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RESEARCH ARTICLE

Innovative conservation tillage and weed management techniques under rice maize-cowpea system for higher productivity, resource use efficiency and healthy soil in coastal Odisha

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Abstract

In rice-growing regions of India particularly in Odisha, tillage intensive cropping practices have reduced soil organic carbon (SOC) levels and declined soil physical properties. The productivity of crops has therefore decreased over time, indicating a requirement for sustainable substitutes. In this context, a long-term field investigation (2016—2018) was undertaken at the Central Research Station (CRS) of Odisha University of Agriculture and Technology, Bhubaneswar, to assess the effects of conservation tillage and weed management practices on the productivity, resource-use efficiency (RUE) and economics of a rice-based cropping system under sandy loam Typic Endoaquepts. The experiment, laid out in a strip-plot design with three replications, evaluated five crop establishment and residue management practices, viz., conventional tillage (CT), zero tillage (ZT), direct-seeded rice (DSR) and their combinations with residue retention, alongside three weed management strategies, i.e., herbicide-based, manual/mechanical and integrated weed management (IWM). Among the tested combinations, the CT (DSR)-CT-ZT sequence recorded the highest rice equivalent yield (REY) of 13.86 t/ha, system productivity of 37.96 kg REY/ha/day and sustainable yield index (SYI) of 0.79. IWM across all crops enhanced REY (13.84 t/ha) and system productivity (37.42 kg REY/ha/day), outperforming sole herbicide use and hand weeding. The best-performing treatment combination, CT (DSR)-CT-ZT with IWM, achieved the maximum REY (14.58 t/ha), nutrient uptake (327 kg N (nitrogen), 115 kg P (phosphorus), 349 kg K (potassium)/ha), net returns (₹ 122535/ha) and benefit-cost ratio (2.48). The RUE ranking was CT (DSR)-CT-ZT > CT (TPR)-ZT-ZT > (ZT (DSR) + R)-(ZT+R)-ZT > CT (TPR)-CT-F > ZT (DSR)-ZT-ZT. These findings underscore CT (DSR)-CT-ZT with IWM as a promising strategy under conservation agriculture, promoting long-term sustainability and enhanced system productivity through improved resource utilization and soil quality.

Keywords: conservation tillage; crop residues; economics; growth; integrated weed management; system yield

Introduction

Rice serves as a fundamental component of India's agricultural economy and food security, with particular emphasis on the state of Odisha. Traditionally, rice cultivation is conducted through transplanting in a puddled environment (TPR), a practice that has led to the depletion of natural resources such as water and energy. While the puddling process in CT systems offers advantages for rice cultivation including reduced percolation losses, decreased weed infestation and facilitated seedling establishment, the practice of prolonged flooding can adversely affect soil health by diminishing its microbial biodiversity and physical properties (1). For a sustainable and profitable production system of rice, it is imperative to adopt resource-conserving technologies like direct seeding, reduced or zero-tillage with residue retention and effective weed, water and nutrient management in a system mode. The introduction of advanced agricultural machinery and effective herbicides has expanded our perspective on crop production, leading to increased productivity and improved soil health (2). Modifying rice cultivation techniques and implementing crop diversification or intensification are considered among the most effective strategies to enhance system productivity and profitability. Sequence and selection of crop in any cropping system are crucial because they can highlight the synergistic interactions between the crops and boost production and sustainability (3). Crop diversification can be facilitated by cultivating sweet corn during the Rabi season, as it is increasingly recognized as a specialty crop within rice-based agricultural systems in India which can suitably address several challenges like food and nutritional guarantee, climate crisis, water shortage, bio-fuel demand, fodder requirement and other industrial requirements (4). The integration of pulses such as cowpea into rice-maize cropping systems presents a multifaceted approach to enhancing agricultural sustainability and productivity, particularly in regions like coastal Odisha. Cowpea's inherent attributes including its high protein content, short growth duration, soil-smothering capabilities, drought tolerance and soil-restructuring properties, make it a versatile and valuable addition to diverse cropping systems (5). Rice-maize-cowpea has been identified as the most productive, profitable and sustainable cropping system for coastal Odisha (6). DSR is found to save labour by 69 % and cost of production by 59 % with yield similar to puddled TPR and non-puddled TPR by machine (7). Direct seeding also has the advantage to settle soil related disputes between rice and following non-rice crops and to increase the sustainability of the rice-based cropping crop and then winter crops (8). Weeds are, however, a threat to the achievement of maximum yield and the further spread of DSR. With maximum control of weeds through herbicides, minimum tillage can supplement the profitability of rice-maize cropping. Keeping in view the above facts, the current study on the rice-maize-cowpea system was carried out under conservation tillage and weed management regimes. In this paper, the results on system yield, resource use efficiency and economics of the rice-maize-cowpea system after the 5th cropping cycle has been reported.

Materials and Methods

Study area

The present field experiment was taken up at the CRS, Odisha University of Agriculture and Technology, Bhubaneswar (20026'N, 85081'E, 25.9 m AMSL (above mean sea level) and around 64 km from Bay of Bengal), Odisha, in the state's East and Southeastern Coastal Plain agro-climatic Zone. Experimental field consisted of alluvial soils with available N (nitrogen), P (phosphorus) and K (potassium) of 210, 15.5 and 178 kg/ha respectively. The present paper deals with only two years of rice crop data after five years of experimentation on "Medium-term impact of tillage and weed management practices in rice-maize-cow pea cropping system" under the aegis of ICAR-AICRP (Indian Council of Agricultural Research-All India Coordinated Research Project) on Weed Management, Bhubaneswar, India, which was initiated in 2014 in a permanently laid out strip-plot design with three replications. In this study, we provided data collected during the 2016-17 and 2017-18 growing seasons. Weather data was recorded by weather stations installed around 5 m away from the experimental area. The details of the weather parameters have been given in Fig. 1.

Experimental details and crop management

Five residual treatments along with three weed control methods

Table 1. Treatment details imposed on different crops in sequence

Kharif (Rice)	Rabi (Maize)	Summer (Cowpea)
T_1 CT (Transplanted, TPR)	CT	-
T_2 CT (Transplanted, TPR)	ZT	ZT
T_3 CT (Direct seeded, DSR)	CT	ZT
T_4 ZT (Direct seeded, DSR)	ZT	ZT
T_5 ZT (Direct seeded, DSR) + Residue	ZT + R*	ZT

Vertical strip: Tillage and residue management (5)

Horizontal strip: Weed management practices (3)

W_1: Herbicide application suitable to particular crop

W_2: Hand weeding / mechanical weeding

W_3: Chemical method + hand weeding / mechanical weeding (W_1+ W_2)

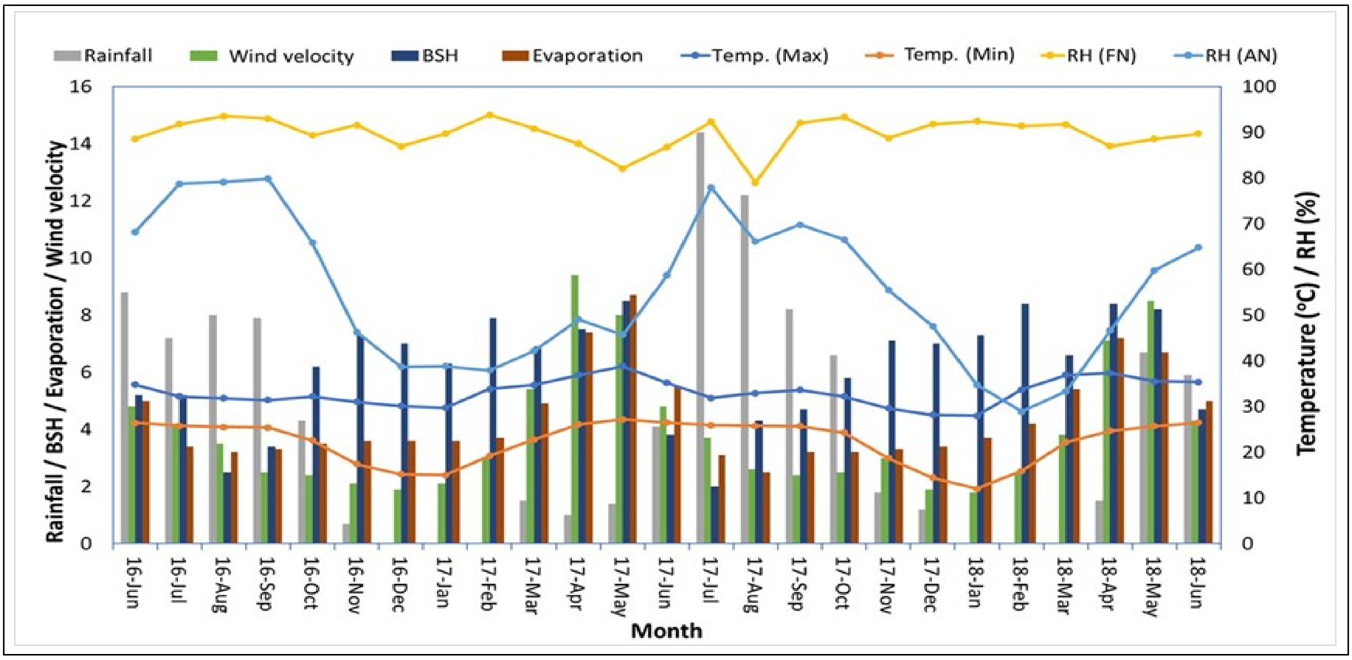

Fig. 1. Mean monthly weather parameters during cropping seasons.

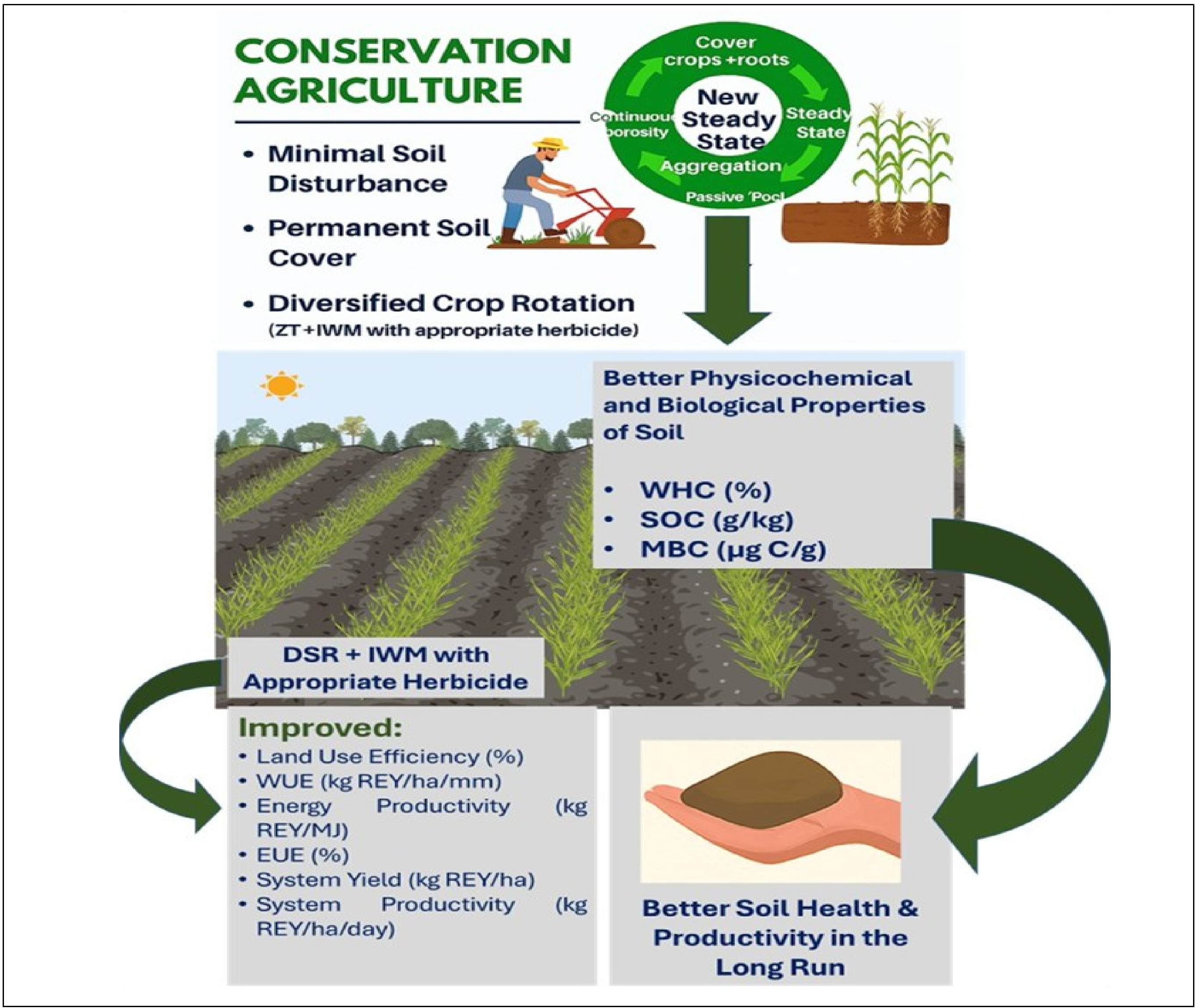

Fig. 2. Graphical abstract of the experimentation.

operate as a cohesive system in this experiment (Table 1). The graphical abstract of the entire experiment is presented in Fig. 2.

The CT practice involved two ploughing operations with a mould board plow to reach 20 cm depth without leaving any crop residues behind. Tillage using planking produced a seedbed with excellent fine texture in the DSR management procedure. The puddling operation for TPR was performed using tractor-driven puddling equipment. An early watering session before planting rice served to guarantee reliable seed sprouting. Glyphosate was applied at a rate of 1.7 kg/ha fifteen days before planting rice in the ZT system. After the application of glyphosate, the rows of rice became Smooth & received direct seeding as the planting method in ZT. The applied amount of crop residues in residue treated plots (T_5) reached 9.0 t/ha of total mass. On rice fields the W_1 treatment was given pretilachlor at 0.5 kg/ha (used pre-emergence at both 2 days after transplanting (DAT) and 1 day after sowing (DAS)) combined with W_2: one mechanical weeding at 20 DAT/DAS followed by 1 hand weeding at 40 DAT/DAS and W_3: pretilachlor at the rate of 0.5 kg/ha (applied pre-emergence right after 2 DAT/1 DAS) with an addition of mechanical weeding at 30 DAT then 1 hand weeding at 60 DAT. For maize crop, weed management treatments are as follows: W_1: treatment was pendimethalin at the rate of 1.0 kg/ha (pre emergence, 1 DAS, W_2: 1 hand weeding (20 DAS) + hoeing (40 DAS), W_3: pendimethalin at the rate of 1.0 kg/ha (pre emergence, 1 DAS) + mechanical weeding (30 DAS) + 1 hoeing (45 DAS). For cowpea, W_1: treatment was pendimethalin at the rate of 1.0 kg/ha (pre-emergence, 1 DAS), W_2: 1 hand weeding (20 DAS), W_3: pendimethalin at the rate of 1.0 kg/ha (pre-emergence, 1 DAS) + mechanical weeding (30 DAS). For rice crops, one-fourth of recommended N, full dose of P and half of K were applied as basal at the time of sowing/planting. The remaining N was applied as top-dressing through urea in two splits i. e., half at 30 DAS or 15 DAT and one fourth at panicle initiation stage. For maize, N was applied in three splits i.e., one fourth as basal, half at 21 DAS and one fourth at 35 DAS and all P and K as basal. For cowpea all fertilizers were applied as basal. Basal dose of nutrients was provided by drilling into the soil through di-ammonium phosphate, urea and muriate of

Table 2. Details of the variety & fertilizer dose used in experimentation along with their characteristics

Crop	Variety	Duration (days)	Potential yield (t/ha)	Fertilizer dose ($N-P_2O_5-K_2O$ kg/ha)
Rice	Pratikshya	145	7.5	80-40-40
Maize	Sugar 75	95	12.66	100-50-50
Cowpea	Sylvinia	75	150	25-50-25

potash (MOP). Different varieties of crops with their specification are given in Table 2.

REY was calculated as follows:

REY (t/ha) = {(Yield of rice x Price of rice) + (Yield of maize x Price of maize) + (Yield of cowpea x Price of cowpea)}/ Price of rice

System productivity (kg REY/ha/day) was calculated as follows:

$$\text{System productivity (kg REY/ha/day)} = \frac{\text{System yield (kg REY/ha)}}{\text{365 days}}$$

The resource use efficiency was calculated as follows:

$$\text{Land use efficiency (\%)} = \frac{\text{Number of days field occupied by crops}}{365} \times 100$$

$$\text{Partial factor productivity (kg REY/kg nutrient)} = \frac{\text{System yield (kg REY/ha)}}{\text{Total nutrient applied (kg NPK/ha)}}$$

$$\text{Water use efficiency (kg REY/ha-mm)} = \frac{\text{System yield (kg REY/ha)}}{\text{Water use (ha-mm)}}$$

Energy input and output were calculated by considering each item of input used and both the main as well as by-product yields (9). Energy-use efficiency was calculated using the following formula:

$$\text{Energy ratio} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy productivity (kg REY/MJ)} = \frac{\text{REY (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

SYI was calculated as follows:

$$\text{SYI} = \text{Ymean - SD/Ymax}$$

Where,

Ymean = Mean yield over years,

SD = Standard deviation

Ymax= Maximum yield over years

Here, the REY of the system for five consecutive years has been taken into consideration for calculating SYI of the rice-maize-cowpea system. The existing market price of economic and by-products as well as the cost of inputs were taken into account when calculating the gross, net returns and the benefit-to-cost ratio (B:C) of various treatments. Net return was calculated by deducting the cost of cultivation from the gross returns. B:C ratio was computed by dividing the gross returns by the cost of cultivation.

Soil analysis

Soil samples from each treatment were collected from 0-5, 5-10 cm depths after the harvest of summer cowpea in 2018. The collected samples were shade dried followed by grinding and sieving and were kept in polythene bags for analysis of soil fertility status. Soil available N, P and K were estimated by using standard methods: Micro Kjeldahl, Vanadomolybdate and Flame photometry respectively.

Water holding capacity (WHC)

The WHC of the soil was performed using Keen-Raczkowski boxes (10). A Keen-Raczkowski box was filled with soil, tapped multiple times and leveled. The box was placed in a water-containing Petri dish and left overnight. The saturated soil was removed; weight was taken and dried in an oven at 105 °C. The top of the soil was leveled and the water holding capacity of soil was recorded.

$$\text{WHC (\%)} = \text{(c - a) - B/B x 100}$$

Where,

B= (100 - m) (b - a)/100a= Weight of box + Filter paper

b = Weight of box + air dry soil

c = Weight of box with wet saturated soil

m = Water content of the air-dry soil

SOC: SOC levels were determined through a modified version of the rapid titration method by Walkley and Black that used ferroin indicator (11).

Microbial biomass carbon (MBC) estimation

The determination of MBC was done using fumigation extraction methods (12). The study involved collecting filtrate from non-fumigated soil (20 g) shaken with 0.5 M potassium sulfate for 30 min and from fumigated soil treated with ethanol-free chloroform for 24 hr. Organic carbon in the extracts was determined through digestion titration, where 10 mL of filtrate was mixed with 10 mL of potassium dichromateand 20 mL of concentrated sulphuric acid, then digested at 170 °C for 30 min. After cooling, 25 mL of ortho-phosphoric acid was added and the mixture was titrated against 0.04 M ferrous ammonium sulfate using ferroin as an indicator. MBC can be calculated as follows:

$$\text{MBC ratio} = \frac{\text{EC of fumigated soil - EC of non-fumigated soil}}{\text{KC}}$$

The variables are extractable carbon and KC. The K_2SO_4 (potassium sulfate) extract efficiency factor amounts to 0.379 (KC).

Statistical analysis

Statistical data analysis relied on the analysis of variance (ANOVA) approach for all measurements taken from the strip-plot design. The research data were combined from two years of experimental work. Critical difference (CD) values at $p \leq 0.05$ were calculated to compare treatment means.

Results and Discussion

System yield and productivity

At CRS, the 2017-18 seasons received the highest cumulative rainfall of 1516 mm, whereas the 2016-17 seasons received the lowest cumulative rainfall of 1196 mm. The rice crop received 1126 mm and 1502 mm rainfall during 2016-17 and 2017-18 respectively, evenly distributed almost in 93 days. The average yield of the rice-maize-cowpea system was 13.00 t REY/ha, which was influenced by both conservation tillage and weed management practices (Table 3, Fig. 3). The CT (DSR)-CT-ZT practice registered the highest REY of 13.86 t/ha and was at par with CT (TPR)-ZT-ZT in both the years and also with (ZT (DSR) + R

Table 3. Effect of conservation tillage and weed management practices on system yield productivity and economics of rice-maize-cowpea system

Particular	System yield (kg REY/ha)			System productivity (kg REY/ha/day)		Net returns (Rs/ha)		B:C	
	2016-17	2017-18	Mean	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Conservation tillage									
CT (TPR)-CT-F	12.50	13.28	12.89	34.24	36.37	109509	141551	1.84	1.91
CT (TPR)-ZT-ZT	13.08	13.76	13.42	35.83	37.70	99175	111161	1.77	1.86
CT (DSR)-CT-ZT	13.64	14.08	13.86	37.36	38.56	127895	117176	2.41	2.56
ZT (DSR)-ZT-ZT	11.49	12.74	12.12	31.48	31.48	73492	95293	1.58	1.75
(ZT (DSR)+R)-(ZT+R)-ZT	12.12	13.34	12.73	33.19	33.19	84412	105732	1.66	1.83
SE(m) ±	0.28	0.23							
CD (0.05)	0.90	0.76							
Weed management									
Chemical	12.73	13.46	13.09	34.87	35.87	95856	108614	1.79	1.89
Cultural	11.49	12.64	12.07	31.47	33.05	88902	109112	1.83	2.01
Integrated	13.48	14.21	13.84	36.92	37.92	111932	124820	1.94	2.04
SE(m) ±	0.20	0.26							
CD (0.05)	0.80	1.02							

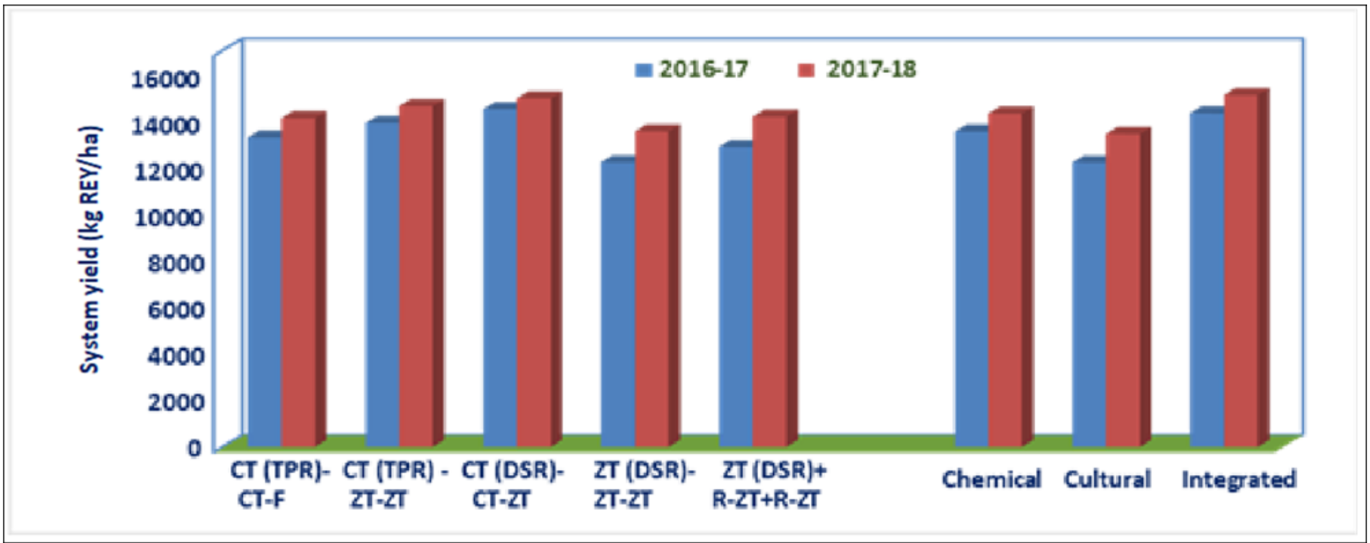

Fig. 3. Effect of conservation tillage and weed management on system yield of rice- maize-cowpea system.

-ZT+R-ZT during 2017-18. System yield was minimum in ZT (DSR) -ZT-ZT practice (12.12 t REY/ha), which was on par with ZT (DSR) + R-ZT+R-ZT in both the years and even with CT (TPR)-CT-F during 2017-18. The practice of residue retention under ZT slightly elevated overall system yields by 5.0 percent. The system yield represents the total combined production of all component crops in one system that gets calculated through the base crop's equivalent value. Adding a third crop type within the system consistently enhanced overall production. Under a particular agro-ecological context the productivity together with profitability levels of rice-based cropping systems largely depend on winter crop performance. The integration of vegetable or similar crops like sweet corn in Rabi season enhances farming system productivity (6, 13-15). When farming combines one exhausting crop such as sweet corn with legume crops including cowpea it produces a combined positive impact on both the basic crop yield and subsequent crops in the system. The system yield achieved highest levels when CT was used in rice under both DSR and TPR followed by identical management in succeeding maize compared to ZT techniques in ZT (DSR)-ZT-ZT and (ZT (DSR)+R)-(ZT+R)-ZT. The component crops yielded better growth characteristics under traditional cultivation methods than under ZT (16, 17) because CT promotes quicker organic decomposition and improved nutrient access together with enhanced root development. Grain yields in maize fields tend to reduce marginally when farmers switch from CT to no-till operation because lower soil N availability limits crop productivity. Soils under the no-till practice demonstrated higher REY than those maintained without crop residues. Soil productivity increased after crop residue incorporation because it led to elevated organic carbon levels and better microbial populations that created advantageous growing conditions for crops. There were steady improvements in soil productivity under ZT systems that built up SOM (soil organic matter) and labile pools while helping ecosystem functions (18). System yields from IWM performed under H+MW+HW (herbicide + mechanical and hand weeding) reached 13.84 t/ha and matched chemical treatment yields (13.10 t/ha) in both years while producing 14.7 % higher crops than the cultural (HW + Hoeing) method with 12.07 t REY/ha. Weeds pose serious threats to crop productivity alongside reducing input-use efficiency and profitability in rice-based cropping systems (19). The IWM practice established weed suppression at an early stage which supported crop development through the availability of crucial edaphic and climatic factors that weeds typically utilized. Extra manual weeding intervention during 30 DAS (days after sowing)/ DAT (days after transplanting) successfully reduced existing weeds which led to less crop competition with weeds both during critical stages and throughout the rest of the season. The research outcomes as generated in other studies (20, 21) showed comparable results by following IWM specifically chemical and cultural practices of management module. The average system productivity over both years was maximum (37.96 kg REY/ha/day) in CT (DSR)-CT- ZT and the treatments were in the order of CT (DSR)-CT-ZT> CT (TPR)-ZT-ZT> CT (TPR)-CT-F> (ZT (DSR)+R)-(ZT+R) -ZT> ZT (DSR)-ZT-ZT. In the case of weed management practices, the highest mean system productivity was obtained from IWM (37.42 kg REY/ha/day) and the lowest mean in the cultural method (32.26 kg REY/ha/day) over both the years. Amongst the crop establishment methods, CT (DSR)-CT-ZT was the most sustainable system with SYI of 0.79 followed by CT (TPR)-ZT-ZT (0.75) and CT (TPR)-CT- F (0.71). The ZT (DSR)-ZT-ZT system exhibited the least SYI of 0.63 as against 0.68 of the same system with residue retention. In the case of weed management practices, IWM was the most sustainable practice having SYI of 0.77 as compared to 0.72 with chemical and the minimum of 0.63 in the cultural method. The treatment combination of CT (DSR)-CT-ZT with IWM (H+MW+HW) resulted in the highest REY of 14.58 t/ha after completion of the 5th cropping cycle, which undoubtedly resulted in the highest system productivity and it was the most sustainable system with SYI of 0.78.

Resource use efficiency

Rice-maize-cowpea with an average system yield of 13.00 t REY/ha, system productivity of 35.01 kg REY/ha/day and SYI of 0.70 is an important resource use efficient cropping system with an average LUE of 71.5 percent, WUE of 4.28 kg REY/ha-mm, partial factor productivity (PFP) of 31.19 kg REY/kg of NPK applied and EUE) of 25.89 kg REY/MJ (Table 4).The CT (DSR)-CT-ZT system showed maximum system yield (13.86 t REY/ha), LUE (83.5 %), WUE (4.58 kg REY/ha-mm), PFP(33.88 kg REY/kg of NPK) and EUE (28.81 kg REY/MJ). The difference in WUE between TPR and DSR exists because puddling in TPR requires larger amount of water resulting in increased surface evaporation along with percolation losses (8). The practice of puddling with pounded water creates a delay of one to three weeks in rice transplanting. When plants are transplanted, they mature late because seedlings experience a stressful recovery after being pulled from their original location. When farmers harvest direct-sown rice earlier, they have the opportunity to plant successive crops at an earlier date. The extended field duration of Rabi and summer crops which follows DSR rice is most likely responsible for the increased LUE reported in DSR systems (22). The average EUE was 25.89 kg REY/MJ and the trend was in the order of CT (DSR)-CT-ZT > CT (TPR)-ZT-ZT > (ZT(DSR)+R)-(ZT+R)-ZT> ZT (DSR)-ZT-ZT>CT (TPR)-CT-F in both the years. Among the various weed management practices, the mean EUE was maximum in IWM (26.92 kg REY/MJ) followed by chemical and cultural methods in sequence over the years. Energy productivity also followed a similar trend. The highest and lowest energy productivity was with CT (DSR)-CT-ZT (1.15 kg REY/MJ) and CT (TPR)-CT-F (1.02 kg REY/MJ). Among ZT treatments, energy productivity was higher with the treatments having addition of residues (1.15 kg REY/MJ) than without it. IWM practices excelled in terms of energy productivity (1.19 kg REY/MJ) over the rest of the treatments. The inclusion of oil seeds and pulses has been reported to increase the energy and nutrient use efficiency of rice-based cropping systems in Odisha (6). Transplanted rice used the most energy whereas ZT required the least amount of energy. The ZT system achieved the best output-input ratio which made it the most energy-efficient method for rice cultivation. Present analysis aligns with previous results (23, 24) which demonstrated that CT practices delivered superior energy output, net energy, EUE and energy productivity because of higher crop yields, but ZT reduced both energy use and required time. The practice of ZT resulted in reduced system yield and poor nitrogen mobilization from surface soil residues leading to decreased N use efficiency in these conditions. The conventional DSR land preparation required less fuel consumption than transplanted cultivation (25). DSR crop produce fewer methane emissions (26) which provides farmers with the potential to earn carbon credits above TPR system profits (27). Weed management practices failed to impart variation in terms of LUE, WUE and energy productivity though IWM showed a higher trend in WUE (4.58 kg REY/ha-mm), PFP (33.22 kg REY/kg of NPK) and EUE (26.92kg REY/MJ), probably due to the highest system yield (13.84 t REY/ha). Better weed management under IWM has optimized the resources for better utilization by crops.

Soil properties

An analysis of ZT-ZT-ZT treatment during the 4th cropping cycle revealed an enhanced WHC level of 41.9 and 39.4 percent relative to the initial 38.8 and 38.2 percent observed at the top two soil layers (0-5 and 5-10 cm). The practice CT-CT-F, in contrast, exhibited a slight declining trend registering a decrease of 1.5 and 1.1 percent over the initial status of corresponding layers. The increase in WHC in the top two layers under ZT-ZT-ZT system was to the tune of 8.8 and 3.3 percent over CT-CT-F system. Practice of ZT-ZT-ZT+R (residue) with H+MW+HW (weed management) resulted in maximum WHC in the top two layers. Table 5 shows the distribution of SOC at different depths between rice-maize-cowpea system fields under various tillage systems and weed management approaches. ZT practice of ZT-ZT-ZT (Kharif-Rabi-

Table 4. Effect of conservation tillage and weed management practices on resource use efficiency of system

Particular	LUE (%)		EUE (%)		EP (kg REY/MJ)		WUE (kg REY/ha-cm)		PFP (kg REY/ kg of NPK)
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2017-18
Conservation tillage									
CT (TPR)-CT-F	63	66	18.51	17.15	0.99	1.05	3.84	3.88	28.40
CT (TPR)-ZT-ZT	78	81	27.84	25.67	1.13	1.09	4.38	4.40	32.36
CT (DSR)-CT-ZT	82	85	29.23	28.39	1.21	1.19	4.55	4.60	33.70
ZT (DSR)-ZT-ZT	62	64	28.66	26.50	1.13	1.14	4.01	4.28	28.73
(ZT (DSR)+R)-(ZT+R)-ZT	66	68	29.42	27.59	1.19	1.15	4.27	4.62	30.18
Weed management									
Chemical	70	73	26.95	24.92	1.16	1.14	4.25	4.36	31.03
Cultural	70	73	25.04	24.61	1.03	1.05	3.85	4.08	28.14
Integrated	70	73	28.20	25.64	1.20	1.18	4.53	4.63	32.86

Table 5. Effect of conservation tillage and weed management practices on physiochemical and biological properties of soil in rice-maize-cowpea system

Particular	WHC (%)		SOC (g/kg)		MBC (µg C/g)	
	0-5 cm	5-10 cm	0-5cm	5-10 cm	0-5cm	5-10 cm
Conservation tillage						
CT (TPR)-CT-F	38.2	37.7	7.1	5.3	144.4	109.2
CT (TPR)-ZT-ZT	39.8	38.1	9.5	6.6	205.1	147.0
CT (DSR)-CT-ZT	39.1	36.9	7.9	6.2	171.2	135.1
ZT (DSR)-ZT-ZT	41.1	38.8	11.0	7.9	243.8	175.9
(ZT (DSR)+R)-(ZT+R)-ZT	42.1	39.1	11.9	9.9	266.6	158.6
SE(m) ±	0.79	0.78	0.21	0.14	4.77	3.45
CD (0.05)	2.6	NS	0.7	0.5	15.5	11.3
Weed management						
Chemical	39.6	37.3	8.9	6.5	191.3	140.8
Cultural	39.1	37.9	8.7	6.4	187.7	139.1
Integrated	40.0	38.4	9.0	6.7	194.5	145.5
SE(m) ±	1.34	1.54	0.28	0.07	6.48	5.06
CD (0.05)	NS	NS	NS	NS	NS	NS
Initial	38.8	38.2	7.8	6.1	148.3	140.8

summer) for the 4th year in succession resulted in maximum elevation in SOC and the increase was by 46.8 and 46.5 percent over the initial content of 7.8 and 6.1 g/kg and by 61.0 and 67.4 percent over CT-CT-F system in the top two layers (0-5 and 5-10 cm). The CT-CT-F practice, in contrast, exhibited a declining trend registering a decrease of 8.8 and 12.4 percent over the initial values for the corresponding layers. Adoption of ZT-ZT-ZT+R (residue) with H+MW+HW (weed management) resulted in maximum build-up of SOC in top two layers (12.1 and 10.0 g/kg). The elevation of SOC among various tillage systems was in the order, ZT-ZT-ZT+R > ZT-ZT-ZT> CT-ZT-ZT> CT-CT-ZT. The tillage management techniques did not show any effects on the organic carbon content within the soil. The MBC under conservation agriculture system increased conspicuously in the top few centimeters of the surface layer and reduction in tillage with residue retention elevated it much more rapidly. Long term practice of ZT-ZT-ZT system increased MBC of soil by 64 and 59 percent over the initial values of 148.3 and 110.3 µg C/g of soil in the top two layers (0 -5 and 5 -10 cm). Continuous practice of CT-CT-F system declined the MBC marginally to 144.4 and 109.2 µg C/g of soil in the corresponding layers. Previously, studies have also reported a notable increase in SOM concentrations when soil inversion is not present (28, 29). Adoption of ZT-ZT-ZT+R practices with H+MW+HW weed management practice resulted in the highest MBC content in the top two layers (272.0 and 228.7 µg C/g of soil). The elevation of MBC among various tillage systems was in the order of ZT-ZT-ZT+R > ZT-ZT-ZT > CT-ZT-ZT > CT-CT-ZT. Continuous deposition of surface litter in ZT-ZT-ZT and ZT-ZT-ZT+R systems with crop residues has been shown to significantly increase SOM content. This is due to the presence of crop residues, which contribute to the positive effect of crop residues. The soil MBC, which accounts for 1-5 % of SOC, also changes in response to tillage management. The higher concentrations of microbial population in surface layers under ZT systems are responsible for elevated MBC contents compared to CT soils. The formerly integrated TOC inside CT soils (CT-CT-F) was exposed to microbial degradation in the upper 10 cm of the soil surface due to intense ploughing operations (30). The high SOC near the surface under ZT is maintained or even enrichment continues, while low MBC in deeper layers is related to a decline in SOM contents. Intense tillage operations in CT soils expose the formerly incorporated TOC to microbial decomposition in the top 10 cm of the soil surface. Thus, to improve soil quality by renewing soil health, more CA (conservation agriculture)-based farming methods would be sought (31). Gradual improvements in soil health (32) and increased soil fertility (33) are near our current research.

Economics

In terms of agricultural establishment procedures, the net returns and B:C ratio were highest in CT (DSR)-CT-ZT, followed by

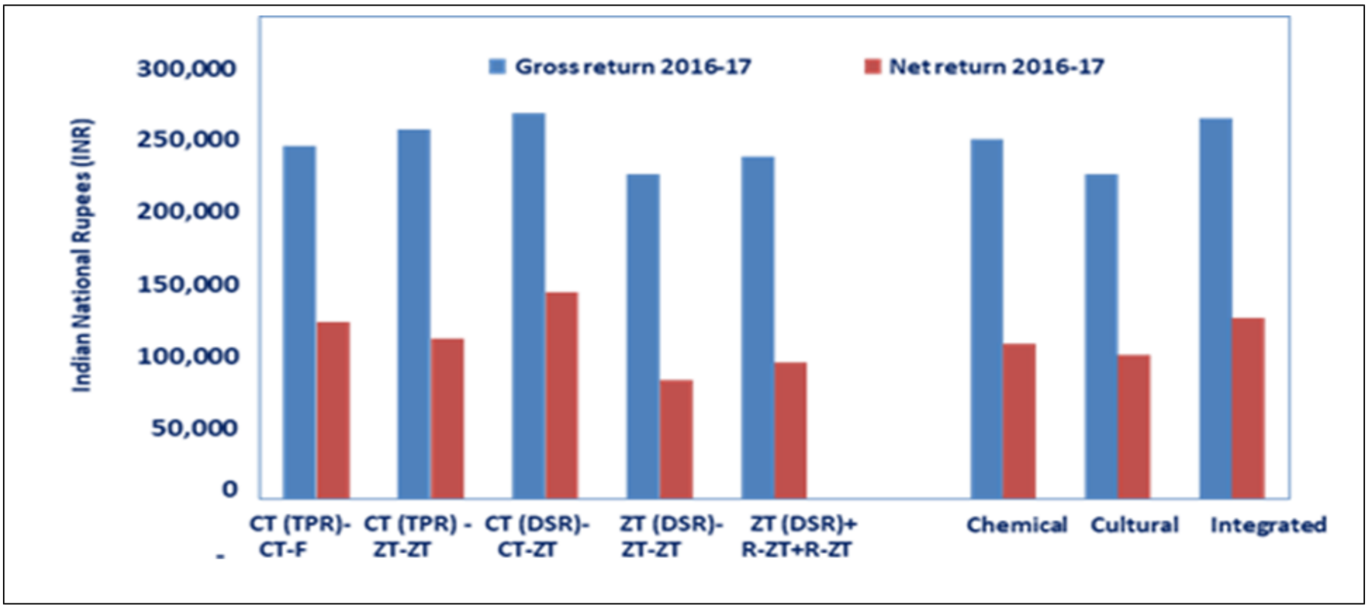

Fig. 4. Effect of conservation tillage and weed management on economics yield of rice-maize-cowpea system (2016-17).

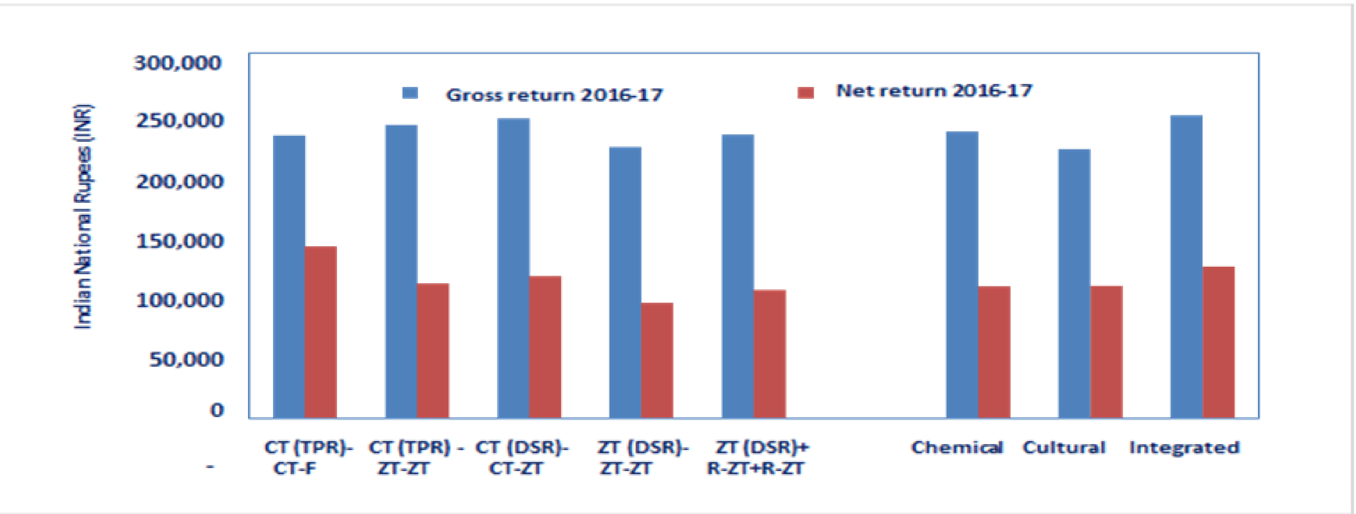

Fig. 5. Effect of conservation tillage and weed management on economics yield of rice-maize-cowpea system (2017-18).

CT (TPR)-ZT-ZT and the lowest when ZT practice was followed for all the component crops (Fig. 4 & 5). This was owing to the fact that the crops yielded better when they were produced under CT. The profitability under TPR has experienced decline due to extensive water usage combined with labour expenses and intensive labour needs (34). The direct seeding technique combined with dry and wet methods avoids nursery cultivation, seedling extraction, puddling and transplanting procedures, thus lowering labour consumption. The findings of (35) showed that while the DSR's yield was comparable to or marginally lower than PTR's, its EUE and EP were higher because it required less energy. The DSR practice in rice-wheat systems with CT has been reported to produce higher REY and net returns than minimum or ZT (36, 37). Among ZT treatments, the B:C ratio was on the higher side with residue retention because of better yield. The IWM practice generated greater revenue through higher net returns and better B:C ratio because it achieved better weed management coupled with elevated system yield. The combination of herbicides with cultural practices used sequentially to control weeds provided the most profitable and sustainable solution for rice-based cropping systems (38). The cost of using potential weed control herbicides during DSR operations remains at least five times lower than what hand weeding would cost (39).

Conclusion

Direct seeded rice under CT practice followed by conventional tilled maize and zero tilled cow pea (CT (DSR)-CT-ZT) in combination with IWM practices comprising of recommended H+MW+HW in a system approach with maximum system yield of 14.58 t REY/ha, net returns of Rs. 164611/ha, B:C of 2.48 and SYI of 0.72 is the most productive, remunerative and sustainable approach for rice based system. Improvements in soil quality parameters under ZT systems, particularly with crop residues, i.e., (ZT (DSR) + R)-(ZT+R)-ZT, have a long- term potential for improving productivity and system sustainability. The future feature of this work comprises residue analysis of the new molecule chemical for weeding under various rice setups for the coastal ecosystem along with the possible outcome towards ecosystem services.

Authors' contributions

SP[1] carried out the research work and lab analysis, participated in the sequence alignment and drafted the manuscript. LMG participated in the design of the study. NH & RDB performed the statistical analysis. RD conceived the study and participated in its design and coordination. PKB has collected the reviews. SD and SP[2] have arranged the drafting of overall writing and set the references. SH & SRB have helped in obtaining lab reports of soil data. SR, SP[3], RG and MK have helped in improving the overall flow of the writing and in designing graphs and figures. All authors read and approved the final manuscript. (SP[1] stands for S Pradhan; SP[2] stands for S Priyadarshini; SP[3] stands for S Pandey)

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used the Grammarly Tool to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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