direct-seeded rice, fifteen OFR trials were undertaken on weed management during *Kharif* 2022 at villages *viz*., Nimbdua, Bhamnodi, Bhamvoda and Porva of Panagar locality and viz., Mandowar, Devri, Chikhli, Jujhari of Sihora locality. Weed management through herbicides with recommended fertilizer dose (RDF) was compared with the farmer's practice. The major weed flora observed were *Commelina communis, Cyperus iria*, *Echinochloa colona*, *Dinebra retroflexa*,*Paspaladium*sp. *Sporobolus diander* and *Phyllanthus niruri* in Panagar and *Paspalidium desertorum*, *Phyllanthus niruri*, *Cyperus rotundus*, *Echinochloa colona*, *Dinebra* spp., *Brachiaria* spp., *Eleusine indica*, *Amaranthus viridis*, *Convolvulus arvensis* and *Alternanthera sessilis* in Sihora locality. Application of recommended fertilizer dose (RDF) (120:60:40 N, P_2O_5, K_2O kg/ha) along with the application of pyrazosulfuron 25 g/ha as PE *fb* bispyribac-sodium 25 g/ha as post-emergence at 18 DAS was more effective (weed biomass 22.5 g/m^2; grain yield 4.93 t/ha; B: C 3.32) than farmers practice (high seed rate + unbalanced fertilizer without proper weed management) (weed biomass, 49.9 g/m^2; grain yield 4.31 t/ha; B: C 2.80). It was also observed that, the improved weed management practice under farmers' practice controlled the weeds effectively compared to the farmers' practice of weed management (Table 125).

Table 125: Weed management, productivity and economics of OFR treatments in direct-seeded rice at during *Kharif*, 2022

Treatment	**Weed density (no./m^2)**	**Weed biomass (g/m^2)**	**WCE (%)**	**Grain yield (t/ha)**	**Gross returns (Rs./ha)**	**Net returns (Rs./ha)**	**B:C**
RDF + CA + IWM	22.5	22.6	71.2	4.93	98161	67869	3.23
RDF + CA + Farmer practice WM	49.9	45.9	36.3	4.31	86415	57706	2.80
CT + Farmer practice WM	49.8	50.5	22.2	4.27	84997	46718	2.29
CT + IWM	67.4	57.7		4.47	89408	51106	2.45
SEm±	1.17	1.61		0.04	941	873	0.03
LSD (p=0.05)	3.60	4.98		0.13	2899	2689	0.08

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

Plate 37. Weed management in direct-seeded rice at during Kharif, 2022

Maize (*Kharif*, 2022)

In maize, ten OFR trials were conducted on weed management during *Kharif*, 2022 at Panagar and Sihora locality. The major weed flora observed was *Commelina benghalensis*, *Cyperus* spp., *Dinebra retroflexa, Echinochloa colona, Eclipta alba* and *Euphorbia geniculata* in Panagar and *Paspalidium desertorum, Euphorbia* spp., *Brachiaria* spp., *Phyllanthus niruri, Alternanthera sessilis, Dactyloctenium aegyptium, Cyperus* spp. and *Commelina communis* in Sihora. Lower weed density (22.7 no./m^2) and biomass (18.0 g/m^2) were observed in application of atrazine 1000 g/ha as PE *fb* tembotrione (120 g/ha) at 30 DAS with RDF (120:60:40 N, P_2O_5, K_2O kg/ha) under CA (Table 126). Grain yield of maize was recorded to the tune of 5.55 t/ha in CA practice with improved weed management technique. Higher net returns (Rs. 110325/ha) and B:C (3.28) was recorded with the same treatment as compared to the farmers' practice. It was also observed that the improved weed management practice under farmers' practice controlled the weeds effectively compared to the farmers' practice of weed management.

Table 126: Weed management, productivity and economics of OFR treatments in maize during *Kharif* 2022

Treatment	Weed density (no./m^2)	Weed biomass(g /m^2)	WCE (%)	Grain yield (t/ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C
RDF + CA + IWM	27.7	18.0	82.2	5.55	110325	76288	3.28
RDF + CA + Farmer practice WM	88.0	61.0	32.0	4.16	82561	48997	2.49
CT + Farmer practice WM	75.5	57.0	30.8	4.18	82306	45033	2.20
CT + IWM	114.9	75.3		4.27	85676	48903	2.37
SEm±	1.24	1.72		0.04	796.9	798.9	0.02
LSD (p=0.05)	3.82	5.30		0.11	2456	2462	0.08

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

Plate 38. Weed management in maize during *Kharif* 2022

NRRI, Cuttack

Three Farmers' training-cum-awareness programme was organized at (1) Ranajhali village, Ganjan District, on 7[th] June, 2022 (2) Balibhanda, Kendrapara, Odisha, on 20[th] June, 2022 and (3) Badakusunpur Village, TangiChoudwar, Cuttack on 21[st] June, 2022.

Table 127: Training-cum-awareness programme

Date of activity	**Name of Nodal Officer (s)**	**No. of Staff members participated**	**No. of Dignitari es**	**Farmers**	**Members of civil society**	**School/ college children**	**Total**
Ranajhali village, Ganjan District, on 7th June	Dr. AK Nayak, PS and Head, Crop Production Division, ICAR-NRRI, Cuttack	Dr. Rahul Tripathy, Dr Anjani Kumar, Dr.BS Satapathand Dr.Sushmita Munda	5	62	2	10	79
Balibhanda, Kendrapara, Odisha, on 20th June, 2020	Dr. AK Nayak, Principal Scientist and Head, Crop Production Division, ICAR-NRRI, Cuttack	Dr. M. Shahid, Dr.BS Satapathyand Dr.Sushmita Munda	4	50	2	10	66
Badakusunpur Village, TangiChoudwar, Cuttack on 21st June, 2022	Dr. AK Nayak, Principal Scientist and Head, Crop Production Division, ICAR-NRRI, Cuttack	Dr. M. Shahid, Dr.BS Satapathy, and Dr.Sushmita Munda	4	55	1	7	67

Plate 39.Farmers' Training Programme at Ranajhali village, Ganjan District, on 7th June, 2022

Plate 40.6 Farmers' Training Programme at Balibhanda village, Kendrapara,Odisha, on 20th June, 2022

Plate 41. Farmers' Training Programme at Badakusunpur Village, TangiChoudwar, Cuttack on 21st June, 2022

NIASM

1. 21 days short term training course on “Conservation Agriculture for Improving Water Productivity and Post–Harvest Quality of Field Crops under Abiotic Stress Conditions (12 September-3 October 2022). Total 22 Masters/PhD students from IARI and SAUs were participated across the India.

2. Short-term course on " Abiotic Stresses in Agriculture: An introduction and Hands-on Training for Skill Development (June 01 to July 10, 2022)". Total 52 Graduate, Masters/PhD students and young researches were participated.

3. One month short term course on “An Overview and Hands-on Instrumentation for Abiotic Stresses in Agriculture” at held ICAR-NIASM (01-30th November, 2022). Total 25 B. Tech Students from the MPKV, Rahuri were participated

4. ICAR sponsored 21 days Winter School on “Climate Change & Abiotic Stresses Management Solutions for Enhancing Water Productivity, Production Quality and Doubling Farmers Income in Scarcity Zones (5-25 January 2023)". Total 25 multidisciplinary trainees (Scientists, Assistant professors and SMS) were participated across the India.

RCER

- 01 day-seed-distribution programme on management of rice fallow areas through oilseeds and pulses was conducted at KVK, Manpur, Gaya.

- Demonstrated technology in KVK Gaya under SCSP programme: 25 acremade double cropping through lentil and mustard under ZT production mode.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गया: कृषि विज्ञान केन्द्र, मानपुर में अनुसूचित जाति कृषकों हेतु प्रशिक्षण का आयोजन


एक नजर में

किसानों को खेती की दी गई जानकारी

गया : कृषि विज्ञान केंद्र मानपुर में किसान संगोष्ठी सह बीज वितरण कार्यक्रम का आयोजन मंगलवार को किया गया। यहां 80 किसानों को मसूर एवं सरसों की खेती वैज्ञानिक तरीके से करने का सुझाव दिया गया। किसानों को बेहतर उपज पाने के लिए गुर सिखाए गए। बाद में किसानों को बीज दिए गए। इस मौके पर आइपीएआर के डा. राकेश कुमार, कृषि विज्ञान केंद्र के वरीय वैज्ञानिक डा. राजीव सिंह, डा. देवेंद्र मंडल, डा. अशोक कुमार उपस्थित थे। (जासं)

- 03 days training programme on “Conservation agriculture technologies for Doubling farmer’s income” under SCSP Scheme during 14-16 March at KVK, Chatra, Jharkhand.


संरक्षण कृषि प्रौद्योगिकी से किसानों को दुगुनी आय पर तीन दिवसीय प्रशिक्षण का शुभारंभ

चतरा (प्रातः आवाज)। भारतीय कृषि अनुसंधान परिषद के कृषि प्रणाली का पहाड़ी एवं पठारी अनुसंधान केंद्र रांची एवं कृषि विज्ञान केंद्र चतरा के संयुक्त तत्वावधान में 14 से 16 मार्च तक तीन दिवसीय प्रशिक्षण का शुभारंभ किया गया। प्रशिक्षण का शुभारंभ डॉ. बाल कृष्ण झा, प्रमुख वैज्ञानिक एवं परियोजना के सह अन्वेशक एवं प्रशिक्षण के निदेशक, वैज्ञानिक डॉ. वीपी राय एवं इंजि. विनोद कुमार पांडेय ने संयुक्त रूप से किया। प्रशिक्षण को प्रारंभ करते हुए डॉ. बाल कृष्ण झा ने संरक्षण कृषि तकनीक जैसे धान की सीधी बुआई, शुन्य जुताई तथा मसूर, तीसी, चना, सरसों की फसलों में अवषेश प्रबंधन के साथ-साथ जल संरक्षण की तकनीक पर बल दिया। उन्होंने कहा कि किसान इन तकनीकों को अपना कर धान की कटाई के पश्चात संरक्षण तकनीक द्वारा खेतों की न्यूनतम जुताई कर बची हुई नमी का उपयोग कर दलहनी एवं तेलहनी फसलों को आवश्यकता अनुसार एक-दो हल्की सिंचाई से फसलों की खेती कर अपनी आमदनी बढ़ा सकते हैं। डॉ. झा ने बताया कि यह कार्यक्रम भारत सरकार के द्वारा अनुसूचित जाति उपयोजना के अंतर्गम संरक्षण कृषि प्रौधौगिकी के अंगर्गत दिया जा रहा है। उन्होनें ने बताया कि इस प्रशिक्षण में किसानों को संरक्षण खेती का महत्त्व, सिद्धांत एवं कृषि क्रियाओं तथा धान-परती भूमि के प्रबंधन पर विस्तृत एवं प्रायोगिक जानकारी दी जाएगी। इसके साथ-साथ किसानों को धान-परती भूमि में खर-पतवार नियंत्रण, मृदा एवं पोशक तत्व प्रबंधन, फसल चक्र द्वारा आय में वृद्धि के गुर सिखाए जाएंगे। जिससे किसानों की आमदनी दुगुनी होने में कारगर साबित होगी। कार्यक्रम को संबोधित करते हुए इंजि. विनोद कुमार पांडेय ने धान-परती भूमि के अंतर्गत ली गई फसलों तथा किसानों को धान-परती भूमि में फसलों के जल प्रबंधन पर विषेश जानकारी प्रदान की। कार्यक्रम में चतरा प्रखंड के विभिन्न ग्रामों के 16 किसान भाग ले रहे है। प्रशिक्षण में डॉ. वीपी राय ने किसानों को पशुधन के उपयोगिता को बताते हुए वर्मी कंपोस्ट के द्वारा धान प्रति प्रणाली प्रबंधन पर विस्तृत जानकारी दी। प्रशिक्षण में श्री सोम्य तीवारी अनुशंधान सहायक ने किसानों को सब्जियों के खेती से संबंधित एवं बिचड़ा उत्पादन के नवीनत जानकारी किसानों को दी। कार्यक्रम में कृषि विज्ञान केंद्र चतरा के उपेंद्र कुमार सिंह, शिवेंद्र कुमार दूबे, मो. जुनैद आलम, अभिजित घोष, नवल किशोर आदि उपस्थित थे।

किसानों को प्रशिक्षण देते।

CIAE, Bhopal

Capacity building of the stakeholders through various skill development programmes for promoting CA machinery

i. Three days training programme

Two farmers’ training program on “Hands-on training and demonstration of improved agricultural implements suitable for conservation Agriculture” was organized under Consortia Research Platform on Conservation Agriculture at ICAR-Central Institute of Agricultural Engineering, Bhopal during 1-3and 8-10 February 2023 (Fig 3.8). A total of 25 and 26 farmers (SC BPL) from Sewaniya, Napaniya and Dhabla Rai village of Sehore district of Madhya Pradesh respectively participated in the training program. During the training program, participants were briefed on updates of technologies on farm mechanization, Conservation agriculture, irrigation, and agro-processing. They were given hands on training along with demonstrations of improved agricultural technologies, necessary adjustments, repair and maintenance. Participants visited to different laboratories to get exposure of different available agricultural technologies. Demonstration of operation-wise implements required for seed bed preparation, sowing/planting and transplanting, spraying, interculture as well as harvesting and threshing were given. Moreover, women friendly tools/implements, conservation agriculture machinery and micro-irrigation spraying systems were also demonstrated. Special emphases were given to covered cultivation technique, soybean processing technologies and making of soy milk, paneer etc., as well as use of renewable energy sources. Various activities related to capacity building and knowledge management for accelerated adoption of conservation agriculture machinery.

Plate 42. Hands-on training and demonstration of improved agricultural implements

ii. Farmers' Awareness Campaign on 'Efficient and Balanced Use of Fertilizers

Farmers' Awareness Campaign on 'Efficient and Balanced Use of Fertilizers (including Nano-Fertilizers) was organized on 14.06.2021, as depicted in fig 3.9. During campaign farmers were enlightened about balance use of fertilizer and its effect on crop productivity and soil health, soil health card and its importance, Integrated Nutrient Management (INM) for sustainable crop production, better soil health and environmental protection. Bio fertilizer manufacturers and supplier also present in the awareness campaign, about 100 farmers and local public.

Fig 3.9 National campaign in Sewaniya village

iii. Demonstration and distribution of improved resource conservation agricultural tools:

Under SCSP Programme, resources/missing input in the form of fertilizer and hand tools were provided for filling the critical gaps in agricultural operations for economicdevelopment of SCs below the poverty line as given in table 128. Awareness about institute developed technologies, conservation technologies was created and hands on training/knowledge also given for use of improved tools for growing better crops.

Table 128: Detail of demonstration and distribution of improved resource conservation agricultural tools among the farmers

Date	No. of farmer and village	Machine demonstration and distribution
28.01.2022	A total no. of (38) farmers from village, of Devali in Sehore district, Madhya Pradesh. Manual hand ridger for women (27) Manual twin wheel hoe (2) Manual cycle wheel hoe (4) Fuel cooking stove (5)	
16.02.2022	A total no. of (32) farmers from village of Khajuri in Bhopal District Madhya Pradesh. Hand held single row vegetable trans planter (15) Manual Naveen Dibbler (10) Hand held two row vegetable trans planter (07)	
08.03.2022	A total no. of (32) farmers from village of LasuriyaKhasin Sehore District, Madhya Pradesh. Hand held single row vegetable trans planter (12) Manual Naveen Dibbler (10) Manual hand ridger for women (10)	
11.03.22	A total no. of (31) farmers from village of Rampalasi in Sehore District, Madhya Pradesh. Hand held single row vegetable trans planter (11) Manual Naveen Dibbler (10) Manual stalk uprooter (10)	

14.06.2022	A total no. of (32) farmer from village of Sewaniya in SehoreDistrict Madhya Pradesh 32 Bags DAP Fertilizer	

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Experiments in farmers' fields were conducted in participatory mode in Kham Kheda, Rasla Khedi, Raipur and Karod khurd villages. Data for various growth and yield attributes were recorded under no till, reduced tillage and compared with conventional tillage farmers practice.

Farmer Field Data 2021-22 (*rabi* season)

Crop – Wheat

A total of 12 demonstrations with wheat crop were conducted during *rabi* season 2021-22. A perusal of the data revealed that zero tillage recorded higher seed yield of wheat (50.77 q/ha) as compared to conventional tillage (47.83 q/ha) and reduced tillage (49.04 q/ha), however the differences in grain yield was not significant.

Table 129:12 demonstrations with wheat crop were conducted during *rabi* season 2021-22

Wheat									
Name of Farmer	**Straw yield (q/ha)**	**Grain yield (q/ha)**	**HI (%)**	**Straw yield (q/ha)**	**Grain yield (q/ha)**	**HI (%)**	**Straw yield (q/ha)**	**Grain yield (q/ha)**	**HI (%)**
	ZT			**RT**			**CT**		
NandlalYadav	73.25	54.25	42.55	67.75	52.25	43.54	65.00	50.50	43.72
ParvatYadav	82.25	49.50	37.57	57.50	47.75	45.37	57.25	45.25	44.15
HemrajYadav	74.25	56.50	43.21	71.50	55.50	43.70	70.00	52.50	42.86
RajnarayanYadav	67.50	52.00	43.51	65.50	50.50	43.53	61.00	48.50	44.29
Karan singhYadav	72.00	51.75	41.82	66.00	49.50	42.86	69.25	50.50	42.17
Deepak Yadav	80.00	54.50	40.52	72.00	52.25	42.05	70.00	51.75	42.51
Naval singhyadav	71.00	47.00	39.83	71.50	49.25	40.79	61.25	45.25	42.49
JagjeevanAhirwar	71.00	53.25	42.86	67.50	49.50	42.31	67.75	51.25	43.07
Himmat Singh Lodhi	69.25	50.25	42.05	66.00	47.25	41.72	64.00	46.00	41.82
Naval Singh Lodhi	72.25	46.50	39.16	70.25	45.25	39.18	69.25	44.00	38.85
Ram Singh Lodhi	73.75	48.50	39.67	69.25	45.50	39.65	73.50	46.00	38.49
Azad Singh	72.25	45.25	38.51	69.50	44.00	38.77	66.50	42.50	38.99
Average	**73.23**	**50.77**	**40.94**	**67.85**	**49.04**	**41.49**	**66.23**	**47.83**	**41.95**

Farmer Field Data 2021-22 (Rabi)
Crop – Chickpea

A total of 8 demonstrations with chickpea crop were conducted during *rabi* season 2021-22. A perusal of the data revealed that zero tillage recorded higher seed yield of chickpea (12.90 q/ha) as compared to conventional tillage (11.61 q/ha) and reduced tillage (11.75 q/ha), however the differences in grain yield were not significant.

Table 130:Demonstrations with chickpea crop were conducted during *rabi* season 2021-22

Chickpea									
Name of Farmer	**Straw yield (q/ha)**	**Grain yield (q/ha)**	**HI (%)**	**Straw yield (q/ha)**	**Grain yield (q/ha)**	**HI (%)**	**Straw yield (q/ha)**	**Grain yield (q/ha)**	**HI (%)**
	ZT			**RT**			**CT**		
SantoshYadav	16.35	12.90	44.10	14.88	12.25	45.16	16.88	11.63	40.79
Jeevan Singh Jat	17.25	13.00	42.98	12.35	11.40	48.00	9.75	12.00	55.17
Badam Singh Jat	15.23	14.00	47.90	14.25	13.13	47.95	12.75	13.00	50.49
Chain Singh Jat	11.00	10.00	47.62	10.88	9.00	45.28	10.75	8.75	44.87
Ram Singh Jat	17.88	14.25	44.36	15.25	13.00	46.02	17.00	12.75	42.86
Vijay Malviya	16.25	15.00	48.00	15.50	13.50	46.55	18.75	13.63	42.08
Phul Singh	10.38	12.00	53.63	10.23	10.50	50.66	12.03	10.10	45.65
Goverdhan	12.33	11.80	48.91	10.05	11.20	52.71	10.88	11.00	50.29
Average	16.35	12.90	47.19	12.92	11.75	47.79	13.60	11.61	46.52

Soybean 2022 (*kharif*)

Twenty field demonstrations under zero tillage and reduced tillage were conducted during kharif season 2022 with soybean crop. A perusal of the data revealed that zero tillage recorded higher seed yield of soybean (13.57 q/ha) as compared to reduced tillage (11.11 q/ha) and conventional tillage (10.45 q/ha), however the differences in seed yield could not attain the level of significance.

Table 131:Twenty field demonstrations under zero tillage and reduced tillage were conducted during kharif season 2022 with soybean crop

S.No.	Name of Farmer's	ZT	RT	CT
1	ParvatYadav	12.87	11.12	11.37
2	NandlalYadav	15.50	10.25	13.13
3	Karan singhYadav	14.50	9.00	11.13
4	HemrajYadav	14.00	10.13	11.00
5	Naval singhyadav	12.00	10.38	9.00
6	Deepak Yadav	13.95	11.23	10.00
7	RajnarayanYadav	14.13	11.75	10.88
8	SantoshYadav	13.25	12.10	9.50
9	Chain Singh Jat	13.25	12.13	9.75

10	Jeevan Singh Jat	15.50	13.20	10.50
11	Badam Singh Jat	13.00	11.88	10.63
12	Ram Singh Jat	12.10	10.38	11.20
13	JagjeevanAhirwar	13.25	11.50	10.25
14	Vijay Malviya	12.75	10.50	8.00
15	Ram Singh Lodhi*	Crop completely damaged due to water logging in the field as a result of excessive rains during the year.		
16	Himmat Singh Lodhi*			
17	Naval Singh Lodhi*			
18	Azad Singh*			
19	Phul Singh*			
20	Goverdhan*			
	Average	**13.57**	**11.11**	**10.45**

11. IIFSR

Activities related to SCSP in project

A total number of 310 farm families of Schedule Caste (SC) from Dalupuri, Rasoolpur Mithiberi and Chamariya villages of Laldhang cluster situated in the foothills of Rajaji National Park, Uttarakhand have been adopted under the project.

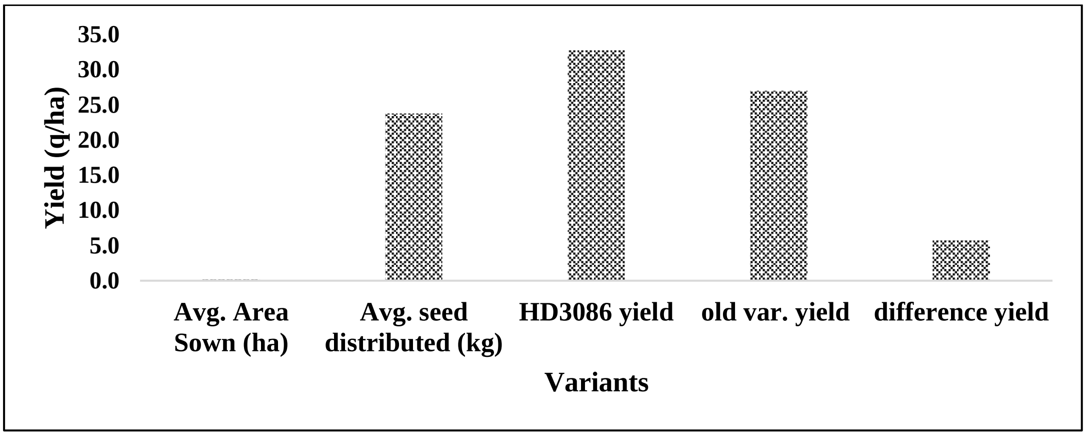

Fig 73: Comparison of farmers practices and improved wheat cultivar on yield enhancement among the adopted farm families

To identify the suitability of integrated farming system component among the farmers of small and marginal farmers' category the basic data related to socio-economic status of the adopted farmers were collected using the standard survey proforma. As per the survey, the selected villagesare dominated by the marginal farmers' category (44%) owning 55.6% marginal; >36.3% small farmers; >22.9% medium and large farmers. The mean level of cropping intensity of adopted villages is 164%. Fig 3.10 and 3.11 contains the data related to comparison of effect of improved wheat varieties and introduction of poultry component on nutritional and livelihood security of the adopted farm families.
The data depicted in fig 73 showed that the average area shown by individual farmers under wheat crop was 0.20 ha in the studied area. The improved HD 3086 variety of wheat produced on an average 32.71 q ha^{-1} yield as compared to the traditional cultivar used by the farmers. Data depicted in Fig 74 shows that an average of 29 birds were distributed among the farmers. The mortality rate was 6.5 birds per farm family. At the same time, the live birds produced on an average of 19 egg per bird which in turn produced a total of 67.67 eggs per farm family.

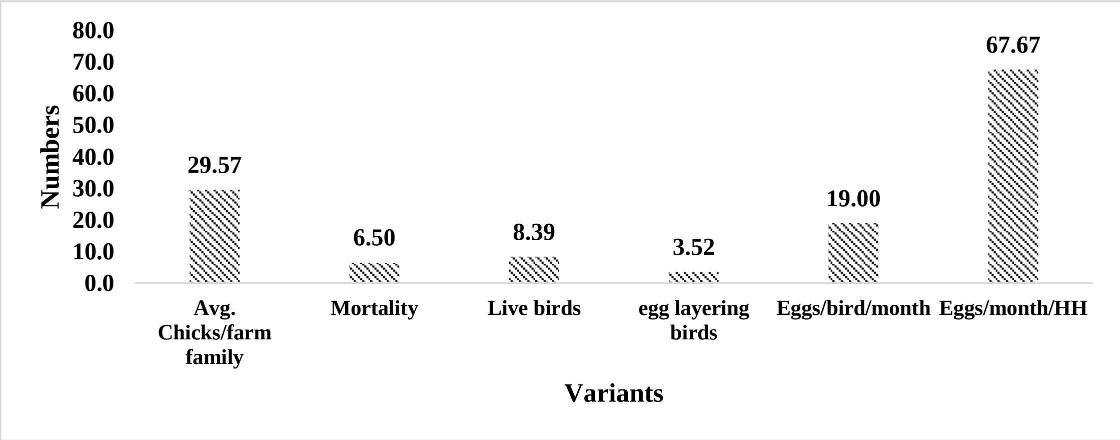

Fig 74: Introduction of commercial poultry birds among the SC farmers for nutritional and livelihood security.

NIASM

Product developed

Multipurpose ratoon drill (MRD) machine

Three prototypes of multipurpose drill machines performing various operations in trash retained ratoon sugarcane fields were developed by ICAR–NIASM in close collaboration with other ICAR Institutes and private entrepreneurs. Recently developed (Prototype–III) of MRD machine is capable to perform five operations *viz.*, stubble saving, off–baring, root pruning, fertilizer placement and sowing of intercrops in single run of tractor (50 HP) in trash retained ratoon sugarcane. During the year, performance of this machine was evaluated over 8–10 farmers' fields. Further, it was demonstrated to more than 250 farmers, students, trainees and entrepreneurs.