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RESEARCH ARTICLE

Brown manuring in conservation agriculture based maize-wheat-greengram cropping system: Effects on weed flora, crop yield, and profitability of maize

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ABSTRACT

An experiment was conducted at the ICAR-Indian Agricultural Research Institute, New Delhi, during 2021 and 2022 to evaluate the efficacy of brown manuring (BM) using *Sesbania* plants in controlling weeds and improving productivity in conservation agriculture-based maize. Treatments included conventional tillage maize (CT-M), conventional tillage maize with green manure from preceding greengram (CT-M+GM), zero tillage maize with residue retention at 3 t/ha (ZT-M+R), and zero tillage maize with *Sesbania* co-culture as brown manuring (ZT-M+BM), combined with five weed control treatments *viz* unweeded check (UWC), pre (atrazine + pendimethalin 750 g/ha, each) + 1 hand weeding (30 DAS), pre (atrazine + pendimethalin 750 g/ha, each) + post (tembotrione) 120 g/ha, pre (atrazine + pendimethalin 750 g/ha, each) + post (pre-mix of mesotrione + atrazine) 120 g/ha, weed free check in sub-plots. Results showed that ZT-M+BM caused 28.4% reduction in total weeds at 60 days after sowing compared to CT-M. Sequential application of atrazine (750 g/ha) and pendimethalin (750 g/ha) *fb* tembotrione (120 g/ha) effectively reduced weed population (78.5%) and dry weight (81.3%) compared to the unweeded control. Maize yield attributes were higher in ZT-M+BM than in CT treatments. The combination of atrazine, pendimethalin, and tembotrione with ZT-M+BM resulted in higher maize productivity (6.88 t/ha) and profitability (₹ 116,570/ha), comparable to the weed-free check. Thus, integrating zero tillage with *Sesbania* brown manure, and pre-emergence application of atrazine + pendimethalin followed by post-emergence tembotrione is recommended for effective weed control and high maize productivity of maize.

Key words: Brown manuring, Integrated weed management (IWM), Resource Conservation Technologies (RCT), Conservation agriculture, HPPD-inhibitor, Cover Crop

INTRODUCTION

Maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-mung bean (*Vigna radiata* L.) cropping system under conservation agriculture (CA) has been proposed (Parihar *et al.*, 2017) as an alternative to rice-wheat in the Indo-Gangetic plains. Maize productivity in India (2689 kg/ha) is significantly lower than the global average (5500 kg/ha), largely due to weed interference, particularly in the IGP where post-emergence herbicides are scarce (Swetha *et al.* 2015). Tillage modifications affect weed seed dynamics, often concentrating seeds in the topsoil of no-till systems (Mulugeta and Stoltenberg 1997). Weed competition can reduce maize yields by up to 90% (Dalley *et al.* 2006), with reductions ranging from 40-80% (Reddy and Tyagi 2005). Integrated weed management through Resources Conservation Technologies (RCT), such as brown manuring, offers an eco-friendly alternative.

Brown manuring (BM), a no-till version of green manuring, uses a selective herbicide (2,4-D) to knock down the legume plants before blossoming, thus contributing organic matter to the soil. Maitra and Zaman (2017) describe the BM technique as growing *Sesbania bispinosa* alongside the crop for the first 25-30 days after sowing and then knocking it down with 2,4-D providing up to 35 kg N/ha. The resulting dark brown or yellow *Sesbania* plants are left in the field to decompose naturally, reducing weed interference through allelopathy or smothering effects (Oyeogbe *et al.* 2017). This research investigates *Sesbania* BM's efficacy in controlling weed species in maize and compares the benefits of zero tillage to conventional tillage practices.

MATERIALS AND METHODS

A field experiment was carried out during the rainy (*Kharif*) season of 2021 and 2022 at the ICAR-Indian Agricultural Research Institute (28°08'N latitude,77°12' E longitude and at an elevation of 228.61 metres (750 feet) above mean sea level) New

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Delhi, India. The treatments were comprised of four tillage methods *viz.* conventional tillage maize (CT-M), conventional tillage maize with green manure from preceding greengram (CT-M+GM), zero tillage maize with residue retention at 3 t/ha (ZT-M+R), zero tillage maize with *Sesbania* co-culture as brown manuring/cover crop (ZT-M+BM) in main plot; and five weed control treatments, *viz.* unweeded check (UWC), pre (atrazine + pendimethalin 750 g/ha, each) + 1 hand weeding (30 DAS), pre (atrazine + pendimethalin 750 g/ha, each) + post (tembotrione) 120 g/ha, pre (atrazine + pendimethalin 750 g/ha, each) + post (pre-mix of mesotrione + atrazine) 120 g/ha, weed free check in sub-plots were evaluated. Atrazine 750 g/ha + pendimethalin 750 g/ha were applied as pre-emergence (day after sowing) with 400 litres of water/ha, followed by the post-emergence application of tembotrione 120 g/ha at 30 DAS using a knapsack sprayer, which was also used to apply a ready-mix herbicide (mesotrione 2.27%W/w + atrazine 22.7%W/w) 120 g/ha with a flat-fan nozzle at 30 DAS. Soil of experimental site was sandy loam, with pH 7.5, low in organic C (0.32%), low in available N (148.4 kg/ha), high in available P (30.8 kg/ha) and medium in available K (256.4 kg/ha). During the winter season (*Rabi*), wheat crop was cultivated with the stipulated treatments, and the leftover crop residues were applied in the subsequent rainy season (*Kharif*) for maize cultivation. Following the wheat harvest, mung bean was cultivated as a green manure crop and then incorporated into the field as per the designated treatment. In the conventional tillage (CT) plots, a tractor-drawn disc plough was used for ploughing, followed by levelling with a planker. For zero tillage (ZT) plots with residues, the residue from the previous wheat crop was kept intact, while ZT plots without residues were left undisturbed. Additionally, a weed-free check was maintained, involving manual weeding carried out at intervals of 30, 60, and 90 days after sowing (DAS). On the same day of maize sowing (18th July 2021 and 20th July 2022), *Sesbania aculeata* L., a leguminous cover crop, was broadcast at a rate of 15 kg/ha. This cover crop served the purpose of suppressing weeds during the early stages of maize growth and also acted as brown manure. On the 30th day after sowing, a blanket spray of 2,4-D herbicide at a rate of 0.25 kg/ha was done over the maize / *Sesbania* plants. Seeds of the '*PJMH-1*' hybrid maize, with a growth duration of 100-110 days, were sown using a 9-tyne zero-till seed drill, maintaining a spacing of 60 cm between lines and a seed-to-seed interval of 20 cm. A calculated amount of nutrients, 120-60-40 kg N, P, K per hectare were applied on the basis of soil-test analysis in maize through urea, single superphosphate and muriate of potash, respectively. Weed species were counted from a 1 × 1m (1 m^2) quadrat, and density was given in number/m^2. The weeds were first dried in the sun, then placed in an electric oven set to 70°C until the weight remained constant. The dry weight was then calculated as g/m^2. The benefit-cost ratios for each treatment were calculated as the ratio of net returns (Using MSP of 2023) to the cost of cultivation. The data were analysed using analysis of variance (ANOVA) for a split plot design to determine the significance of overall treatment differences using the "F" test and conclusion was drawn at 5% probability level. To assess weed control efficacy (WCE), weed control index (WCI), following calculations were made according to Das (2008):

$$WCE\ (\%) = \frac{(Weed\ density\ in\ control\ plot - Weed\ density\ in\ treated\ plot)}{Weed\ density\ in\ control\ plot} \times 100$$

$$WCI\ (\%) = \frac{(Weed\ dry\ matter\ in\ control\ plot - Weed\ dry\ matter\ in\ treated\ plot)}{Weed\ dry\ matter\ in\ control\ plot} \times 100$$

Two years mean data (2021 and 2022) were used for analysis. The standard error of the mean was calculated for each case. When the 'F' value from the ANOVA was significant, the least significant difference (LSD) was computed to test treatment significance. To address data variability, weed density and dry weight were normalized using the square-root [$\sqrt{x+0.5}$] transformation before ANOVA.

RESULTS AND DISCUSSION

Weed management attributes

In the experimental plot, a diverse array of annual and perennial weeds was observed, encompassing narrow-leaved weeds, *Setaria viridis* L., *Digitaria sanguinalis* L., and *Dactyloctenium aegyptium* L. On the other hand, among the broad-leaved weeds, the dominant species were *Commelina benghalensis* L., *Amaranthus viridis* L., *Trianthema portulacastrum* L., and *Digera arvensis* L. Additionally, among the perennial weeds, *Cyperus rotundas* L. and *Cynodon dactylon* L., were observed.

Tillage and weed control treatments had significant ($p<0.05$) effect on broad-leaf weeds (BLW), narrowleaf weeds (NLW) and sedges distribution. At 30 DAS, the count of BLW was higher (80.7%) in CT-M compared to ZT+BM plots, and also the perennial weed species like sedges *(Cyperus rotundas*) were abundant in ZT than in CT plots. The total weed count was higher in CT-M compared to ZT-M+BM, indicating the weed-suppressing effect of BM (**Table 1**), with dominant weed species including *C. dactylon* and *C. benghalensis* among narrow-leaf weeds, *C. rotundas* in sedge weeds, and *A. viridis* among broad-leaf weeds. The CT-maize had the highest *C. benghalensis* population (6.3/m²), while the ZT-M+BM plot had the lowest (3.7/m²), with similar trend for *A. viridis*. At 60 DAS, weed populations were lower but followed similar trends (**Figure 1**). Unweeded check had the highest weed density, while the weed-free check and pre + post (tembotrione) herbicide-applied plot had the best control. Zero tillage in conservation agriculture (CA) resulted in less effective early weed suppression, leading to variable initial weed growth.

At 30, 60, and 90 days after sowing (DAS), NLW exhibited higher densities compared to broad-leaf weeds (BLW) and sedges. The CT-M recorded the highest weed density at 30 DAS, with 67.6 weeds/m^2, comprising BLW (14.1), NLW (26.4), and sedges (12.1/m^2). Conversely, the ZT-M+BM had the lowest weed density among all crop establishment methods, with a total of 49.2 /m^2 (7.8 BLW, 20.0 NLW, 15.4 sedges/m^2). Among the weed management options, the weed-free check plot consistently had the lowest weed density, followed by pre + post (tembotrione) herbicide.

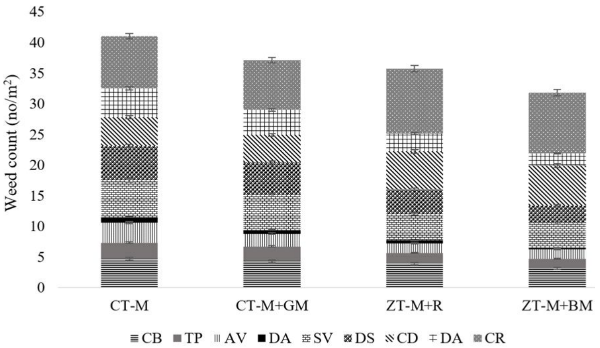


Figure 1. Species wise weed distribution pattern in main plot at 60 DAS

The results demonstrated that *Sesbania* had a smothering effect as a cover crop, leading to a significant reduction in weed population. The sequential application of atrazine 750 g/ha with pendimethalin 750 g/ha (pre) *fb*. tembotrione 120 g/ha (post) outperformed the other weed control techniques by considerably reducing the number of weed species (78.5% reduction over the weedy check) in comparison to pre (atrazine +pendimethalin 750 g/ha) + 1 HW at 25 DAS and pre (atrazine + pendimethaline 750g/ha) + post (premix mesotrione + atrazine 120 g/ha).

At 30 DAS, CT-M exhibited the highest weed dry weight, while ZT-M+BM achieved the most substantial reduction in weed dry weight by 10.4% due the smothering effect of BM. ZT-M+R and CT-M+GM showed reduction of 2.5% and 8.1%, respectively. A similar pattern emerged at 60 DAS in both years, with the lowest weed dry matter accumulation compared to the other two growth stages, indicating the effectiveness of BM (**Table 2**).

Table 1. Effect of crop establishment methods and weed management on species-wise weed distribution (no./m^2) at 30 DAS in maize (two years pooled data)

Treatment	BLW			NLW					Sedge
	Commelina benghalensis	*Trianthema portulacastrum*	*Amaranthus viridis*	*Digera arvensis*	*Setaria viridis*	*Digitaria sanguinalis*	*Cynodon dactylon*	*Dactyloctenium aegyptium*	*Cyperus rotundus*
Crop establishment									
CT-maize	2.4(6.3)	1.4(3.3)	1.9(3.7)	1.1(0.8)	2.6 (7.6)	2.42 (6.9)	2.1(5.5)	2.2 (6.0)	2.8 (10.1)
CT-maize + green manure	2.3(5.5)	1.4(2.7)	1.6(2.5)	1.0(0.7)	2.7 (8.2)	2.43 (6.8)	2.2(6.5)	2.3 (5.6	3.1 (12.0)
ZT-maize + residue*	2.2(5.1)	1.3(2.1)	1.5(2.1)	1.0(0.6)	2.5 (6.8)	1.86 (4.3)	2.9(9.7)	1.8 (4.0)	4.5 (25.1)
ZT-maize + *Sesbania* brown manure	1.9(3.7)	1.1(1.7)	1.6(1.9)	0.9(0.4)	2.3 (5.8)	1.67 (3.2)	2.7(8.3)	1.9 (3.8)	4.3 (21.4)
LSD (p=0.05)	0.3(1.5)	NS	0.3(1.1)	NS	NS	NS	0.3(2.2)	NS	0.9 (9.1)
Weed management									
Un-weeded check	2.9(8.5)	1.6(4.9)	2.1(4.3)	1.1(0.8)	2.9 (8.5)	2.57 (6.9)	3.6(13.0)	2.0 (4.6)	5.3 (30.3)
Pre +1 HW	2.3(4.8)	1.5(2.0)	1.8(3.0)	1.2(1.1)	2.9 (8.4)	2.66 (8.3)	2.5(6.7)	2.8 (7.9)	4.2 (19.3)
Pre + Post (*Tembotrione)*	2.6(6.7)	1.3(2.8)	1.8(2.8)	1.0(0.7)	3.0 (8.7)	2.34 (5.8)	2.7(7.9)	2.0 (4.2)	4.0 (17.7)
Pre+ Post (premix *meso+atra*) §	2.5(5.8)	1.3(2.5)	1.7(2.8)	1.0(0.5)	3.2 (9.9)	2.20 (5.5)	2.9(9.8)	2.6 (7.6)	4.1 (18.4)
Weed free check	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7 (0.0)	0.71 (0.0)	0.7(0.0)	0.7 (0.0)	0.7 (0.0)
LSD (p=0.05)	0.3(1.6)	0.3(1.1)	0.3(1)	0.3(0.6)	0.6 (3.5)	0.85 (4.1)	0.8(4.0)	0.8 (4.3)	1.0 (7.7)

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3t/ha; Pre: pre-emergence (atrazine + pendimethaline 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120g/ha; §:pre-mix dose of mesotrione + atrazine 120 g/ha. The data were subjected to square root transformation "x+0.5 before statistical analysis. Figures in parentheses are the original values

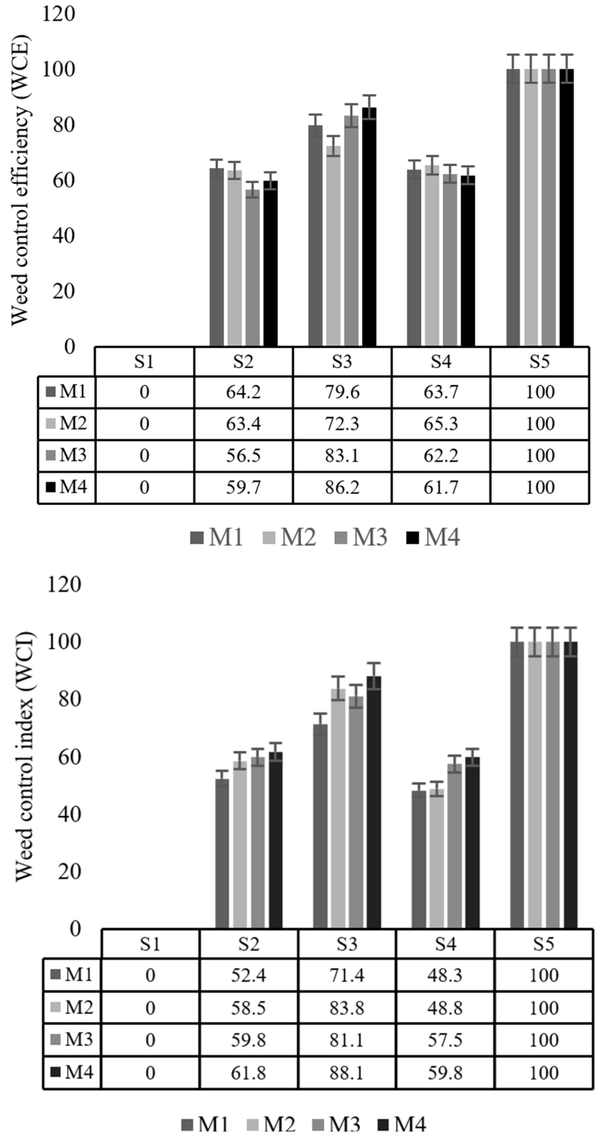
Table 2. Effect of crop establishment methods and weed management on weed dry weight (g/m^2) in maize (mean data of two years)

Treatment	30 DAS	60 DAS	90 DAS
Crop establishment methods			
CT-maize	7.7(71.2)	4.6(26.2)	7.7(72.7)
CT-maize + green manure	7.4(65.4)	4.4(23.9)	7.5(68.2)
ZT-maize + residue*	7.6(69.4)	4.2(21.4)	7.2(64.2)
ZT-maize + *Sesbania* brown manure	7.3(63.8)	3.8(18.4)	6.9(59.3)
LSD (p=0.05)	0.2(4.5)	0.1(2.1)	0.5(8.5)
Weed management options			
Un-weeded check	10.0(99.3)	7.2(52.3)	11.4(129.2)
Pre +1 HW	9.0(79.7)	5.0(24.5)	8.5(71.6)
Pre + post (*tembotrione)*	8.8(76.7)	3.2(9.8)	7.8(61.0)
Pre+ post (premix *meso+atra*) §	9.1(81.6)	5.1(25.8)	8.3(69.0)
Weed free check	0.7(0.0)	0.7(0.0)	0.7(0.0)
LSD (p=0.05)	0.3(6.3)	0.2(2.4)	0.3(5.3)

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3 t/ha; Pre: pre-emergence (atrazine + pendimethaline 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120 g/ha; §:pre-mix dose of mesotrione + atrazine 120 g/ha. The data were subjected to square root transformation “x+0.5 before statistical analysis. Figures in parentheses are the original values

Application of atrazine 750 g/ha with pendimethalin 750 g/ha (pre) + post application of tembotrione resulted in the lowest weed dry weight at 60 DAS (9.8 g/m²), followed by atrazine 750 g/ha with pendimethalin 750 g/ha (pre) + 1 hand weeding) and atrazine 750 g/ha with pendimethalin 750 g/ha (pre) + post application of premix meso + atra), relative to the unweeded check. These findings underscore the efficacy of herbicide along with *Sesbania* brown manure in significantly reducing weed dry weight at 60 and 90 DAS, demonstrating their effectiveness in weed control during the later stages of crop growth in 2021 and 2022.

The weed control efficiency (WCE) and weed control index (WCI) at 60 DAS using mean data of two years are shown in **Figure 2**. At 30 DAS, the crop establishment and weed management effects did not have a significant impact. Evidently, the weed-free check plot had the highest weed control index value of 100%. The ZT-M+BM (M4) combined with pre + post tembotrione treatment was the second most effective, with a WCI of 88.1%. At 60 DAS, weed-free check plot showed highest efficiency in controlling the weeds showing a value of 100%. The sequential application of atrazine 750 g/ha with pendimethalin at 750 g/ha (pre), *fb* tembotrione 120 g/ha (post) along with ZT+BM showed the second-best efficiency in terms of weed control efficiency by showing a value of 86.2%, followed by in the application of same herbicide in ZT+R plot which showed a value of 83.1%. This might be due to higher



Where by, M1: CT-maize; M2: CT-maize + green manure; M3: ZT-maize + residue*; M4: ZT-maize + *Sesbania* brown manure; S1: Un-weeded check ; S2: Pre (atrazine + pendimethalin 750 g/ha) +1 HW at 25 DAS; S3: Pre (atrazine + pendimethalin 750g/ha) + Post (tembotrione 120 g/ha); S4: Pre (atrazine + pendimethalin 750 g/ha) + Post (premix mesotrione + atrazine 120 g/ha) § ; S5: Weed free check

Figure 2. Effect of crop establishment methods and weed management on weed control efficiency (WCE), and weed control index (WCI) at 60 DAS

efficacy of herbicides which resulted in lower weed density, weed dry weight along with the smothering effect of cover crop *Sesbania*. Similar reports of higher WCE with tank mix of HPPD inhibiting herbicides with atrazine have been given by Madhavi *et al.* (2014).

Crop growth parameters

Growth parameters of maize such as plant height, total dry matter (g/plant), leaf area (cm^2/plant) and leaf area index (LAI) were significantly ($p<0.05$) affected by tillage and weed management treatments

(**Table 3**). Zero tillage with brown manure (ZT+BM) showed substantial increases in plant height over conventional tillage without mulch (CT-M) in both years, with improvements of 27%, 8.1%, 9.5%, and 12.4% at 30, 60, 90 days after sowing (DAS), and harvest, respectively. Although plant dry weight did not differ significantly at 30 DAS, ZT-M+BM produced the highest dry weights at all subsequent stages (60 and 90 DAS), followed by ZT-maize with residue and CT-maize with green manure. ZT-M+BM had the highest LAI at 30 DAS (1.6), surpassing CT-M by 64%, ZT-M+R by 43.2%, and CT-maize with green manure by 20.6%. The weed-free check recorded the highest dry weight at harvest (227.8 g/plant), 14% more than the un-weeded check, with pre + post (tembo) and pre + post (premix meso + atra) also showing significant improvements. LAI was highest in the weed-free check (1.4), followed by pre + post (tembotrione) and pre + post (pre-mix meso. + atra.) treatment.

During the initial growth phase (0-30 DAS), the crop growth rate (CGR) ranged from 3.4 to 2.5 g/m²/day, averaging 2.9 g/m²/day, with ZT-M+BM showing the highest CGR, which was significantly more than CT-M and ZT-M+R. From 30-60 DAS, CGR increased significantly, averaging 23.37 g/m²/day with a range of 20.4 to 26.4 g/m²/day. The highest CGR occurred during 60-90 DAS (**Figure 3**) in 2021 and 2022, with a mean of 27.55 g/m²/day, again with ZT-M+BM leading and then decreased at harvest. Similarly, for weed management, the weed-free check plot recorded the highest CGR (3.2 g/m²/day) during 0-30 DAS, which increased to an average

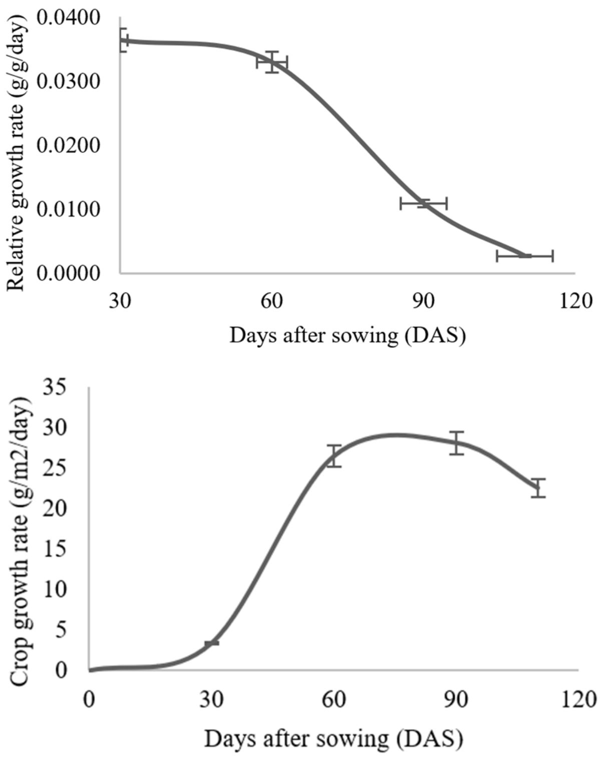


Figure 3. Effect of crop establishment methods and weed management on crop growth rate (CGR) and relative growth rate (RGR) of maize

of 23.45 g/m²/day during 30-60 DAS, and peaked at 11.2 g/m²/day during 60-90 DAS and then decreased. Effective weed management prevented crop-weed competition, and enhanced growth of maize. The relative growth rate (RGR) was significantly affected during 0-30 DAS, with ZT-maize and *Sesbania* brown manuring exhibiting the highest RGR in both

Table 3. Effect of crop establishment methods and weed management on different crop growth parameter. (mean data of 2 years)

Treatment	Plant Height (cm)		Dry matter accumulation (g/plant)		Leaf area index (LAI)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Crop establishment methods						
CT-maize	32.9	120.3	9.1	82.4	1.0	3.7
CT-maize + green manure	35.9	126.4	9.3	85.4	1.2	3.8
ZT-maize + residue*	34.6	123.9	10.8	102.5	1.4	4.0
ZT-maize + *Sesbania* brown manure	41.8	130.1	12.4	107.6	1.6	4.3
LSD (p=0.05)	NS	6.2	NS	9.1	0.1	0.28
Weed management options						
Un-weeded check	31.9	119.8	9.5	80.7	1.2	3.4
Pre +1 HW	33.9	123.3	10.0	89.3	1.2	3.8
Pre + post (*tembotrione)*	38.0	127.3	10.6	98.6	1.4	4.0
Pre+ post (premix *meso+atra*) §	36.4	124.9	10.3	94.7	1.3	3.9
Weed free check	41.2	130.5	11.5	109.4	1.4	4.6
LSD (p=0.05)	NS	6.7	NS	7.1	0.09	0.23

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3 t/ha; Pre: pre-emergence (atrazine + pendimethalin 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120g/ha; §: pre-mix dose of mesotrione + atrazine 120 g/ha.

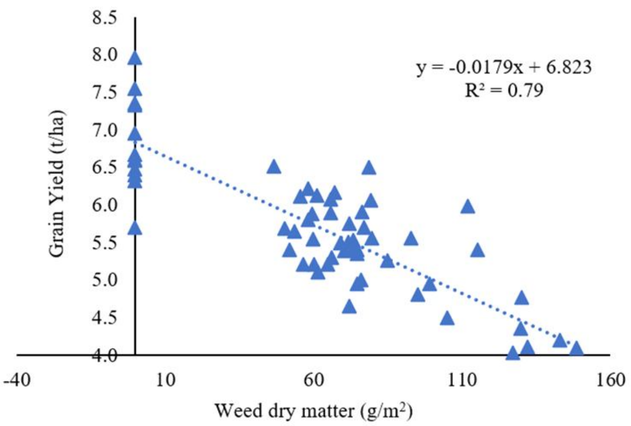
years. While RGR averaged 0.0336 g/g/day at 0-30 DAS, it decreased at later stages (0.0107 g/g/day 60-90 DAS) due to maturation of crop and senescence and at harvest it was the lowest. (**Figure 3**)

Crop growth significantly improved due to co-culture of ZT-maize and *sesbania* brown manure, combined with the application of pre + post (tembotrione) herbicide due to reduced weed competition. Weed management strategies directly reduce crop-weed competition and indirectly lessen competition for resources like light, space, water, and nutrients. Lower weed density and biomass create more space for optimal leaf and branch expansion, enhancing early plant growth and LAI (Gul and Khanday 2015).

Yield attributes

The ZT-M+BM treatment achieved significantly higher kernel yields attributed to superior yield parameters compared to CT-Maize. It demonstrated notably greater cob dimensions (16.14 cm in length, 15.79 cm in girth, and 130.13 g in the weight) and shelling percentage (81.57%) at harvest, surpassing CT-Maize. Additionally, ZT-M+BM exhibited higher values for rows per cob (13.37), kernels per row (29.99), kernel weight per cob (98.50 g), and 100-kernel weight (24.49 g) compared to CT-Maize. Weed management also significantly influenced cob dimensions and shelling percentage, with the weed-free plot showing superior results compared to unweeded plots. The pre + post (tembotrione) treatment similarly contributed positively, with results aligning closely with weed-free conditions (WFC). These findings underscore the efficacy of the ZT-M+BM treatment in enhancing maize productivity through optimized grain production.

Various crop establishment methods and weed management practices had significant impacts ($p<0.05$) on maize yield metrics (**Table 5**). The ZT-M+BM significantly outperformed the CT-Maize



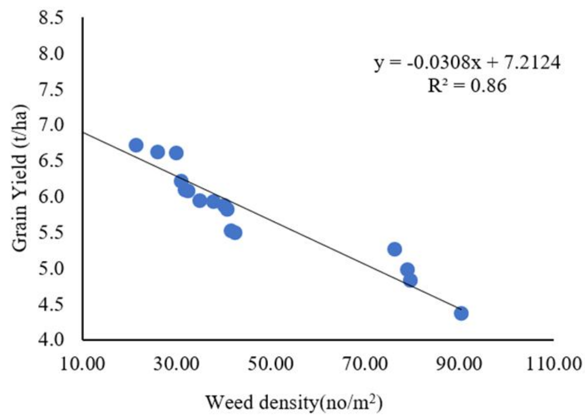


Figure 4. The relationship of grain yield with weed dry matter and weed density at 60 DAS

Table 4. Effect of crop establishment methods and weed management on yield attributes of maize (two years mean data)

Treatment	Cob length (cm)	Cob girth (cm)	Cob weight (g)	No of Kernel/ row	No of Kernel row /cob	Kernel weight/ cob(g)	Seed index (g)	Shelling %	Harvest index (%)
Crop establishment methods									
CT-maize	13.3	12.7	117.7	27.0	11.7	83.8	22.8	72.0	42.21
CT-maize + green manure	13.4	12.9	119.5	27.0	12.3	86.8	23.0	73.6	42.79
ZT-maize + residue*	14.6	13.7	123.9	28.8	12.5	88.0	23.8	76.0	43.42
ZT-maize + *Sesbania* Brown manure	16.1	15.8	130.1	29.9	13.4	98.5	24.5	81.6	43.47
LSD (p=0.05)	1.4	1.2	8.6	2.1	0.5	7.1	1.2	6.5	NS
Weed management options									
Un-weeded check	11.5	12.0	110.3	25.9	10.9	75.8	22.0	69.2	42.00
Pre +1 HW	13.7	13.1	119.2	26.4	11.7	81.8	21.8	71.6	42.83
Pre + Post (*tembotrione)*	15.4	14.6	126.5	29.4	13.2	96.9	24.2	80.6	43.10
Pre+ Post (premix *meso+atra*) §	14.8	13.9	122.5	27.9	12.5	82.3	23.2	70.1	42.92
Weed free check	16.5	15.4	135.6	31.9	14.1	109.5	26.4	87.3	44.01
LSD (p=0.05)	1.1	1.3	10.5	2.2	0.7	6.1	1.5	6.3	NS

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3 t/ha; Pre: pre-emergence (atrazine + pendimethalin 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120 g/ha; §: pre-mix dose of mesotrione + atrazine 120 g/ha method, yielding higher grain (6.72 t/ha), stover (8.70 t/ha), yields, and harvest index (43.47%). This represented a 17.7% increase in grain yield over CT maize. Similarly, the pre + post (tembotrione) treatment demonstrated an 18.8% increase in grain yield compared to the unweeded check (UWC). Effective weed management, particularly in the weed-free check plot and with the pre + post (tembotrione) treatment, resulted in superior grain (6.32 t/ha), stover (8.72 t/ha) and harvest index (43.10%), emphasizing their crucial role in enhancing maize productivity and overall crop performance. The grain and straw yield showed significant improvement in ZT-maize with *Sesbania* brown manuring, indicating synergistic interactions of BM between vegetative and reproductive growth components. These qualities are positively correlated with maize grain yield, leading to increased productivity in ZT-maize treatments. Effective crop residue management can enhance nutrient cycling and overall crop yields (Sarkar *et al.* 2020). Turmel *et al.* (2015) suggested that excessive soil disturbance from tillage operations is unnecessary for optimal crop yields.

In terms of net returns (calculated based on the minimum support price (MSP) of 2023 on pooled data of grain yield), ZT-Maize + BM performed the best, with a value of ₹ 116,570/ha, followed by CT-Maize with ₹ 94,320/ha. Among the crop establishment methods, ZT-M+BM achieved the highest net benefit-cost (B:C) ratio of 3.71, surpassing other methods. Among the weed management methods, (weed-free check) achieved the highest net returns at ₹ 112,320/ha, followed by S3 (pre + post tembotrione) at ₹ 109,230/ha, and (pre + 1 HW at 30 DAS) at ₹ 97,730/ ha. In contrast, W1 (un-weeded check) yielded net returns of ₹ 77,530/ ha. Although the weedy check had the lowest cultivation costs, it resulted in the lowest returns due to reduced yields. For weed management, the pre + post (tembotrione) option had the highest net B:C ratio of 3.01, outperforming other options. The superior B:C ratios for ZT-maize with *Sesbania* brown manuring and pre + post (tembotrione) was due to their higher yields and lower cultivation costs.

A negative linear correlation between weed density and dry weight accumulation with maize yield indicated that as weed density or biomass increased, maize yield decreased linearly (calculation based on the pooled data of weed parameters). This correlation suggests that weeds adversely affected maize growth by competing for resources like water, nutrients, and sunlight. At 60 DAS, grain yield showed strong correlation with weed biomass (R^2 = 0.79) and weed density (R^2 = 0.86), indicating that weed biomass and density accounted for 79% and 86% of the variation in maize yield, respectively. The outcome is backed by the research conducted by Mitra *et al.* (2018).

In summary, findings from a 2-year field study suggested that brown manuring in zero tillage combining 15 kg/ha of *Sesbania* seed with 0.25 kg/ha of 2,4-D applied at 30 days after sowing for knocking it down, effectively managed weeds in maize cultivation. This integrated approach, particularly effective when paired with pre-emergence application of atrazine 750 g/ha and pendimethalin 750 g/ha, followed by post-emergence treatment with 120 g/ha of tembotrione, demonstrated superior weed suppression mainly the perennial weed compared to

Table 5. Effect of crop establishment methods and weed management on grain yield, straw yield, total biomass yield, gross return, net return and net benefit cost ratio(B:C)

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Gross returns (x10^3 ₹/ha)	Net returns (x10^3 ₹/ha)	Net B:C
	2021	2022	Mean	2021	2022	Mean			
Crop establishment									
CT -maize	5.34	5.72	5.53	7.63	7.57	7.60	129.26	94.32	2.70
CT-maize + green manure	5.96	5.85	5.91	7.96	7.80	7.88	130.22	90.27	2.26
ZT-maize + Residue*	5.97	6.06	6.01	8.14	8.0	8.07	133.34	93.90	2.38
ZT-maize + *Sesbania* brown manure	6.63	6.81	6.72	8.74	8.66	8.70	148.00	116.57	3.71
LSD (p=0.05)	0.69	0.72	0.70	0.64	0.63	0.64	10.8	10.8	
Weed management									
Un-weeded check	5.26	5.0	5.13	7.06	7.00	7.03	109.38	77.53	2.43
Pre +1 HW	5.69	5.75	5.72	7.98	7.70	7.84	133.88	97.73	2.70
Pre + post (*tembotrione)*	6.43	6.21	6.32	8.74	8.70	8.72	145.48	109.23	3.01
Pre+ post (premix *meso+atra*) §	6.32	6.02	6.17	7.88	7.90	7.89	132.61	97.02	2.73
Weed free check	7.05	6.71	6.88	9.16	8.60	8.83	154.67	112.32	2.65
LSD (p=0.05)	0.64	0.62	0.63	0.98	0.96	0.97	17.7	17.7	

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3 t/ha; Pre: pre-emergence (atrazine + pendimethalin 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120g/ha; §: pre-mix dose of mesotrione + atrazine 120 g/ha other methods. This strategy significantly reduced weed dry matter accumulation and density, leading to higher grain and stover yields in maize, thereby enhancing overall productivity and net returns in the North-Western Indo-Gangetic plains of India.

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