



Carry-over effect of brown manuring supplemented with nitrogen on productivity and profitability in succeeding wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was carried out on wheat (*Triticum aestivum* L.) (2017-18) in succession to maize (*Zea mays* L.) crop grown with several brown manuring (BM) practices (2017) at ICAR-Indian Agricultural Research Institute, New Delhi. The field layout was fixed for both maize and wheat. The 12 brown manuring/weed control treatments adopted in maize were taken as main plot treatments, and three levels of N, viz. 0, 60 and 120 kg N/ha were taken as sub-plot treatments. At 40 DAS, with respect to weed control, all BM/weed control treatments were inferior to weed-free control, which was freshly employed in both seasons, but was superior to un-weeded control. Among the BM treatments, the *Sesbania* + *Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS resulted in lowest total weed density (~31.8/m²), which was 46.5% lower than that in the un-weeded control. Total weed density was positively correlated with N level. Total weed density was highest at the highest dose of nitrogen at 120 kg/ha (~37.1/m²) and was significantly higher than those in no nitrogen (~32.0/m²). *Sesbania* + *Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS was superior to others with respect to wheat's ear bearing tillers (419.6), grains/spike (49.1), 1000-grain weight (40.3 g), harvest index (38.5%), grain yield (4.41 t/ha) and biological yield (11.42 t/ha), gross returns (111500 ₹/ha) and net returns (80600 ₹/ha). This treatment also resulted in higher grain yield (4.80 t/ha) and net returns (89400 ₹/ha) than other treatments at 60 kg N/ha, and was at par with weed-free control with 120 kg N/ha (5.19 t/ha and 92200 ₹/ha, respectively). Therefore, the carry-over effects 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 35 DAS in combination with 60 kg N/ha can lead to higher wheat productivity and profitability.

Key words: Brown manuring, Carry-over effects, Nitrogen supplement, Weeds Wheat

Maize (*Zea mays* L.)–wheat (*Triticum aestivum* L.) is the third most important cropping system, grown on about 1.83 million ha in India, which contributes nearly 3% to the national food basket after rice–wheat and rice–rice system (Sepat *et al.* 2013). Replacing the rice–wheat with maize–wheat system would greatly reduce the amount of irrigation water-use with numerous other benefits (Humphreys *et al.* 2010). Herbicides, though offer easier, quicker, more economical and effective weed control, can cause weed flora shift and resistance/cross-resistance in weeds (Das 2008). Brown manuring (~BM) can be a workable component of integrated weed management (IWM) in reducing herbicide use and intake into environment. For BM, *Sesbania bispinosa*/*Crotalaria juncea* (BM species) is grown as a co-culture with crops and knocked down at 25-30 days after sowing (DAS) by a selective herbicide like 2,4-D (Tanwar *et al.* 2010, Maitra and Zaman 2017). Live BM plants initially, and dead BM plant residues later can lead

to achieve better control of weeds and reduce herbicide use along with various ecosystem services including addition of organic C, N, P and K in soil through BM biomass. Till date, studies on carry-over effects of brown manuring are very limited. However, there are several reports regarding residual effects of green manuring (Fageria 2007, Herridge *et al.* 2008, Prasad *et al.* 2001). Green manuring/brown manuring legumes give more N than mature harvested crop to the soil, as a considerable amount of crop N (between 34% and 63%) can be translocated towards grain formation and removed at harvest (Evans *et al.* 2003). Kumar *et al.* (2007) reported *Sesbania cannabina* at 30 DAS accumulated 97.8 kg N/ha, of which 41-43% was mineralized after 15 days of incorporation. Residual effects of *Sesbania aculeata* incorporation increased rice yield by 34% through addition of 96 kg N/ha (Chettri *et al.* 2003). The grain yield response of cereals due to the residual effect of tropical grain legumes varied from 0.2 to 3.68 tonnes/ha compared with cereal–cereal mono crop yields, with relative increases reported in the range of 16–353% (Peoples and Herridge 1990). Therefore, one of the specific objective of the study was to assess the carry-over effects of brown manuring in combination with different N levels

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on weeds, and wheat crop productivity and profitability in maize-wheat sequence.

MATERIALS AND METHODS

The experiment was undertaken at the Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi (28°35' N latitude, 77°12' E longitude; altitude 228.6 m above mean sea level) during rainy (2017) and winter (2017-18) seasons. The climate is semi-arid, sub-tropical with hot and dry summer and cold winter. Soil was sandy loam (Inceptisol) in texture with pH 7.9. During rainy season, in maize, there were 12 treatments, laid out in a randomized block design with three replications. The treatments included 8 BM treatments, involving two brown manure species (*Sesbania bispinosa* and *Crotalaria juncea*) sown at two seed rates (15 and 25 kg/ha) as sole/mixture (1:1), and were knocked down at two stages (25 and 35 DAS) using 2,4-D at 0.5 kg/ha. Four controls, namely, unweeded control, weed-free control, tank mixture of pendimethalin 0.75 kg/ha + atrazine 0.75 kg/ha, and atrazine 0.75 kg/ha + 1 hand-weeding at 35 DAS (HW) were also adopted with BM treatments. In all BM treatments, pendimethalin at 1 kg/ha was applied as pre-emergence. In winter, 12 brown manuring/weed control treatments adopted in maize were taken as main plot treatments, which are divided longitudinally into 3 strips/sub plots without any land preparation practices and disturbances in field layout and three levels of N, viz. 0,

60 and 120 kg N/ha were taken as sub-plot treatments to study residual effect of brown manuring in wheat crop (Table 1). The wheat sowing was carried out by using a tractor-drawn seed drill at a seed rate of 100 kg/ha with 20 cm row spacing. No herbicide was applied till 40 DAS. Among main plot treatments, only weed free control was regularly hand weeded to keep it weed free throughout the growth period. At 40 DAS, ready mix of metsulfuron methyl and sulfosulfuron was applied in all the main plot treatments, except unweeded control. An area of 100 cm (along one row) × 20 cm (both sides of the row, i.e. one row-width) was randomly selected from the central rows in each plot at 40 DAS. Weeds samples were collected from that area and quantified. Number of ear-bearing tillers was counted from one metre-row randomly from two rows, means were calculated and expressed as number of ear-bearing tillers/m. The crop was harvested manually and threshed mechanically by a thresher, and grains were cleaned properly. Weight of biomass and grain yield per plot was expressed in tonnes per ha. Harvested grain yields of wheat were reported at 12% moisture content (Oyeogbe *et al.* 2017). Grains from randomly sampled 20 earheads were separated, counted and expressed as the number of grains/earhead. Thousand grains of wheat from the harvested bulk grains of each plot were counted by using a seed counter, and their weight was expressed in g. Harvest index was computed by dividing the grain yield by the total biological yield and was expressed in percentage. Gross returns and

Table 1 Total weed density at 40 DAS, biological yield and gross returns (GR) in wheat across various treatments

Treatment	Total weed density (no./m ²)§	Biological yield (t/ha)	GR (x1000 ₹/ha)
Weed control treatment during previous rainy-season			
<i>Sesbania</i> 15 kg/ha and 2,4-D applied at 25 DAS	6.0 (36.0)	10.51	102.9
<i>Sesbania</i> 25 kg/ha and 2,4-D applied at 25 DAS	5.8 (33.0)	11.11	108.6
<i>Crotalaria</i> 15 kg/ha and 2,4-D applied at 25 DAS	6.5 (41.8)	9.79	96.1
<i>Crotalaria</i> 25 kg/ha and 2,4-D applied at 25 DAS	6.0 (36.4)	10.32	101.2
<i>Crotalaria</i> 15 kg/ha and 2,4-D applied at 35 DAS	6.4 (40.4)	9.90	97.6
<i>Crotalaria</i> 25 kg/ha and 2,4-D applied at 35 DAS	5.7 (32.3)	10.68	105.4
<i>Sesbania</i> + <i>Crotalaria</i> mixture (12.5+12.5 kg/ha) and 2,4-D applied at 25 DAS	5.7 (32.1)	10.85	106.6
<i>Sesbania</i> + <i>Crotalaria</i> mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS	5.7 (31.8)	11.42	111.5
Pendimethalin + atrazine	6.2 (38.1)	9.53	94.6
Atrazine + HW	6.2 (37.7)	9.82	97.2
Unweeded control	7.7 (59.4)	8.61	81.3
Weed-free control	0.7 (0.0)	10.80	105.2
LSD (P=0.05)	0.7 (9.3)	0.57	5.3
No nitrogen	5.5 (32.0)	7.56	72.5
Nitrogen at 60 kg/ha	5.8 (35.7)	10.94	107.5
Nitrogen at 120 kg/ha	5.9 (37.0)	12.32	122.1
LSD (P=0.05)	0.2 (2.6)	0.20	1.9

§ Data presented are $(x+0.5)^{1/2}$ transformed values; †Figures in parentheses are original values.

net returns were calculated by using equation 1 and 2, respectively (Das and Das 2018).

$$\text{Gross returns} = (\text{Value of the grains} + \text{value of straw/stover}) \quad (1)$$

$$\text{Net returns} = (\text{Gross returns} - \text{Total cost}) \quad (2)$$

Data on weeds and wheat crop were analyzed by the analysis of variance (ANOVA) technique for randomized complete block design using MSTAT C software (CIMMYT, Mexico City, Mexico). Weed data on density and dry weight having greater coefficient of variation than 20% were transformed through square-root ($\sqrt{x+0.5}$) method (Das 1999), and the transformed weed data were used for the ANOVA (Pal and Sarkar 2015). The significance was tested by the variance ratio (~F value) at $P \leq 0.05$. Standard error (SE) and least significant difference (LSD) were calculated for comparing treatment means of the studied variables of weeds and wheat.

RESULTS AND DISCUSSION

Weed interference in wheat

In wheat, three N levels were adopted under the previously adopted BM/weed control treatments in maize. It was observed that all BM/weed control treatments were inferior to the weed-free control in terms of reductions in total weed density at 40 DAS (Table 1). But, all the BM/weed control treatments resulted in significantly lower total weed

density than the unweeded control. The lowest total weed density ($\sim 31.8/\text{m}^2$), which was 46.5% lower than that in the unweeded control, was recorded in the *Sesbania*+*Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS. The BM treatments received pre-emergence application of pendimethalin 1.0 kg/ha and post-emergence 2,4-D application for knocking down *Sesbania*/*Crotalaria* plants. Probably, the seed bank of some winter weeds in the rainy season may have been exhausted by pendimethalin and 2,4 D, which were applied in BM treatments during rainy season as pre-emergence and post-emergence, respectively. The exhausted weed seed bank led to lower weed density in the winter season. Susha *et al.* (2018) reported similar reasons for significant carry-over effects of imazethapyr herbicide applied to maize in wheat. Besides, enough succulent biomass (~ 0.92 - 2.40 t/ha) was supplied in the BM treatments, which got easily decomposed before maize crop harvested. The decomposition could release certain organic acids/allelochemicals, which might have some harmful effects on weed seed bank (Das 2008). This might be responsible for significant carry-over effect of BM treatments on weeds in wheat. Three N levels superimposed on the previous season BM/weed control treatments could further influence weed population and dry weight in wheat. The N having positive effect on plants growth, weed population increased gradually with the increase in N doses from 0 to 120 kg N/ha. Total weed density was positively correlated with N level. Total weed density was highest due

Table 2 Yield attributes of wheat across various treatments

Treatment	Ear bearing tillers/ m^2	Grains/ spike	1000- grain weight (g)	Harvest Index (%)
Weed control treatment during previous rainy-season				
<i>Sesbania</i> 15 kg/ha and 2,4-D applied at 25 DAS	396.0	47.1	39.9	38.7
<i>Sesbania</i> 25 kg/ha and 2,4-D applied at 25 DAS	409.0	48.0	40.1	38.9
<i>Crotalaria</i> 15 kg/ha and 2,4-D applied at 25 DAS	384.4	45.7	39.5	38.6
<i>Crotalaria</i> 25 kg/ha and 2,4-D applied at 25 DAS	393.2	46.2	39.6	38.8
<i>Crotalaria</i> 15 kg/ha and 2,4-D applied at 35 DAS	387.7	46.3	39.5	38.4
<i>Crotalaria</i> 25 kg/ha and 2,4-D applied at 35 DAS	404.3	47.6	39.9	39.1
<i>Sesbania</i> + <i>Crotalaria</i> mixture (12.5+12.5 kg/ha) and 2,4-D applied at 25 DAS	409.7	47.8	40.1	39.0
<i>Sesbania</i> + <i>Crotalaria</i> mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS	419.6	49.1	40.3	38.5
Pendimethalin + atrazine	375.6	44.7	39.5	39.4
Atrazine + HW	383.7	45.5	39.4	39.1
Unweeded control	338.0	41.4	39.1	35.9
Weed-free control	402.9	47.2	40.3	38.3
LSD (P=0.05)	36.5	3.2	NS	NS
Nitrogen management				
No nitrogen	278.8	42.0	39.0	37.1
Nitrogen at 60 kg/ha	424.1	46.4	39.8	38.9
Nitrogen at 120 kg/ha	473.1	50.7	40.6	39.8
LSD (P=0.05)	11.2	1.77	NS	1.1

to nitrogen at 120 kg/ha ($\sim 37.1/\text{m}^2$) and were significantly higher than those in no nitrogen ($\sim 32.0/\text{m}^2$). The total weed density under the nitrogen at 120 kg/ha was 16% higher than those in no nitrogen. However, the treatment having nitrogen at 60 kg/ha having total weed density of $35.7/\text{m}^2$ was comparable with the nitrogen at 120 kg/ha. There was no significant interaction between the BM/weed control treatments and N levels.

Yield attributes and productivity of wheat crop

All BM/weed control treatments resulted in significantly greater numbers of ear bearing tillers (EBT) and grains/spike than the unweeded control (Table 2). Among them, the *Sesbania+Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS resulted in significantly higher values of ear bearing tillers ($\sim 419.6/\text{m}^2$) and grains/spike ($\sim 49.1/\text{spike}$). But, all other treatments, except the pendimethalin + atrazine, and the unweeded control for EBT, and except the *Crotalaria* 15 kg/ha and 2,4-D applied at 25 DAS, pendimethalin + atrazine, atrazine + HW and the unweeded control for grains/spike, were comparable with it. There were no significant differences in 1000-grain weight and harvest index due to BM/weed control treatments. The N levels adopted in wheat showed that the EBT number, grains/spike and harvest index were positively correlated with N level. The highest level of N (N at 120 kg/ha) resulted in highest numbers of EBTs ($\sim 473.1/\text{m}^2$), grains/spike ($\sim 50.7/\text{spike}$) and harvest index ($\sim 39.8\%$), which were significantly higher than those in no nitrogen ($\sim 278.8/\text{m}^2$, $42.0/\text{spike}$ and 37.1% , respectively). The EBT, grains/spike

and harvest index were 69.7%, 20.7% and 6.7% higher in N at 120 kg/ha than the no nitrogen, respectively. The N at 60 kg/ha having EBT number of 424.1/ m^2 , grains/spike of 46.4/spike and harvest index of 39.8% was comparable with the N at 120 kg/ha. There was no significant difference in 1000-grain weight between the levels of N. Also, there was no significant interaction between the BM/weed control treatments and N levels with respect to EBT, grains/spike, 1000-grain weight and harvest index.

The *Sesbania+Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS resulted in significantly higher wheat grain yield (Table 3) and biological yield (Table 1), but the *Sesbania* 25 kg/ha and 2,4-D applied at 25 DAS, *Crotalaria* 25 kg/ha and 2,4-D applied at 35 DAS, *Sesbania+Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 25 DAS and weed-free control were comparable with it. Irrespective of the BM/weed control treatments, higher the dose of N, higher was the wheat grain and biological yields and *vice-versa*. The highest dose of N at 120 kg/ha gave significantly higher grain and biological yields than N at 60 kg/ha and no nitrogen. There was significant interaction between the BM/weed control treatments and N levels on grain yield (Table 3). Wheat grain yield invariably in all BM/weed control treatments increased almost linearly from 0 to 120 kg N/ha. The increases in yield due to N at 60 kg/ha and N at 120 kg/ha were comparable under the *Sesbania* 25 kg/ha and 2,4-D applied at 25 DAS, *Sesbania+Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 25 DAS and *Sesbania+Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS

Table 3 Grain yield of wheat across various treatments

Treatment	Grain yield (t/ha)			
	No nitrogen	Nitrogen at 60 kg/ha	Nitrogen at 120 kg/ha	Mean
<i>Sesbania</i> 15 kg/ha and 2,4-D applied at 25 DAS	2.88	4.37	4.99	4.08
<i>Sesbania</i> 25 kg/ha and 2,4-D applied at 25 DAS	3.21	4.64	5.07	4.31
<i>Crotalaria</i> 15 kg/ha and 2,4-D applied at 25 DAS	2.53	4.00	4.91	3.82
<i>Crotalaria</i> 25 kg/ha and 2,4-D applied at 25 DAS	2.78	4.32	4.95	4.02
<i>Crotalaria</i> 15 kg/ha and 2,4-D applied at 35 DAS	2.57	4.18	4.93	3.89
<i>Crotalaria</i> 25 kg/ha and 2,4-D applied at 35 DAS	3.06	4.55	5.03	4.21
<i>Sesbania</i> + <i>Crotalaria</i> mixture (12.5+12.5 kg/ha) and 2,4-D applied at 25 DAS	3.07	4.60	5.05	4.24
<i>Sesbania</i> + <i>Crotalaria</i> mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS	3.30	4.80	5.12	4.41
Pendimethalin + atrazine	2.53	3.98	4.89	3.80
Atrazine + HW	2.60	4.11	4.94	3.88
Unweeded control	2.32	3.30	3.68	3.10
Weed-free control	2.84	4.40	5.19	4.15
Mean	2.81	4.27	4.90	
<i>LSD</i> ($P=0.05$)				
Main plot treatments (A)		0.32		
Sub plot treatments (B)		0.10		
A $\times$ B		0.46		

Table 4 Net returns (NR) across various treatments in wheat

Treatment	NR ($\times 1000$ ₹/ha)			
	No nitrogen	Nitrogen at 60 kg/ha	Nitrogen at 120 kg/ha	Mean
<i>Sesbania</i> 15 kg/ha and 2,4-D applied at 25 DAS	43.8	79.2	93.2	72.1
<i>Sesbania</i> 25 kg/ha and 2,4-D applied at 25 DAS	51.5	85.0	96.9	77.8
<i>Crotalaria</i> 15 kg/ha and 2,4-D applied at 25 DAS	36.4	71.0	88.1	65.2
<i>Crotalaria</i> 25 kg/ha and 2,4-D applied at 25 DAS	41.2	77.6	92.2	70.4
<i>Crotalaria</i> 15 kg/ha and 2,4-D applied at 35 DAS	37.2	74.4	88.5	66.7
<i>Crotalaria</i> 25 kg/ha and 2,4-D applied at 35 DAS	47.0	82.3	94.3	74.5
<i>Sesbania</i> + <i>Crotalaria</i> mixture (12.5+12.5 kg/ha) and 2,4-D applied at 25 DAS	48.2	83.7	95.3	75.7
<i>Sesbania</i> + <i>Crotalaria</i> mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS	54.7	89.4	97.9	80.6
Pendimethalin + atrazine	36.0	68.9	86.2	63.7
Atrazine + HW	37.8	72.6	88.5	66.3
Unweeded control	33.9	57.7	65.7	52.4
Weed-free control	34.2	71.0	92.2	65.8
Mean	45.8	80.0	93.9	
LSD ($P=0.05$)				
Main plot treatments (A)		5.3		
Sub plot treatments (B)		1.9		
A $\times$ B		6.8		

brown manuring treatments, but not in other treatments. The *Sesbania*+*Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS with N at 60 kg/ha gave comparable grain yield (~ 4.89 t/ha) with weed-free control applied with N at 120 kg/ha (~ 5.12 t/ha), indicating a saving of 60 kg N/ha ($\sim 50\%$ N) in this treatment. The addition of N through brown manure crop biomass resulted in better N nutrition in BM treatments, which led to significant enhancement of yield attributes, viz. ear bearing tillers, grains/spike, and grain and biological yields of wheat. Nawaz *et al.* (2017) also reported increase in wheat yields due to brown manuring in preceding rice crop.

Profitability of wheat crop

Among the BM/weed control treatments, the *Sesbania*+*Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS resulted in significantly higher gross returns (~ 111500 ₹/ha) and net returns (~ 80610 ₹/ha) than all other treatments, except the *Sesbania* 25 kg/ha and 2,4-D applied at 25 DAS and *Sesbania*+*Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 25 DAS, which were comparable with it in these regards (Table 1 and 4, respectively). Higher the dose of N, higher was the gross and net returns and *vice-versa*. Gross and net returns invariably in all BM/weed control treatments increased almost linearly from 0 to 120 kg N/ha. There were significant interactions between BM/weed control treatments and N levels on net returns (Table 4). Almost all BM/weed control treatments gave significantly higher gross returns in N at 120 kg/ha than N at 60 kg/ha and no nitrogen. But, the *Sesbania*+*Crotalaria*

mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS with N at 60 kg/ha gave comparable net returns (~ 89400 ₹/ha) with weed-free control applied with N at 120 kg/ha (~ 92200 ₹/ha). The weed-free control (WFC) treatment was maintained weed free throughout the crop growing period in wheat. The previously-adopted other 11 treatments (in maize) were kept as such to assess their residual effects. As a result, there were no treatment costs involved for these 11 treatments, but WFC incurred extra-treatment cost in wheat. Better residual weed control and N nutrition in wheat provided by the *Sesbania* 25 kg/ha and 2,4-D applied at 25 DAS, *Sesbania*+*Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 25 DAS and *Sesbania*+*Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS treatments led to higher wheat productivity. Higher crop productivity and lower cost of cultivation led to higher profitability in these treatments.

Conclusion

This study showed that the brown manuring had considerable carry-over effects on weeds, and productivity and profitability of succeeding wheat. The brown manuring that involved *Sesbania*+*Crotalaria* mixture (12.5+12.5 kg/ha) and 2,4-D applied at 35 DAS showed highest carry-over effect when was supplemented with 120 kg N/ha, but 60 kg N/ha was similar to it with respect to grain yield. Even this treatment was comparable with the weed-free control at 120 kg N/ha in terms of grain yield and net returns. This indicates a saving of 60 kg N/ha in wheat. The mixture of *Sesbania bispinosa* and *Crotalaria juncea* (12.5+12.5

kg/ha) and 2,4-D 0.5 kg/ha applied at 35 DAS combined with 60 kg N/ha can provide higher wheat productivity and profitability, and, therefore, may be recommended.

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