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Effects of brown manure species, seed rate and time of application of 2,4-D on weed control efficiency, productivity and profitability in maize

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ABSTRACT

Weeds result in yield losses up to 40% in maize in India. Brown manuring can suppress weeds better and provide ecosystem services. It has been hardly studied in crops other than rice. It offers potential for adoption in maize, but needs to be optimized because maize differs from rice in growth habit and architecture and has no tillering capacity. Therefore, this study was undertaken to optimize brown manuring option(s) that involved two brown manure species, their mixture and seed rates, and the times of application of 2,4-D. Results revealed that all brown manuring treatments suppressed noxious weed *Cyperus rotundus* better than the recommended tank-mixture of atrazine + pendimethalin. Among them, a brown manuring option that involved 1:1 mixture of *Sesbania bispinosa* (12.5 kg seed/ha) + *Crotalaria juncea* (12.5 kg seed/ha) + 2,4-D 0.5 kg/ha applied at 35 DAS resulted in highest reduction in weed density (~91%). Another brown manuring option, *i.e.*, *Sesbania* + *Crotalaria* (12.5+12.5 kg/ha) mixture and 2,4-D 0.5 kg/ha applied at 25 DAS gave similar weed suppression, and was superior to it on maize grain yield (~13.4%), gross return (~15.7%) and gross benefit:cost (~15.6%). This brown manuring would be a profitable weed management practice in maize. It may lead to sequester C and N in soil and provide ecosystem services as well.

Maize (*Zea mays* L.), the 'Queen of Cereals' is an emerging cereal crop, ranking third after rice and wheat in India with an area of 9.5 million ha and annual production of 24.5 million tonnes (Das *et al.* 2018). It, due to wider adaptability to diverse environments and seasons, could be a potential driver for diversification of the most dominant rice-wheat system in the Indo-Gangetic Plains (IGP) of India (Hobbs and Gupta 2003, Humphreys *et al.* 2010). Maize productivity in India, however, is about half of the world average due to several biotic and abiotic stresses. Wider spacing, initial slower crop growth, and higher nutrients and water requirement of maize provide an ideal microclimate to weeds for stronger interference from the early stages (Susha *et al.* 2018). The sole use of herbicides may lead to shift and resistance of weeds. Besides, the lack of effective sedge killing herbicides, and usually less tolerance of maize plants to most post-emergence herbicides suggest that herbicides cannot be fool-proof strategy for weed management. Rather, efficient weed management strategy needs to be explored through integration of herbicides with other alternative options.

Brown manuring (BM) is a practice of growing *Sesbania*/*Crotalaria* as co-culture with a crop for a short period of 25-30 days after sowing (DAS), and then, killing by the application of post-emergence herbicides selective to the crop of prime interest (Tanwar *et al.* 2010, Maitra and Zaman 2017). It decreased weed density by 40-50% (Rehman *et al.* 2007), 37-42% (Singh *et al.* 2009) and 41-56% (Nawaz *et al.* 2017) in rice through concurrent/smothering and residual (allelopathic) effects and reduce herbicide usage (Gupta and Seth 2007, Ramachandran *et al.* 2012). Several workers (Singh *et al.* 2008, Kumar and Mukherjee 2008, Dubey 2014, Seema *et al.* 2015, Sen *et al.* 2018) have reported better weed suppression through BM in rice. Maize being a cereal crop is selective to 2,4-D, which offers opportunities for adoption of BM in maize. But, maize unlike rice is a non-tillering crop and might suffer from interference by the brown manure plants at the initial stage (0-30 DAS) that could affect the emergence, plant stand, crop growth and, ultimately yield of maize. Hence, BM in maize requires to be optimized in terms of seed rate of BM species individually or in mixtures, and time and dose of 2,4-D application for an optimum balance between maize and BM species apart from the weed control effects of BM.

This experiment was conducted at the ICAR-Indian Agricultural Research Institute, New Delhi, India during the rainy season of 2017 in maize under natural infestations of weeds to assess the impacts of brown manuring on weed control efficiency and maize crop productivity and profitability, The experiment had 12 treatments including eight BM treatments laid out in a randomized complete block design with three replications. The plot size was 5 m (along the rows) x 4.9 m (across the rows). The BM treatments included two brown manure species (*Sesbania bispinosa*; *Crotalaria juncea*) sown at two seed rates (15 and 25 kg/ha) as sole or mixture (1:1). The BM plants were knocked down at two stages (25 and 35 DAS) using 2,4-D at 0.5 kg/ha. Four controls, namely, unweeded control (UWC), weed-free control (WFC), pre-emergence tank mixture of pendimethalin 0.75 kg/ha + atrazine 0.75 kg/ha (*i.e*., recommended herbicides control), and atrazine 0.75 kg/ha + hand-weeding (HW) at 35 DAS (*i.e*., farmers practice control) were also adopted in this study. All BM treatments were applied with a common pre-emergence application of pendimethalin 1.0 kg/ha to control initial flushes of weeds. The maize variety '*PMH 1*' was sown at 70 cm (row to row) x 30 cm (plant to plant) spacing with a seed rate of 20 kg/ha on July 13, 2017. An area of 90 cm (along one row) x 70 cm (both sides of the row, *i.e*., one row-width) was randomly selected from the central rows in each plot at 60 DAS and weeds species were collected from that area. Individual weed species were counted and categorized into grassy, broad-leaved and perennial *Cyperus rotundus* L. (~nutsedge) weeds. Weed samples were sun-dried for 2 days and kept in an oven at 70 ± 5°C for 48 h for recording weed dry weight (Das 2001), which is considered a reliable estimate for evaluating weed control effects of the treatments. Having recorded the densities and dry weights of weeds collected/sampled from the above-mentioned areas, weed control efficiency (WCE) was determined (Das and Yaduraju 2012). Maize cobs were harvested manually from the net plot areas and grain yield was recorded at 15% moisture content (Oyeogbe *et al*. 2018). The minimum support price of maize grains was used for calculating economics. The gross returns (GR), and gross benefit:cost (GB:C) were worked out as per Das and Das (2018). Weed data on density and dry weight having greater coefficient of variation than 20%, were transformed through square-root $(x+0.5)^{½}$ method (Das 1999), and the transformed weed data were used for the ANOVA (Pal and Sarkar 2015).

Trianthema portulacastrum L. (Horse purslane) among broad-leaved weeds; *Acrachne racemosa* Heyne ex Roem Ohwi (Goose grass) among grassy weeds; and *Cyperus rotundus* L. (purple nutsedge) among sedges were dominant weed species in the experimental maize field. Besides, *Commelina benghalensis* L. (tropical spiderwort); *Digera arvensis* Forsk. (false amaranth); *Amaranthus viridis* L. (slender pigweed); *Setaria glauca* (L.) Beauv. (Yellow foxtail); and *Cynodon dactylon* (L.) Pers. (Bermuda grass) was present at lower frequencies. There was a significant reduction in density of broad-leaved weeds (~97%), grassy weeds (~94%) and total weeds (~92%) due to the atrazine + HW at 60 DAS (**Table 1**). The reduction was comparable with those observed in the BM treatments such as *Sesbania* + *Crotolaria* (1:1) mixture 12.5+12.5 kg/ha with 2,4-D applied at 35 DAS, *Sesbania* 25 kg/ha with 2,4-D applied at 25 DAS, and *Sesbania* + *Crotolaria* (1:1) mixture 12.5+12.5 kg/ha with 2,4-D at 25 DAS. In atrazine + HW treatment, the vigorously growing maize crop canopy suppressed grassy and broad-leaved weeds effectively and led to greater reduction in weed interference. Hand weeding, however, incurred more cost, and could not control the problematic perennial sedge *Cyperus rotundus* effectively. But, the *Sesbania* + *Crotolaria* (1:1) mixture 12.5+12.5 kg/ha with 2,4-D applied at 35 DAS (~2.7/m^2) resulted in 90% reduction of this weed compared to the unweeded control. The other treatments, namely, the *Sesbania* 25 kg/ha with 2,4-D applied at 25 DAS, atrazine +HW, and *Sesbania* + *Crotolaria* (1:1) mixture 12.5+12.5 kg/ha with 2,4-D applied at 25 DAS were comparable with it. There was a poor control (~21%) of *Cyperus rotundus* due to the application of tank-mixture of atrazine + pendimethalin, which was as similar/inferior as the unweeded control. The physical interference of BM species capturing space early, and/or allelopathic effects might have played roles. Besides, some activities of 2,4-D against tender *C. rotundus* plants, although less known/ reported, cannot be ignored.

In this study, kinds of weeds, BM species, and the time of application of 2,4-D influenced the overall weed control efficacy of the treatments. Among the treatments of mixed stand of BM species, the treatment having 2,4-D application at 35 DAS was superior to that having at 25 DAS. The prolonged space capture by BM species in the former BM mixture, probably, led to slightly higher WCE than the latter (Behera and Das 2019). These BM mixtures were comparable with the atrazine + HW, which, among the weed control treatments, was most effective against weeds. The overall positive effect of BM might be due to early space capture, higher growth rate and biomass accumulation, and larger canopy cover of BM species, leading to better suppression of weeds, particularly late-emerging weeds through live and dead residues/mulches.

The weed-free control, atrazine + HW, *Sesbania* + *Crotalaria* (1:1) at 25 kg/ha with 2,4-D applied at 25 DAS; *Sesbania* 25 kg/ha with 2,4-D applied at 25 DAS and pendimethalin + atrazine treatments **(Table 1)** gave 69.4, 65.4, 63.2, 61.2 and 47.3% higher maize grain yield, respectively than the unweeded control (3.53 t/ha), and the grain yields were comparable. Higher grain yield in the atrazine + HW could be attributed to greater maize biomass (source), which was mobilized to the reproductive parts (sink). Lower crop-weed interference in this treatment (discussed above) shifted the balance in favour of maize. The 25 kg seed of BM species/ha (sole or mixture) as against 15 kg/ha; and prolonged space capture for 35 DAS as against 25 DAS under the BM mixture *Sesbania* + *Crotalaria* (1:1) at 25 kg/ha with 2,4-D applied at 35 DAS gave better weed suppression *vis-à-vis* offered greater interference with maize during the initial 35 DAS. Probably, this might be the reason why this BM mixture in spite of having better weed suppression, gave lower grain yield than the other BM mixture, which had slightly lower but comparable weed suppression. This suggested that the optimum BM combination in terms of seed rate of brown manure species mixture and time of 2,4-D application could be the 1:1 mixture of *Sesbania* (12.5 kg/ha) + *Crotalaria* (12.5 kg/ha) and 2,4-D 0.5 kg/ha applied at 25 DAS. This BM intervention likely offered greater interference against weeds but less-limiting interference on maize by the brown manure species during initial stages of growth, thus, providing competitive advantage to the maize crop against weeds. Sharma *et al.* (2008) reported that the yield of direct-seeded rice with *Sesbania* brown manuring (~3.65 t/ha) was comparable with conventional transplanting (~3.69 t/ha) and significantly higher than direct-seeding without brown manuring (3.24 t/ha).

The atrazine + HW fetched lower gross returns by 2,300 `/ha, but 13.7% higher gross benefit:cost than the WFC (**Table 1**). The weed-free control, atrazine + HW, *Sesbania* + *Crotalaria* (1:1) at 25 kg/ha with 2,4-D applied at 25 DAS, *Sesbania* 25 kg/ha with 2,4-D applied at 25 DAS and pendimethalin + atrazine tank-mixture were similar with each other on gross returns, and gross benefit: cost. This suggested that the *Sesbania* + *Crotalaria* (1:1) mixture with 12.5 + 12.5 kg seed per ha and 2,4-D applied at 25 DAS might be as profitable as the herbicide mixture, herbicide + HW, or complete weed-free control (WFC). Kumar and Mukherjee (2008) also reported similar results that the butachlor 1.5 kg/ha as pre-plant surface application + brown manuring with *Sesbania rostrata* + 2,4-D 0.50 kg/ha treatment resulted in highest net returns and benefit:cost in rice.

The combined analysis of variance (ANOVA) was done for weed density and dry weight, weed

Table 1. Effect of brown manuring/weed control treatments on category-wise and total weed density, and weed control efficiency (WCE) at 60 DAS, maize grain yield, gross return and gross benefit:cost

Treatment	Weed density (no./m^2)§			Total weed density (no./m^2)§	WCE (%)	Grain yield (t/ha)	Gross returns (x10^3 `/ha)	Gross benefit: cost
	Broad-leaved	Grassy	*Cyperus rotundus*					
Sesbania 15 kg/ha 2,4-D at 25 DAS*	4.8 (23.3)†	5.7 (32.0)†	5.5 (29.3)†	9.2 (84.6)†	71.9	4.84	80.9	2.51
Sesbania 25 kg/ha 2,4-D at 25 DAS*	2.7 (8.7)	3.9 (14.7)	3.4 (12.0)	5.9 (35.4)	87.9	5.69	92.9	2.85
Crotalaria 15 kg/ha 2,4-D at 25 DAS*	5.5 (30.7)	6.9 (48.7)	6.4 (40.7)	10.9(120.1)	63.8	4.55	76.9	2.38
Crotalaria 25 kg/ha 2,4-D at 25 DAS*	5.1 (26.0)	6.0 (36.0)	5.8 (34.0)	9.8 (96.0)	69.4	4.79	80.1	2.44
Crotalaria 15 kg/ha 2,4-D at 35 DAS*	5.3 (28.7)	6.5 (41.3)	6.0 (36.0)	10.3 (106.0)	67.0	4.73	79.5	2.46
Crotalaria 25 kg/ha 2,4-D at 35 DAS*	4.2 (18.0)	4.9 (23.3)	5.1 (25.3)	8.2 (66.6)	79.2	5.15	86.2	2.62
Sesbania + *Crotalaria* mixture (12.5+12.5 kg/ha) 2,4-D at 25 DAS*	3.3 (10.7)	4.1 (18.7)	4.0 (15.7)	6.7 (45.1)	86.2	5.76	94.4	2.89
Sesbania + *Crotalaria* mixture (12.5+12.5 kg/ha) 2,4-D at 35 DAS*	2.7 (7.3)	3.4 (11.3)	2.7 (7.3)	5.1 (25.9)	91.1	5.08	81.6	2.50
Atrazine + pendimethalin	4.1 (16.7)	3.5 (12.7)	7.4 (54.7)	9.2 (84.1)	73.9	5.20	87.2	2.85
Atrazine + HW	2.2 (4.7)	2.6 (6.7)	3.6 (12.7)	4.9 (24.1)	91.9	5.84	95.7	2.90
Unweeded control	12.0 (146.7)	10.5 (110.0)	8.3 (69.3)	18.0 (326.0)	0.0	3.53	63.3	2.26
Weed-free control	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	100.0	5.98	98.0	2.55
LSD (p=0.05)♣	1.8 (25.2)	1.5 (17.7)	1.3 (15.6)	2.0 (46.5)	8.9	0.77	11.6	0.36

*All brown manuring treatments were applied with a pre-emergence application of pendimethalin 1.0 kg/ha. §Data presented are $(x+0.5)^{1/2}$ transformed values; †Figures in parentheses are original values; ♣LSD, least significant difference at p=0.05

Table 2. Analysis of variance for various parameters of weeds and crop yield observed in this study

Source	DF	Weed density (no./m^2)	Weed dry weight (g/m^2)	Weed control efficiency (WCE) (%)	Grain yield (t/ha)
Replication(R)	2	-	-	-	-
Treatments (T)	11	37.26*	32.72*	71.84*	6.88*
Contrasts					
Sesbania BM *vs* pendimethalin + atrazine	1	NS	NS	NS	NS
Sesbania BM *vs* atrazine + HW	1	9.75*	8.20*	10.35*	NS
Sesbania BM *vs* unweeded control	1	150.65*	152.83*	460.79*	29.28*
Sesbania BM *vs* weed-free control	1	-	-	-	NS
Crotalaria BM *vs* pendimethalin + atrazine	1	NS	NS	NS	NS
Crotalaria BM *vs* atrazine + HW	1	39.59*	33.33*	42.25*	12.51*
Crotalaria BM *vs* unweeded control	1	111.80*	118.92*	421.86*	18.84*
Crotalaria BM *vs* weed-free control	1	-	-	-	16.12*
Mixture BM *vs* pendimethalin + atrazine	1	21.56*	10.16	15.61*	NS
Mixture BM *vs* atrazine + HW	1	NS	NS	NS	NS
Mixture BM *vs* unweeded control	1	292.01*	197.51	566.10*	34.75*
Mixture BM *vs* weed-free control	1	-	-	-	NS

DF = Degrees of freedom; *Sesbania* BM treatment = *Sesbania* 15 kg/ha 2,4-D at 25 DAS and *Sesbania* 25 kg/ha 2,4-D at 25 DAS; *Crotalaria* BM treatment = *Crotalaria* 15 kg/ha 2,4-D at 25 DAS, *Crotalaria* 25 kg/ha 2,4-D at 25 DAS, *Crotalaria* 15 kg/ha 2,4-D at 35 DAS and *Crotalaria* 25 kg/ha 2,4-D at 35 DAS; Mixture BM treatment = *Sesbania* + *Crotalaria* mixture (12.5+12.5 kg/ha) 2,4-D at 25 DAS and *Sesbania* + *Crotalaria* mixture (12.5+12.5 kg/ha) 2,4-D at 35 DAS; NS= non-significant; * = significant at p=0.05.

control efficiency (WCE), and maize grain yield (**Table 2**). The effects of treatments (8 BM + 4 controls) and three kinds of contrast [*Sesbania* BM vs controls; *Crotalaria* BM vs controls; and Mixture BM vs controls] were analyzed. It was observed that *Sesbania* and *Crotalaria* BMs individually was comparable with the pendimethalin + atrazine, but inferior to atrazine + HW treatments in terms of weeds suppression. However, the 1:1 mixture of *Sesbania* and *Crotalaria* (BM) was superior to pendimethalin + atrazine as well as was comparable with the atrazine +HW in this regard. This indicated that the mixture BM had lower weed density, dry weight, higher weed control efficiency and led to better weed suppression. This was reflected on the maize grain yield. The sole *Crotalaria* BM was inferior to the atrazine + HW and weed-free control, but was comparable with the pendimethalin + atrazine on maize grain yield. In this regard, the sole *Sesbania* BM and the 1:1 mixture of *Sesbania* and *Crotalaria* BM were comparable with the three controls (*i.e.*, weed-free control; atrazine + HW; pendimethalin + atrazine) adopted in this study. But, the contrast analysis revealed that the mixture BM was superior to the sole *Sesbania* and *Crotalaria* BMs with respect to weed suppression and maize yield enhancement and proved to be the best BM option.

This study shows that BM although poses slight interference to maize during first 25 DAS, can be an effective management practice for diverse weeds, including noxious *Cyperus rotundus* without significant penalty on maize yield. A combination of 1:1 mixture of *Sesbania bispinosa* and *Crotalaria juncea* (12.5 + 12.5 kg/ha) and 2,4-D 0.5 kg/ha applied at 25 DAS would be the best possible BM practice in maize for higher weed control efficiency, maize crop productivity and profitability. This may be adopted in maize under irrigated and rainfed conditions across the States of the North-western Indo-Gangetic Plains of India and in similar agro-ecologies of the tropics and sub-tropics.

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