Indian Journal of Agricultural Sciences **86** (2): 197—201, February 2016/Article
https://doi.org/10.56093/ijas.v86i2.55944

Sequential and tank-mix application of herbicides for weed management ensuring higher productivity of soybean (*Glycine max*)

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Received: 29 September 2014; Accepted: 7 December 2015

ABSTRACT

A field experiment aimed to evaluate the bioefficacy of pre- and post-emergence herbicides on weed dynamics and yield in soybean (*Glycine max* L.) was conducted during *kharif* season of 2011 and 2012 at New Delhi. Herbicide treatments provided weed control efficiency ranging from 43.25% to 72.81% over weedy check. Sequential application of metribuzin @ 250 g/ha as pre-emergence followed by (*fb*) propaquizafop @ 50 g/ha at 3 weeks after sowing (WAS) as post-emergence was found most effective in reducing weed growth, augmenting seed and stover yield with the highest net monetary return. Combined application of pendimethalin @ 750 g/ha as pre-emergence *fb* propaquizafop @ 50 g/ha at 3 WAS was also equally effective. Quantitative analysis of soil microflora showed that herbicidal application significantly suppressed the microbial population at 30 DAS which recovered at the harvest of soybean.

Key words: Herbicides, Microbial population, Soybean, Weed control efficiency, Yield

Soybean (*Glycine max* L.) a legume oilseed crop is one of the most important crops in India for human consumption whose yield is severely reduced by persistent and complex weed competition. The extent of yield reduction due to biotic stress caused by uncontrolled weeds can go up to 85% reduction in seed yield depending on the weed species, their intensity and duration of weed infestation (Upadhyay *et al*. 2012). The root and shoot interference by the weeds are the main factors that cause reduction in the yield of soybean (Jannink *et al*. 2000). Several herbicides, viz. pendimethalin, alachlor, metribuzin etc. are presently being used for controlling the weeds in soybean, but on the wake of weed shift caused by continuous use of these herbicides and the greater possibility of development of herbicide resistant weeds, the relevance and rationality of using alternate herbicides, sequential application and tank-mixes of different herbicides come to the picture. These methods may widen the application window, provide effective weed management in soybean, facilitate herbicide rotation and avoid the ill effects of repeated use of same herbicides. Likewise, intensive use of herbicides without adequate knowledge of its effects on soil microflora may cause adverse impact on soil biochemical processes and cycling of nutrients. Keeping this in view, the present investigation was undertaken to evaluate the post-emergence application of propaquizafop coupled with other herbicides to identify new appropriate options for effective weed management in soybean.

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MATERIALS AND METHODS

Field trial was conducted during *kharif* season of 2011 and 2012 at Indian Agricultural Research Institute, New Delhi, situated at 28^0 352 N latitude and 77^0 122 E longitude and at an altitude of 228.6 m above mean sea level to evaluate the bioefficacy of different herbicides in soybean. The soil of experimental field was sandy loam in texture, low in organic carbon (0.38%) and available P (9.22 kg/ha), medium in available K (259.9 kg/ha) with pH 7.6. Ten treatments of weed control measures (Table 1) were laid out in randomized block design and replicated thrice. Soybean variety Pusa 9814 was sown in line with row spacing of 45cm at 75 kg seed/ha on 10 July 2011 and 12 July 2012, respectively. A uniform dose of 25 kg N, 60 kg P_2O_5 and 25 kg K_2O /ha were applied basal by broadcasting and mixed in the soil before sowing. Standard agronomic practices were followed to raise the crop. Herbicides were applied with the help of a manually operated knapsack sprayer fitted with flat-fan nozzle as per treatment schedule (Table 1).

The data on weed flora and weed count were recorded at 60 DAS and weed dry weight at 60 DAS by placing quadrats of size 0.25 m^2 randomly at two spots in each plot. Weed data were subjected to square root transformation before statistical analysis to normalise their distribution. Weed control efficiency (at 60 DAS) and weed index (at harvest) were calculated by the formula suggested by Patel *et al*. (1983) and Gill and Kumar (1969), respectively.

Table 1 Effect of weed control measures on different weed species in soybean (pooled data of 2 years)

Treatment	Weed density* (No/m^2) at 60 DAS					Total weed density	Total weed dry weight at 60 DAS (g/ m^2)	Weed control efficiency at 60 DAS (%)
	Cyperus rotundus	*Dactyloctenium aegyptium*	*Digera arvensis*	*Digitari-a sanguinalis*	*Trianthe-ma portul-acastrum*			
Pendimethalin @ 1 000 g/ha (PE)	4.82 (22.73)	4.99 (24.40)	3.18 (9.61)	3.53 (11.96)	3.82 (14.09)	9.82 (95.93)	9.49 (89.56)	61.05
Pendimethalin @750 g/ha (PE) *fb* propaquizafop @ 50 g/ha (3 WAS)	4.96 (24.10)	2.99 (8.44)	3.61 (12.53)	2.95 (8.20)	4.15 (16.72)	8.66 (74.50)	8.35 (69.22)	69.46
Metribuzin @ 500g/ha (PE)	4.68 (21.4)	4.86 (23.12)	2.99 (8.44)	3.170 (9.55)	3.62 (12.60)	9.11 (82.49)	9.14 (83.04)	66.10
Metribuzin @ 250g/ha (PE) *fb* propaquizafop @ 50 g/ha (3 WAS)	4.78 (22.35)	2.99 (8.44)	3.42 (11.20)	2.44 (5.45)	4.17 (16.89)	8.18 (66.41)	8.02 (63.82)	72.81
Propaquizafop @75 g/ha (2 WAS)	6.46 (41.23)	3.23 (9.93)	4.28 (17.82)	2.60 (6.26)	6.64 (43.59)	11.30 (127.19)	11.78 (138.27)	47.88
Propaquizafop @ 50 g/ha + imazethapyr @ 50 g/ha (3 WAS)	5.46 (29.31)	5.97 (35.14)	3.80 (13.94)	4.41 (18.95)	4.32 (18.16)	11.02 (120.94)	10.99 (120.28)	50.93
Propaquizafop @ 75 g/ha (3 WAS)	6.68 (44.12)	3.42 (11.20)	4.44 (19.21)	2.73 (6.95)	6.73 (44.79)	11.79 (138.50)	11.97 (142.78)	43.25
Propaquizafop @ 50 g/ha + chlorimuron-ethyl @ 9g/ha (3 WAS)	4.82 (22.73)	5.85 (33.72)	3.61 (12.53)	4.26 (17.65)	3.95 (15.10)	10.28 (105.18)	10.27 (104.97)	56.87
Weed free check	0.71 (0.0)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	100.00
Weedy check	7.07 (49.48)	8.23 (67.23)	4.59 (20.57)	5.70 (31.99)	7.19 (51.20)	15.74 (247.25)	16.90 (285.11)	0.00
SEm±	0.18	0.17	0.15	0.16	0.19	0.22	0.22	1.84
LSD(P=0.05)	0.52	0.49	0.43	0.46	0.54	0.63	0.63	5.27

PE, Pre-emergence; DAS, Days after sowing; WAS, Weeks after sowing; *fb*, Followed by.*Data were subjected to square root transformation before statistical analysis. Figures in parentheses are original values.

Data on crop dry matter, yield attributes and seed yield of soybean were taken at harvest. Soil samples were also collected at 30 DAS and harvest of the crop from each plot for investigating the effect of herbicides on total population of soil microbes namely bacteria, actinomycetes and fungi by following dilution technique. Enumeration of the total number of bacteria (Allen 1959), fungi (Martin 1950), and actinomycetes (Allen 1959) using suitable dilutions, was carried out by the dilution plate method. The plates were incubated at 30 ± 1^0C and observations for their numbers were recorded accordingly and population was calculated and expressed as number of cells × 10^n/g soil. The data were statistically analyzed as described by Gomez and Gomez (1984). Where, the F test was significant (at 5% level of significance), the Least Significant Differences (LSD) was used to compare mean at P=0.05 due to variation.

RESULTS AND DISCUSSION

Weed flora

The experimental field of soybean crop was infested mainly with *Dactyloctenium aegyptium* (23.58%) and *Digitaria sanguinalis* (11.22%) among grasses and *Trianthema portulacastrum* (17.96%) and *Digera arvensis* (7.21%) among broad-leaved weeds and *Cyperus rotundus* (17.36%) among sedges (Table 1). The predominance ofthese weeds in soybean under Delhi condition was reported earlier by Idapuganti *et al.* (2005). Weed control measures profoundly influenced the distribution of weed flora, population and dryweight of all dominant weed species infesting the experimental field. Among herbicide treatments, the lowest density and dry weight of weeds was recorded by sequential application of metribuzin @ 250 g/ha as pre-emergence (PE) followed by (*fb*) propaquizafop @ 50 g/ha as post-emergence at 3 weeks after sowing (WAS), but remained statistically at par with combined application of pendimethalin @ 750 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS. Pre-emergence application of metribuzin @ 500 g/ha registered the lowest weed density and dry weight among different sole application herbicidal treatments, which, however, was found at par with pre-emergence application of pendimethalin @ 1 000 g/ha. The post-emergence application of propaquizafop effectively controlled all the grassy weeds, but failed to control sedges and broad-leaved weeds. Similar result on the efficacy of propaquizafop was reported earlier by Tiwari and Mathew (2002). Post-emergence application of propaquizafop at 2 WAS showed the lower density and dry weight of weeds compared to its application at 3 WAS but was found statistically similar to the latter treatment.

In tank-mix combination of herbicides, post-emergence application of propaquizafop @ 50 g/ha + chlorimuron-ethyl @ 9 g/ha at 3 WAS recorded the lowest density and dry weight of weeds compared to the other treatment (propaquizafop @ 50 g/ha + imazethapyr @ 50 g/ha at 3 WAS). Both of the tank-mix treatments were expected to provide broad-spectrum control of weeds but have failed to provide so, especially for grass control. The tank-mix combinations of propaquizafop + imazethapyr and propaquizafop + chlorimuron-ethyl registered significantly lower control of grassy weeds compared to the sole applications of propaquizafop at 2 WAS and 3 WAS. This reduced control of weeds by the tank-mixes might be due to antagonistic reactions between the component herbicides. Similar reports of antagonism when broad leaf herbicides were mixed with post-emergence graminicides was observed by Holshouser and Coble (1990) and Vidrine *et al.* (1995). The most widely reported examples of such antagonism concern the aryloxyphenoxypropionate and cyclohexanedione families of graminicides. The antagonism could be due to many factors, including physical incompatibility in the tank mix, alterations in herbicide uptake, translocation and metabolism and interference with specific metabolic processes or regulatory cellular events (Barnwell and Cobb 1994). The fact that propaquizafop belongs to aryloxyphenoxypropionate family indicates the possibility of antagonistic reactions in tank-mixes. Tiwari and Mathew (2002) also noted that the efficacy of propaquizafop was reduced when it was mixed with chlorimuron-ethyl, probably due to antagonistic effect leading to decline in seed yield/ha.

Growth, yield and yield attributes of soybean

The growth of soybean in terms of dry matter accumulation was the highest with weed free treatment which, however was found at par with combined application of metribuzin @ 250 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS (Table 2). All weed control treatments significantly favoured yield attributes such as, pods per plant and 100-seed weight (seed index) as compared to weedy check (Table 2).The effect of different treatments on seeds/pod was non-significant. Among herbicidal treatments, highest values for different growth attributes like pods/plant, seeds/pod, seed index were recorded in plots treated with sequential application of metribuzin @ 250 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS. Second best herbicidal treatment favouring higher yield attributes was combined application of pendimethalin @ 750 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS. Consequently, these two treatments viz. metribuzin @ 250 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS and pendimethalin @ 750 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS produced highest seed, stover and biological yield of soybean (Table 2) among herbicide treatments. The regression equation predicted linear decrease in the grain yield with a unit increase in the weed dry matter (Fig 1). The extent of decrease could be 0.567 tonnes/ha in seed yield due to a unit increase in weed dry matter. The regression analysis further justified the importance of weed control measures for higher seed yield of soybean.

Table 2 Effect of weed control measures on growth, yield attributes, yield and economics of soybean (pooled data of two years)

Treatment	Crop dry matter (g/plant)	Pods/ plant	Seeds/ pod	Seed index (g)	Seed yield (tonnes/ha)	Stover yield (tonnes/ha)	Net monetary returns (× 10^3 ₹/ha)	B:C ratio
Pendimethalin @ 1000 g/ha (PE)	24.9	41.8	2.2	12.42	1.68	3.02	23.53	2.77
Pendimethalin @ 750 g/ha (PE) *fb* propaquizafop @ 50 g/ha (3 WAS)	26.0	44.2	2.3	12.72	1.90	3.44	26.63	2.95
Metribuzin @ 500g/ha (PE)	25.3	41.7	2.3	12.50	1.73	3.15	23.48	2.70
Metribuzin @ 250 g/ha (PE) *fb* propaquizafop @ 50 g/ha (3 WAS)	27.1	46.9	2.3	12.82	1.94	3.46	27.23	2.97
Propaquizafop @ 75 g/ha (2 WAS)	23.1	35.8	2.2	12.23	1.52	2.92	18.69	2.44
Propaquizafop @50 g/ha + imazethapyr @ 50 g/ha (3 WAS)	23.0	37.1	2.2	12.30	1.59	3.08	20.24	2.55
Propaquizafop @ 75 g/ha (3 WAS)	22.2	34.2	2.1	12.11	1.47	2.92	17.19	2.32
Propaquizafop @ 50 g/ha + chlorimuron-ethyl @ 9g/ha (3 WAS)	24.3	41.3	2.2	12.50	1.64	3.10	22.75	2.74
Weed free	28.1	49.8	2.4	13.03	2.10	3.65	24.11	2.27
Weedy check	14.2	23.8	2.1	11.67	0.53	1.10	2.75	1.22
SEm±	0.4	0.8	0.4	0.12	0.03	0.08		
LSD(P=0.05)	1.15	2.29	NS	0.34	0.09	0.23		

PE, Pre-emergence, DAS, Days after sowing; WAS, Weeks after sowing; *fb*; Followed by.

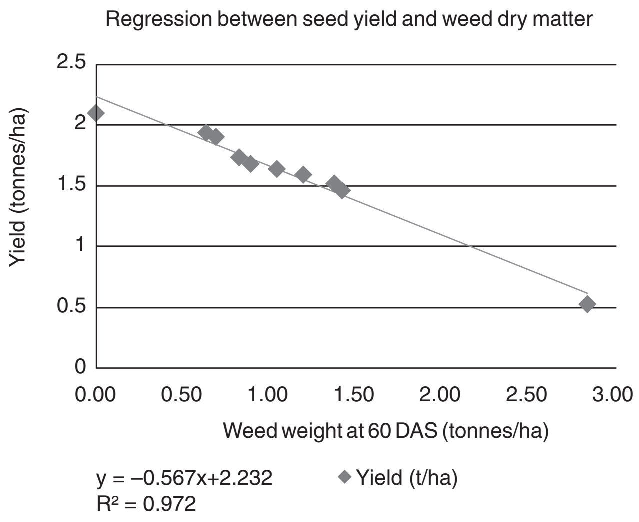

Fig 1 Linear regression between seed yield and weed dry weight

Economics of soybean cultivation as affected by weed management treatments

The economic analysis of weed management treatments (Table 2) revealed that higher economic benefits were realized under sequential application of different herbicides. Sequential application of metribuzin @ 250 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS registered the highest net profit of ₹ 27 232 followed by sequential application of pendimethalin @ 750 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS (₹ 26 629). Higher B:C ratio was also associated with sequential application of metribuzin @ 250 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS (2.97) followed by sequential application of pendimethalin @ 750 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS (2.95).

Effect of herbicides on soil microflora

Application of herbicides had significant impact on soilmicroflora (Table 3). Population of bacteria, fungi and actinomycetes was significantly reduced due to herbicides application at 30 DAS as compared to untreated plots (weedy check and weed free check). This can be attributed to the effect of herbicides itself or its degradation products on microbial activity (Kim and Hong, 1988). However, the population of all three microbes didnot vary significantly due to herbicidal treatments at the harvest of the crop. This might be due to resilience inthe population of bacteria, fungi and actinomycetes probably due to reduction in the adverse effect of herbicides with passage of time. These findings are in accordance with that of Rajendran and Lourduraj (1999).

Maximum microbial population in soybean rhizosphere was noticed in untreated plots, whereas, minimum was in plots treated with tank-mix of propaquizafop @ 50 g/ha + chlorimuron-ethyl @ 9 g/ha at 3 WAS which however was at par with tank-mix of propaquizafop @ 50 g/ha + imazethapyr @ 50 g/ha at 3 WAS, combined application of metribuzin @ 250 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS and combined application of pendimethalin @ 750 g/ha (PE) *fb* propaquizafop @ 50 g/ha at 3 WAS.

Based on the present data, it may be concluded that maximum yield of soybean with the highest net monetary return owing to better and timely weed control could be obtained with either sequential application of metribuzin @ 250 g/ha followed by propaquizafop @ 50 g/ha applied as pre-emergence and post-emergence, respectively, or the sequential application of pendimethalin @ 750 g/ha as pre-emergence followed by propaquizafop @ 50 g/ha as post-emergence. Quantitative analysis of soil at the harvest of soybean did not show any adverse effect on soil microflora.

Table 3 Soil microflora as affected by weed control treatments in soybean (pooled data of two years)

Treatment	Bacteria (10^{-7} CFU/g soil)		Fungi (10^{-4} CFU/g soil)		Actinomycetes (10^{-5} CFU/g soil)	
	30 DAS	At harvest	30 DAS	At harvest	30 DAS	At harvest
Pendimethalin @ 1000 g/ha (PE)	164.500	165.83	16.000	24.17	52.33	62.33
Pendimethalin @ 750 g/ha (PE) *fb* propaquizafop @ 50 g/ha (3 WAS)	141.667	169.17	12.167	25.83	40.50	64.00
Metribuzin @ 500g/ha (PE)	164.500	160.17	15.333	26.50	48.50	66.00
Metribuzin @ 250 g/ha (PE) *fb* propaquizafop @ 50 g/ha (3 WAS)	143.500	167.17	12.500	27.50	40.67	65.00
Propaquizafop @ 75 g/ha (2 WAS)	157.500	170.50	16.500	26.17	50.33	64.33
Propaquizafop @ 50 g/ha + imazethapyr @ 50 g/ha (3 WAS)	143.167	164.17	13.000	27.50	41.67	63.33
Propaquizafop @ 75 g/ha (3 WAS)	147.500	163.17	15.500	25.17	46.50	62.67
Propaquizafop @ 50 g/ha + chlorimuron-ethyl @ 9g/ha (3 WAS)	138.667	167.17	11.500	27.83	39.83	62.00
Weed free check	194.667	167.50	23.000	25.17	65.83	63.00
Weedy check	200.167	165.83	23.833	26.83	69.00	65.67
SEm±	1.793	1.53	0.634	0.61	0.87	1.18
LSD(P=0.05)	5.13	NS	1.82	NS	2.48	NS

PE, Pre-emergence, DAS, Days after sowing; WAS, Weeks after sowing; *fb*, Followed by; NS, non-significant.

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