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RESEARCH ARTICLE

Weed suppression and productivity influenced under conservation agriculture and organic weed management practices in rice-maize rotation

Subhra Sahoo[1], Dhirendra Kumar Roy[1], Sumit Sow[1*], Shivani Ranjan[1], Souvik Sadhu[2] and Parmeswar Dayal[3]

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ABSTRACT

Weeds pose a significant threat to crop productivity, and ineffective management can exacerbate the issue. Therefore, it is crucial to reduce weed severity to maintain and enhance crop productivity. With this aim, a field study was conducted at Dr. Rajendra Prasad Central Agricultural University to evaluate the impact of organic weed management (OWM) on the weed dynamics and yield of rice–maize rotation under conservation agriculture. Four tillage practices as main plots and five OWM treatments as subplots arranged in split-plot design with three replications. The tillage management treatments included ZTR *fb* ZTM: zero-tillage (ZT) direct-seeded rice (DSR) followed by (*fb*) ZT-maize, PBDSR+R *fb* PBDSM+R: DSR *fb* maize both in permanent bed (PB) with residue retention, PBDSR-R *fb* PBDSM-R: DSR *fb* maize both in PB without residue retention and CTR *fb* CTM: conventionally tilled rice *fb* maize. In OWM, five treatments were as follows: UWC: unweeded check, VM: vermicompost mulching, PVM: phosphorous (P) enriched VM, LM: live-mulch of *Sesbania* spp. in rice and *Pisum sativum* in maize, WFC: weed-free check. PBDSR+R *fb* PBDSM+R recorded significantly lowest weed biomass and highest weed control efficiency over other treatments in both the years. Except weed free treatment, LM reported significantly higher yield attributes and grain yield of rice and maize over other OWM practices across the two years of study. The PBDSR+R *fb* PBDSM+R recorded significantly highest grain yield of rice (6.3, 6.6 t/ha) and maize (9.3, 9.4 t/ha) throughout the study. The study revealed that residue incorporation under rice–maize rotation with permanent bed system along with LM improved the weed control efficiency, yield attributes and yield.

Keywords: Conservation tillage, Maize, Organic weed management, Permanent bed, Residue, Rice, Weed control efficiency

INTRODUCTION

Rice-based cropping systems are prevalent in the Eastern regions of India. However, in continuous intensive tillage and chemical weed management systems, yield and productivity of rice-maize rotation is declining consistently (Roy *et al*. 2023). This decline is associated with the deterioration of soil physicochemical properties and a increase in weed density. Furthermore, weeds pose a significant challenge to rice (*Oryza sativa* L.) and maize (*Zea mays* L.) production, leading to a considerable decrease in crop yield ranging from 24 to 65% . In Eastern India specifically, the yield loss is even more pronounced, falling within the range of 32 to 46% (Duary *et al*. 2021). Recently, most crop producers have transitioned to herbicide-based weed management strategies due to their effectiveness, ease of use, and reduced manpower requirements compared to traditional cultural and mechanical methods. However, relying solely on herbicides for weed control can create herbicide selection pressure, leading to the emergence of herbicide-resistant weed species (Kumar *et al*. 2023). Low-input or organic production systems offer an alternative to conventional methods for addressing current challenges in crop production in Eastern India. These systems reduce reliance on synthetic external inputs, instead depending on ecological and natural processes to maintain crop productivity and ensure crop protection.

To address the issue of climate change, soil health degradation, and challenges related to water, energy, and labor shortages in rice-based cropping system, the adoption of conservation agriculture (CA) practices, notably zero tillage (ZT), no-tillage (NT), and minimum tillage (MT) can be a viable solution (Alhammad *et al*. 2023). The global acceptance and popularity of CA have grown

[1] Department of Agronomy, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar 848125, India

[2] Department of Soil Science and Agricultural Chemistry, Bihar Agricultural University, Sabour, Bihar 813210, India

[3] Division of Agronomy, ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi 110012, India

* Corresponding author email: sumitsow19@gmail.com

significantly in recent years. Several studies suggest that ZT not only contributes to reduced fuel consumption but also results in lower production costs and higher net income as compared to conventional tillage (CT) (Stanzen *et al*. 2017). Studies have shown that the adoption of ZT coupled with crop residue retention decreased weed biomass and enhance yields compared to CT across various crops (Ghosh *et al*. 2022). Traditional tillage practices expose old and dormant weed seeds to suitable light and ambient climatic conditions, promoting their germination and contributing to a higher weed population (Dayal *et al*. 2023). Conversely, CA practices often create conditions unfavorable for weed germination, effectively reducing weed populations (Travlos *et al*. 2020).

To address the limitations of an intensive herbicide system, conventional farmers are now turning to organic production methods, necessitating a grasp of fundamental organic farming principles. Organic weed management (OWM) has emerged as a practice that integrates traditional approaches with modern innovation and science. Its significance has grown in response to the escalating demand for alternative, healthy food sources, while also prioritizing soil health and ecosystem conservation (Herzog *et al*. 2019). OWM emphasizes key components of effective weed management, incorporating cultural and mechanical methods such as mulching, crop residue utilization, and the application of compost extracts (Mhlanga *et al*. 2015). Mulching, in particular, has proven to be a dependable method for managing the agroecosystem, simultaneously addressing environmental concerns associated with weed management (Rhioui *et al*. 2023). Retaining crop residues of live plant as mulch can inhibit weed germination and establishment and contributes to enhanced crop productivity (Choudhary 2023). While vermicompost is recognized for enhancing soil organic matter decomposition, improving soil structure, and enhancing aeration and moisture retention (Rehman *et al*. 2023), it has been observed that using vermicompost as mulch effectively controls weeds. Additionally, this practice enriches the soil with nutrients, ensuring sustained crop yield without compromising soil health (Ganguly *et al*. 2022).

Weed dynamics can vary significantly under different tillage and crop establishment systems due to the complex interactions between weeds and tillage practices. To address these challenges, CA-based sustainable intensification of the rice-maize system utilizing ZT, surface residue retention, and use of organic sources along with inorganic source of nutrients has been identified as an effective approach. However, very few research data are available on the dynamics of major weeds under CA systems with OWM practices. The hypothesis proposed that CA based practices, mulching through organic amendment and live plant could be employed to suppress weeds and enhance productivity. Consequently, this study aimed to investigate the effects of tillage combined with crop residue mulching on soil surface coverage, weed suppression, crop productivity, and the weed seed bank within a maize-rapeseed cropping system. Keeping all the above facts in view, an attempt was made to compare the effect of CT and CA based crop establishment with OWM practices on weed dynamics, and yield of rice-maize in Eastern India.

MATERIALS AND METHODS

The field experiment was conducted for two years during the summer and winter seasons of 2019-20 and 2020-21 at the Crop Research Centre of Dr. Rajendra Prasad Central Agricultural University (20º 58' 49.0'' N latitude, 85º 40' 33.41'' E longitudes, at an altitude of 173 m above the mean sea level), Pusa, Bihar, India. The climate of the experimental site is characterized by a hot sub-humid eco-region that experiences cold and dry winters and hot and humid summers. This investigation is consisted of four main treatments and five sub-treatments in a split-plot design with three replications. The main plot treatments consisted of zero-tillage direct seeded rice and zero-tillage maize (ZTR *fb* ZTM); ZTDSR and maize both on permanent raised beds with residue retention (PBDSR+R *fb* PBDSM+R); PBDSR and PBM without residue retention (PBDSR-R *fb* PBDSM-R) and conventional tillage puddled transplanted rice and conventional tillage maize (CTR *fb* CTM). 50 % rice residue retention for maize, 25% maize residue retained on the soil surface for rice in PB and ZT treatments. All the remaining 50% rice and 75% maize residues were utilized as fodder for cattle. The subplots comprised unweeded control (UC); vermicompost mulch (VM) at the rate of 5 t/ha before sowing/transplanting; P- enriched vermicompost mulch (PVM) at the rate of 5 t/ha before sowing/ transplanting; live mulch (LM) with *Sesbania* spp. in rice and *Pisum sativum* in maize and weed-free (WF). In LM treatment, seeds of *Sesbania* spp. and *Pisum sativum* were broadcast at a seeding rate of 40 kg/ha. After 30 days of live mulching, the mulched plants were turned down on the soil and left as mulch cover. The nutrient content of the *Sesbania* spp. used in the experiment was 3.5% N, 0.6% P, and 1.2% K, while *Pisum sativum* contained 0.9% N, 0.3% P, and 0.4% K. Furthermore, the physicochemical composition of the vermicompost was 2.21, 1.11, and 1.25% N, P, and K, respectively whereas in P-enriched vermicompost it was 2.30, 1.23, and 1.37% N, P and K, respectively.

The study was conducted on a gross plot size of 7.0 × 3.6 m with a net plot size of 6.0 × 2.6 m during each year in the same plot. Rice cv. Rajendra Mahsuri was sown with seed rates of 25 kg/ha, 20 kg/ha and 12 kg/ha under ZTR, PBDSR, and conventional treatments, respectively. Winter maize cv. DKC 9081 was sown with a uniform seed rate of 25 kg/ha in all the treatments. ZT and PB rice was sown on June 8, 2019, and June 3, 2020, and harvested on November 23, 2019, and November 15, 2020, respectively. In contrast, CT rice was sown on June 30, 2019, and June 27, 2020, and harvested on November 25, 2019, and November 18, 2020. Whereas, maize crops were sown on December 5, 2019, and November 27, 2020, and harvested on May 22, 2020, and May 7, 2021. During the growing season, monsoon rice received a dose of N: P: K: Zn - 150: 26: 17.5: 10 kg/ha and winter maize received a dose of N: P: K: Zn-200:35:26:10 kg/ha. During both years, 50% N and whole P, K, and Zn were applied as basal fertilizer using di-ammonium phosphate, muriate of potash, and zinc sulphate heptahydrate applied with seed cum-fertilizer drills. During tillering and panicle initiation in rice and V5 and VT phases in maize, the remaining N was applied as urea in two equal splits. Weed biomass of total weeds was taken by placing a quadrat of 50 × 50 cm (0.25 m^2) randomly in the sampling area. At 30 days after sowing (DAS), the weeds were uprooted, cleaned by washing, placed in sunlight for few hours and were kept in a hot air oven for drying at 70 °C for 72 hours or more till constant weights were recorded. Weed control efficiency (WCE) (%) was then computed based on weed density as formulated by Mani *et al.* (1973):

Weed control efficiency (%) =(WDc - WDt)/WDc×100

Where, WDc is weed density of unweeded control

WDt is weed density in the treated plot under consideration

The weed index (WI) (%), otherwise known as the weed competition index, is the yield reduction caused by the presence of weeds relative to the weed-free plot. The formula was used to compute the weed index as given by Gill and Vijaykumar (1969):

Weed Index (WI) (%) = (Ww - Wt)/Ww×100

Where, Ww is the grain yield of a weed-free plot

Wt is grain yield from the treated plot

Ten random plants were selected plants for measurements of all yield attributes of rice-maize rotation. Grain yields (t/ha) were assessed from a 10 m^2 sampling area at the center of each subplot. Grain yield was recorded at 14% moisture content.

The weed biomass data underwent a square root transformation, and the transformed data were employed for analysis. The statistical analysis was conducted using R-3.6.3, employing a split plot design at a significance level of 5%. as given by Gomez and Gomez (1984).

RESULT AND DISCUSSION

Weed flora and biomass

During two years of study, the experimental field was infested with *Dinebra retroflexa* (Vahl.), *Cyperus rotundus* (L.) *Digitaria sanguinalis* (L.) Scop., *Echinochloa colona* (L.) Link., *Eclipta alba* (L.), *Gnaphalium indicum* (L.), *Polygonum plebeium* R.Br., *Solanum nigrum* (L.) and *Sphaeranthus indicus* (L.) as major weeds. However, *Convolvulus arvensis* (L.), *Alternanthera sessilis* (L.) and *Eleusine indica* (L.) also recorded as minor weeds under rice-maize rotation.

Among the tillage and residue management methods, significantly lower weed biomass (2.8, 2.5 g/m^2 average of two years) was recorded in with PBDSR-R *fb* PBDSM-R in both rice and wheat, respectively (**Figure 1**). This might be because of residue retention in PB that significantly suppressed the weed seed germination and emergence in PBDSR-R *fb* PBDSM-R, which ultimately resulted in lower weed biomass. Choudhary and Sharma (2023), Ghosh *et al.* (2022) also observed reduction in total weed density and biomass under CA-based practices. Weed free treatment recorded minimum weed biomass but LM practices recorded significantly lower weed biomass of 2.7 and 2.3 g/m^2 over the others OWM practices during both the years of experimentation. This might be due to better weed control by live mulching that favoured crop growth, which resulted in quick coverage of ground and more shading affect by crop thereby reducing growth of weeds. Moreover, mulching smothers weeds by blocking light and creating a physical barrier that prevents their germination and emergence (Bahadur *et al.* 2015, Jaiswal *et al.* 2023).

Weed control indices

The WCE differed according to treatments during the study period (**Table 1**). Among the various residue and tillage management practices in rice, the

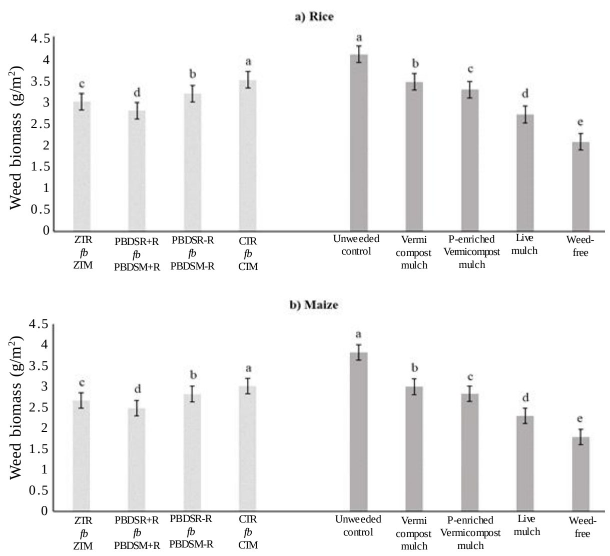

Figure 1. Weed biomass (g/m^2) at 30 DAS (combined data of 2 years) of rice (a) and maize (b) as affected by tillage, residue, and organic weed management practices. Treatment means followed by the unlike lower-case letters are significantly diverse at $\sqrt{x+0.5}$ levels of significance as per Duncan's multiple range test.

PBDSR+R *fb* PBDSM+R showed 2.5 and 4.8% higher WCE relative to CTR *fb* CTM across the years respectively but the lowest WCE was recorded with PBDSR-R *fb* PBDSM-R. Whereas, in the case of maize during 2019-20 highest WCE was obtained with ZTR *fb* ZTM but during 2020-21 maximum WCE was recorded with PBDSR+R *fb* PBDSM+R. Likewise in maize, CTR *fb* CTM recorded 7.4 and 10.7% lower WCE relative to PBDSR+R *fb* PBDSM+R during 2019-20 and 2020-21 respectively. Apart from weed-free treatment, the highest WCE was found with live mulch in rice, which was 52.5 and 54.6% more relative to P-enriched vermicompost mulch across the years respectively. A similar was witnessed in maize.

WI was found maximum with CTR *fb* CTM in rice-maize rotation. However, during the first year (2019) of rice, ZTR *fb* ZTM recorded minimum WI but in the second year (2020) minimum WI was observed in PBDSR+R *fb* PBDSM+R treatment. Across the years of field experiments in maize, the minimum weed index was recorded with PBDSR+R *fb* PBDSM+R (2.17 and 2.04, respectively) (**Table 1**). Under various organic weed management regimes in rice-maize rotations, WI was found highest in unweeded control for both years of the experiment. Live mulch recorded 75.2 and 58.5% lower WI than vermicompost mulch in rice for 2019 and 2020 respectively. Additionally in maize, the live mulch recorded 96.9, 83.5 and 66.3% lower WI relative to unweeded control, vermicompost mulch, and P-enriched vermicompost mulch treatment respectively during the 2019-20. A similar trend was witnessed in the second year (2020-21) in maize.

This results proved that tillage exposes weed seed on the upper layer of the soil and enable seedlings to emerge from deeper in the soil, which may account for a higher weed population than un-tilled soil (Alhammad *et al.* 2023). Choudhary and Sharma (2023) also noted the highest WCE in ZT+R than CT. In our experiments, different organic weed management strategies were tested, among them *Sesbania* and *Pisum* as live mulch were able to provide, within a short period, a long-lasting soil cover (Mishra *et al*. 2022). Similar findings were consistent with Chetan *et al.* (2023).

Table 1. Weed control indices in rice-maize rotation in response to tillage and residue management practices and organic weed management in rice-maize rotation

Treatment	WCE (%)		WI (%)		WCE (%)		WI (%)	
	2020	2021	2020	2021	2019-20	2020-21	2019-20	2020-21
Tillage and residue management								
ZTR *fb* ZTM	46.27	47.87	14.81	16.77	37.69	38.00	4.06	3.39
PBDSR+R *fb* PBDSM+R	46.87	49.90	15.97	15.77	36.79	38.74	2.17	2.04
PBDSR-R *fb* PBDSM-R	43.05	45.75	15.58	17.85	34.90	35.20	4.45	4.04
CTR *fb* CTM	42.97	46.03	19.05	21.84	31.96	32.08	4.69	4.93
LSD (p=0.05)	-	-	-	-	-	-	-	-
Organic weed management								
Unweeded control	0.00	0.00	53.94	53.13	0.00	0.00	49.26	48.08
Vermicompost mulch	27.81	29.92	17.24	16.62	28.85	29.15	9.29	8.60
P- enriched Vermicompost mulch	35.53	38.54	6.30	13.65	37.56	37.67	4.55	4.08
Live mulch	47.79	51.23	4.27	6.89	50.15	51.37	1.53	1.73
Weed-free	68.03	69.87	0.00	0.00	60.12	61.83	0.00	0.00
LSD (p=0.05)	-	-	-	-	-	-	-	-

ZTR-Zero tillage rice followed by zero tillage maize; PBDSR+R *fb* PBDSM+R- DSR *fb* maize both in permanent bed (PB) with residue retention; PBDSR-R *fb* PBDSM-R-DSR *fb* maize both in PB without residue retention; CTR *fb* CTM- Conventionally tilled rice *fb* maize

Crop yield attributes and yield

Rice: Tillage, residue, and weed management had a substantial influence on yield characteristics and yield of rice over the two-year experimental period (**Table 2**). The PBDSR+R *fb* PBDSM+R treatment consistently had the highest number of panicles/m^2, with values of 404.8 and 430.7 throughout the two years. Among the various organic weed management strategies, weed-free treatment had the utmost number of panicles/m^2 in 2019 and 2020, which was statistically at par with the application of live mulch. Similarly, panicle length, panicle weight, number of filled grains/panicle, and test weight were uppermost in PBDSR+R *fb* PBDSM+R and minimum in CTR *fb* CTM. Additionally, in weed management treatments, the number of filled grains/panicle was recorded maximum *i.e.* 114.3 and 118.8 with weed-free treatment and was statistically the same with live mulch during both years respectively. A similar trend was observed in panicle weight, panicle length, and test weight for both years. In a long term application of CA practices with integrated weed management practices resulted in higher yield attributes in rice under the PB with legume residue than no-residue, and this might be due to better soil health and microenvironment created by the continuous adoption of these resources conserving practice (Kumar *et al.* 2024, Ganapathi *et al.* 2023).

Moreover, the maximum grain yield of 6.36, 6.60 t/ha during the both the years respectively was achieved in PBDSR+R *fb* PBDSM+R (**Table 2**). The findings of Kumar *et al.* (2023) and Roy *et al.* (2023) are also in agreement with it. Amongst the weed management options, unweeded treatment recorded the minimum grain yield during both years. The weed-free treatment showed highest grain yield among weed management strategies and was statistically similar with live mulch. Furthermore, the live mulch had 16.0 and 12.3% greater grain yield than vermicompost mulch respectively. This might be due to lower crop weed competition for growth resources throughout the crop growing period enabling the crop for maximum utilization of nutrients, moisture, light and space, which enhanced the vegetative and reproductive potential of the crop (Stanzen *et al.* 2017).

Maize: Yield attributes and yield of maize were affected by tillage and organic weed management strategies across the years. The result revealed that cob circumference, cob length, and cob weight were found to be maximum with bed planting of rice with retention of crop residues (PBDSR+R *fb* PBDSM+R) and was statistically the same with ZTR *fb* ZTM and PBDSR-R *fb* PBDSM-R during both years of study. During the first year of the experiment, the number of grains/cob, the weight of grains/cob and test weight was recorded maximum in PBDSR+R *fb* PBDSM+R *i.e.* 462.8, 65.9g, and 28.57g which was 9.3, 7.0 and 5.8% higher than PBDSR-R *fb* PBDSM-R respectively (**Table 3**). The CTR *fb* CTM recorded 11.0, 16.5, and 9.8% lower weight of grains/cob, number of grains/cob, and test weight in comparison to PBDSR+R *fb* PBDSM+R respectively during the year 2020-21. ZT and PB which improves the physical and chemical qualities of the soil, that may greatly impact on root development, is likely to give similar or even higher yield attributes than CT. These findings were in agreement with Dayal *et al.* (2023) and Parihar *et al.* (2016).

Table 2. Yield attributes and grain yield of rice as affected by tillage, residue, and organic weed management in rice

Treatment	No. of panicles/m^2		Panicle length (cm)		No. of filled grains/panicle		Test weight (g)		Grain yield (t/ha)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Tillage and residue management (T)										
ZTR *fb* ZTM	392.7^{a}	416.9^{a}	23.6^{a}	24.2^{ab}	101.7^{a}	104.4^{a}	21.13^{b}	21.50^{b}	5.70^{b}	6.18^{b}
PBDSR+R *fb* PBDSM+R	404.8^{a}	430.7^{a}	24.2^{a}	25.3^{a}	107.4^{a}	110.3^{a}	22.99^{a}	23.30^{a}	6.36^{a}	6.60^{a}
PBDSR-R *fb* PBDSM-R	372.1^{a}	403.7^{a}	22.6^{a}	23.2^{b}	88.2^{b}	90.4^{b}	20.73^{bc}	21.17^{bc}	5.52^{b}	5.74^{c}
CTR *fb* CTM	332.5^{b}	346.0^{b}	19.6^{b}	20.2^{c}	78.5^{c}	80.5^{c}	19.74^{c}	20.04^{c}	4.90^{c}	4.76^{d}
LSD (p=0.05)	34.5	32.9	2.1	1.4	9.3	9.1	1.12	1.37	0.43	0.38
Organic weed management (W)										
Unweeded control	240.6^{d}	256.3^{c}	17.3^{d}	17.8^{c}	63.5^{d}	63.8^{d}	19.71^{b}	20.06^{d}	3.08^{d}	3.31^{d}
Vermicompost mulch	381.5^{c}	400.6^{b}	21.1^{c}	22.2^{b}	90.6^{c}	94.6^{c}	21.10^{a}	21.15^{bcd}	5.56^{c}	5.92^{c}
P- enriched Vermicompost mulch	398.1^{bc}	416.1^{b}	23.0^{b}	23.9^{b}	96.6^{c}	97.2^{c}	21.23^{a}	21.57^{ac}	6.31^{b}	6.14^{c}
Live mulch	424.2^{ab}	458.8^{a}	25.0^{a}	25.5^{a}	104.7^{b}	107.5^{b}	21.68^{a}	22.26^{ab}	6.45^{ab}	6.65^{b}
Weed-free	433.2^{a}	464.8^{a}	26.2^{a}	26.9^{a}	114.3^{a}	118.8^{a}	22.02^{a}	22.48^{a}	6.71^{a}	7.09^{a}
LSD (p=0.05)	28.7	27.4	1.7	1.6	8.0	7.6	0.93	1.14	0.36	0.31
T×W										
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	S	S

Treatment means followed by the unlike lower-case letters are significantly diverse at $\sqrt{x+0.5}$ levels of significance as per Duncan's multiple range test, NS: non-significant, S: significant

In weed management practices, the weed-free treatment showed the highest cob length (19.61 cm), cob circumference (18.15 cm), and cob weight (159.8 cm) which was on par with live mulch in the year 2019-20. Similarly, in the second year 40.1, 16.8 and 10.2 % higher cob length, cob circumference, and cob weight were found in weed-free treatment than in unweeded control, vermicompost mulch, and P-enriched vermicompost mulch respectively. Additionally, the weight of grains/cob, the number of grains/cob, and test weight were found highest in weed-free treatment. Among the other treatments except for weed-free, was found highest with the application of live mulch which recorded 105.4, 39.0, and 31.1 % higher weight of grains/cob, number of grains/cob, and test weight in the first year and 38.1, 106 and 31% in the second year relative to unweeded control respectively (**Table 3**).

Among tillage and residue management practices, CTR *fb* CTM recorded lowest grain yield of 7.95, 8.04 t/ha during the two years of study respectively; whereas, PBDSR+R *fb* PBDSM+R which showed maximum grain yield of 9.30, 9.43 t/ha respectively. The ZTR *fb* ZTM showed 11.3, 12.2% higher grain yield than CTR *fb* CTM and was on par with PBDSR+R *fb* PBDSM+R (**Table 3**). The lowest grain yield was found with unweeded control and maximum in weed-free treatment. The weed-free treatment recorded grain yield of 9.80 and 9.90 t/ha respectivly but was found statistically similar to P-enriched vermicompost mulch and live mulch. The findings of this study showed the paybacks of shifting from flats to permanent bed systems coupled with residue retention. This might be due to low weed density during the initial crop growth stage (30 DAS) in these treatments. Conventional and zero tillage treatments with residue retention resulted in higher values of yield attributes. This could be due to sustaining optimum soil moisture, improved nutrient availability, and moderate soil temperature. The raised bed may have led to effective control of irrigation and drainage, reducing the short-term temporary aeration stress under high rainfall conditions. The higher yield attributes in weed-free could be accredited to increased soil temperature, effective weed control, and better soil moisture conservation (Dayal *et al.* 2023) The lower grains per cob in the unweeded control may be ascribed to increased interspecific competition and weed infestation. Similarly, a field experiment conducted at Ludhiana (India), found about 25% higher grain yield with a PB planting of maize than flat sowing (Kaur and Mahey 2012). Straw mulch increases soil moisture storage and productivity (Verma and Acharya 2004, Jaiswal *et al.* 2023). Higher soil water content improves yield with mulching (Paswan *et al.* 2023).

In the second year of maize, grain yield had a negative correlation (R^2=-0.87) with weed biomass (**Figure 2**). The yield attributes of maize were significantly positively corelated with grain yield. Whereas, higher weed biomass resulted in lower yield as yield attributes were negetavively corelated with weed biomass. Chauhan and Opena (2013) also noted a direct association between weed biomass and rice grain yield at harvest under direct-seeded conditions. This showed that effective and timely weed management through the OWM practices reduced the weed dry matter accumulation of various weed

Table 3. Yield attributes and grain yield of maize as influenced by tillage, residue, and organic weed management in maize

Treatment	Cob length (cm)		Cob weight (g)		Cob circumference (cm)		No. of grains/ cob		Weight of grains/cob (g)		Test weight (g)		Grain yield (t/ha)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Tillage and residue management (T)														
ZTR *fb* ZTM	18.32^{ab}	18.45^{ab}	146.8^{ab}	148.6^{a}	15.75^{ab}	16.04^{ab}	444.9^{ab}	453.2^{ab}	64.0a^{b}	64.5a^{b}	27.35a^{b}	28.51a^{b}	8.85^{a}	9.02^{a}
PBDSR+R *fb* PBDSM+R	18.89^{a}	19.15^{a}	151.1^{a}	152.2^{a}	16.24^{a}	16.54^{a}	462.8^{a}	470.5^{a}	65.9^{a}	66.7^{a}	28.57^{a}	29.78^{a}	9.30^{a}	9.43^{a}
PBDSR-R *fb* PBDSM-R	17.59^{ab}	17.86^{abc}	137.5^{bc}	138.8^{b}	14.91^{bc}	15.25^{b}	423.4^{b}	431.5^{b}	61.6a^{bc}	61.9^{bc}	26.99^{abc}	28.14^{abc}	8.08^{b}	8.19^{b}
CTR *fb* CTM	16.64^{c}	16.81^{c}	135.5^{c}	137.0^{b}	13.94^{c}	14.16^{c}	385.5^{c}	392.7^{c}	58.2^{c}	59.3^{c}	25.77^{c}	26.86b^{c}	7.95^{b}	8.04^{b}
LSD (p=0.05)	1.3	1.4	10.6	9.1	0.97	0.91	28.7	27.6	4.6	4.2	1.73	1.80	0.64	0.57
Organic weed management (W)														
Unweeded control	14.03^{d}	14.22^{d}	114.0^{c}	112.8^{d}	11.61^{d}	11.83^{d}	339.5^{d}	346.3^{d}	36.6^{d}	36.9^{d}	22.30^{d}	23.25^{d}	5.00^{d}	5.17^{d}
Vermicompost mulch	17.72^{c}	17.93^{c}	136.8^{b}	138.3^{c}	13.04^{c}	13.29^{c}	413.6^{c}	421.5^{c}	57.9^{c}	58.6^{c}	26.17^{c}	27.28^{c}	8.90^{c}	9.06^{c}
P-enriched vermicompost mulch	18.47^{bc}	18.68^{abc}	145.0^{b}	148.0^{b}	15.86^{b}	16.16^{b}	437.6^{b}	445.9^{b}	63.8^{b}	64.8^{b}	27.85^{b}	29.03^{b}	9.36^{abc}	9.49^{abc}
Live mulch	19.49^{ab}	19.71^{ab}	158.0^{a}	159.4^{a}	17.39^{a}	17.73^{a}	471.8^{a}	478.4^{a}	75.2^{a}	76.0^{a}	29.24^{ab}	30.48^{ab}	9.66^{ab}	9.73^{ab}
Weed-free	19.61^{a}	19.80^{a}	159.8^{a}	162.3^{a}	18.15^{a}	18.48^{a}	483.4^{a}	492.8^{a}	78.7^{a}	79.3^{a}	30.30^{a}	31.59^{a}	9.80^{a}	9.90^{a}
LSD (p=0.05)	1.1	1.2	8.8	7.6	0.81	0.76	23.9	22.9	3.8	3.5	1.44	1.50	0.53	0.48
T×W														
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment means followed by the unlike lower-case letters are significantly diverse at $\sqrt{x+0.5}$ levels of significance as per Duncan's multiple range test, NS: non-significant, S: significant

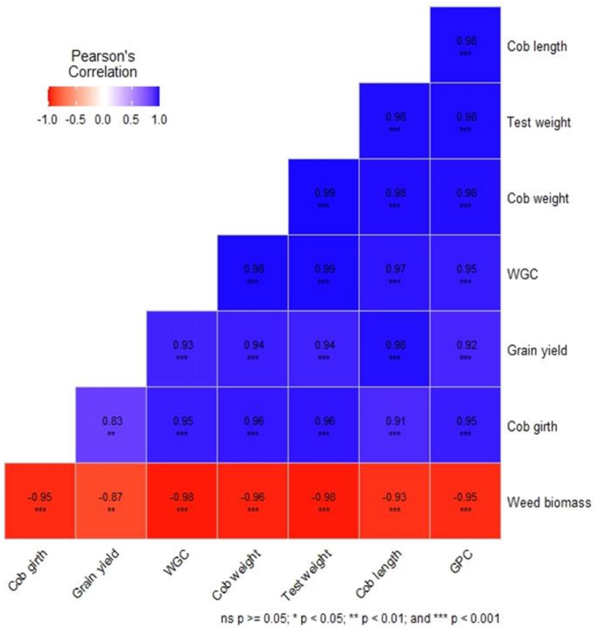

Figure 2. Pearson's correlation of yield attributes, grain yield, and weed biomass, across the years (mean of 2 years), as augmented by different residue, tillage, and weed management methods in maize. GPC (grains per cob); WGC (weight of grains per cob)

species throughout the crop's life cycle, as well as the competition for nutrients, moisture, light and space, resulting in higher grain yield. Similar observations on integrated weed management were also reported by Kaur and Singh (2019), Jain *et al.* (2022).

Conclusion

It is evident from the results that CA practices reduced weed biomass during the two years of experimentation. Live mulch and P-enriched vermicompost suppressed the emergence of weeds. Moreover, PBDSR+R *fb* PBDSM+R with live mulch practices had significant importance in achieving higher WCE and WI in both of the crops. PB and OWM practices in rice-maize rotation under conservation agriculture, realised higher grain yield besides managing agro-ecosystem for improved and sustained productivity than other tillage and weed management practices. Thus, PBDSR+R *fb* PBDSM+R with live mulching may be an effective weed management option for rice-maize rotation in Eastern India.

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