Indian Journal of Weed Science (2023) **55**(2): 174–180
http://dx.doi.org/10.5958/0974-8164.2023.00031.X

RESEARCH ARTICLE

Development and performance evaluation of herbicide applicator-cum-planter to manage weeds in soybean

R.R. Potdar[1]*, P.S. Tiwari[1], D. Singh[1], M. Kumar[1], A.K. Roul[1], B. Jyoti[1], A.P. Pandirwar[1] and C.R. Chethan[2]

Received: 22 August 2022 | Revised: 9 May 2023 | Accepted: 12 May 2023

ABSTRACT

Manual weeding or herbicide application using manual operated tools/equipment are commonly used by farmers to manage weeds in *Kharif* season and they are laborious and time-consuming. During the rainy season, mechanical weed management is difficult in the early stages of crop growth due to prevailing environment. To address this issue, the ICAR-CIAE, Bhopal, conceived and developed a tractor-operated 6-row pre-emergence herbicide strip-application system used in conjunction with an inclined-plate planter to manage weeds in widely spaced crops. The developed pre-emergence herbicide applicator-cum-planter (PREHAP) was evaluated, during the *Kharif* season, to compare its efficacy using different pre-emergence herbicides with hand weeding and inter cultivation between crop rows for weed management in soybean. The lowest weed density and weed infestation were observed with the broadcast application of pre-emergence herbicide with PREHAP followed by one hand weeding and resulted in highest soybean plant height, number of pods, seed yield, net economic return and B:C. The PREHAP that could spray herbicide in both band and wide area was found to be a good way to apply herbicide while sowing the crop .

Keywords: Herbicide applicator cum planter, Herbicide, Inclined plate planter, Soybean, Weed management

INTRODUCTION

Weed control is extremely crucial to achieve optimal production and productivity of various cultivated crops. Weeds compete with cultivated crops for moisture, nutrients sunlight, and space. It has been reported that if adequate weed control measures are not used, crop yield can be reduced by more than, 50% (Gharde *et al.* 2018). Weed control operations are mainly carried out after the emergence of the crop and weeds. Weed management is done using mechanical, cultural, and chemical approaches. Mechanical weed management comprises just pulling away the weeds by hand or the use of equipment and machines operated by animal or mechanical power sources or their combination. Manual weeding is a highly labour-demanding, drudgery involved, time-consuming, and costly operation (Kumar *et al.* 2019, Kumar *et al*. 2021; Chethan *et al.* 2022). The heavy machines used in mechanical weed control disrupt the soil surface, resulting in soil erosion and loss of nutrients. Weed management with herbicides does not create soil disturbance but may have detrimental impact on the environment. Integrated weed management (IWM) aims to minimise environmental problems, boost economic returns and adoption of non-chemical approaches without reducing yield levels (Swanton and Weise 1991, Rao and Nagamani 2010, Niazmand *et al.* 2008, Talnikar *et al.* 2008). To control the weeds at different stages of the crop's growth, the herbicide can be administered pre-planting, pre-emergence, and post-emergence of the crop. The herbicides are primarily applied either by broadcasting or by banding along the crop rows.

Broadcasting, *i.e.*, spraying of herbicide over an entire agricultural field, is the existing practice of herbicide application in India. The excessive use of herbicides results in environmental problems such as entering the herbicide into underground water resources and deep wells or movement of the herbicide to far places by rainwater or flooding (Kalkhoff *et al*. 2003). Applying herbicide along crop rows, i.e., banded application (Swanton *et al.* 2002, Sankula *et al*. 2001) and mechanical cultivation between the rows, can solve the problem (Malik *et al.* 2006). Herbicide banding consists of spraying herbicide primarily over the crop rows, covering a width of around 200–300 mm. The weeds in the gap between two crop rows could be controlled either manually or mechanically.

[1] ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh 462038, India

[2] ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India

* Corresponding author email: rrpotdar@gmail.com

The biggest challenge in carrying out weeding activities is the erratic and continuous rains during the *Kharif* season. Due to climate change, the monsoon pattern has changed drastically. This resulted in persistent heavy rainfall, generating flood like scenarios in some areas and frequent dry periods in other sections of the country. Therefore, a lack of opportunity time makes mechanical as well as chemical weed management problematic in the initial stages of crop growth. In such situations, the application of pre-emergence herbicide along with sowing or planting operations in either band or broadcast mode will provide better control over the weed in the early stages of crop growth. When the pre-emergence herbicide is applied concurrently with the sowing or planting device, both time and money can be saved. In addition, it is evident that banded application of herbicide with mechanical cultivation can minimise herbicide consumption by up to 50% without decreasing crop production. Thus, a pre-emergence herbicide applicator-cum-planter (PREHAP) with a band and broadcast herbicide-spraying ability was developed and the developed machine was evaluated for different weed control treatments.

MATERIALS AND METHODS

Development of herbicide applicator-cum-planter

The tractor-drawn PREHAP (**Figure 1**) is made up of a frame with a cat-II 3-point linkage, a tool bar, one herbicide solution tank, one single action piston pump, one pressure gauge, hose connections, a fertiliser box, six modular seed boxes attached with spray-nozzle assembly, furrow openers, and a ground wheel drive power system to operate the seed and fertiliser metering mechanisms. The solution tank is made of stainless steel with baffles inside the tank to maintain the centre of gravity in the middle line of the frame. An inside-fitting lid is also provided to prevent spillage during operation. A Micronics fitter assembly is fitted inside the tank, and filtered liquid is sent to the intake port of the plunger pump. The overflow pipe returns excess liquid to the top of the tank. Liquid from the bottom of the tank is conveyed to the inlet of the piston pump through a flexible PVC suction hose. After that, the liquid is conveyed from the outlet of the pump to spray nozzles at a desired pressure, as indicated by a pressure gauge, through flexible PVC delivery hoses. For ease of fixing and leak-proof connections, water-tight standard tank nipples of 12.5 and 20 mm are used for overflow and outlet, respectively. A spray nozzle assembly is attached to the seed boxes with the help of mounting clamps. The mounting clamps have provision for adjusting the angle and height of the spray nozzles, which facilitates the system for accurately applying a strip or broadcast of pre-emergence herbicide. The seed boxes have an inclined plate type seed metering mechanism. Seed plates for sowing different seeds can be selected and easily changed in the seed boxes. The plate thickness, number of cells, and size of cells on the seed plate vary according to seed size and desired plant-to-plant spacing. Bold seeds as well as small seeds can be sown with this planter by just changing the suitable metering plate. In addition,

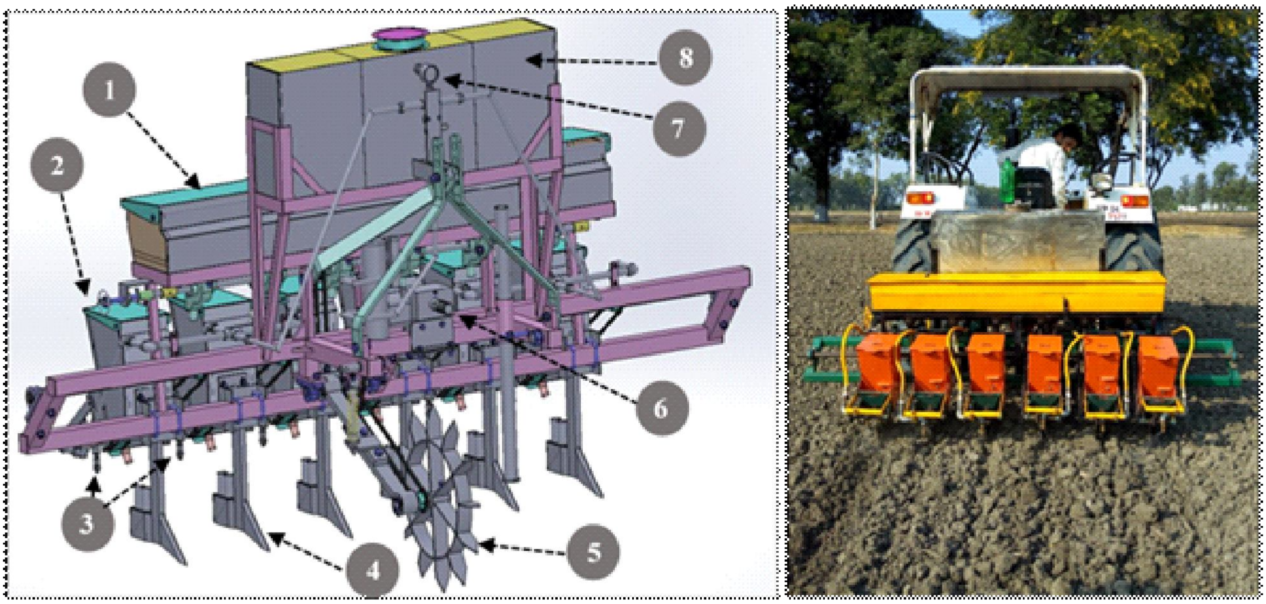

Figure 1. Developed herbicide applicator-cum-planter (1 – Fertilizer box; 2 – Seed box; 3 – Spray nozzle assembly; 4 – Furrow opener; 5 – Ground wheel; 6 – Single-action piston pump; 7 – Pressure gauge; 8 – Herbicide tank)

simultaneous sowing of different intercrops can be possible with the PREHAP. The PREHAP has the benefit that row-to-row spacing between the seed boxes can be easily adjusted. Inverted T-type furrow openers were used for making well-defined groove in the soil for proper placement of the seed. The seed box-furrow opener assemblies are adjustable for sowing seeds at different row-to-row spacings. The fertiliser box, mounted on the main frame, has a fluted roller type metering mechanism for the application of granular fertilizers. All manual adjustments on the PREHAP are made in accordance with ergonomic design principles (Gite *et al.* 2020). The technical details of the PREHAP are given in **Table 1**.

Selection of the spray pump capacity and spray nozzle tip for herbicide application system

For the selection of the spray pump capacity and spray nozzle tip, a few preliminary calculations were made to determine the required spray discharge rate per nozzle tip, total spray discharge rate through all nozzles, and the required spray tank capacity for pre-emergence herbicide application in banded as well as broadcast mode. Generally, the pre-emergence herbicide (pendimethalin) was applied at a rate of 1 kg/ha using 500 L of water (Dixit and Varshney 2009). The required discharge rate per nozzle tip was worked out as 500 mL/min for 450 mm row-row spacing, 200 mm of herbicide band width, and 3 km/h of tractor operating speed. A total discharge rate of 3.0 L/min at pressure 1.0 kg/cm^2 was determined for

Table 1. Technical specifications of the developed herbicide applicator-cum-planter

Particular		Value
Overall dimensions (l×b×h), mm	:	2300 × 1120 × 1010
Size of fertilizer box (l×b×h), mm	:	1600 × 250 × 200
Capacity of fertilizer box, kg	:	150
Machine frame size (l×b×h), mm	:	2510 × 650 × 400
Power source	:	Tractor of 26 kW or higher
No of rows	:	Six
Ground wheel size (diameter), mm	:	540 × 50
Row to row spacing, mm	:	Adjustable from 250 to 450
Seed metering	:	Inclined plates with cells on the periphery made of machined aluminium
Fertilizer metering	:	Casted aluminium fluted rollers.
Furrow openers	:	Inverted T-type
Power train for metering	:	Chain and sprockets and bevel gears
Seed box capacity, kg	:	8 to 10
Number of seed boxes	:	Six
Size of herbicide tank (l×b×h), mm	:	1000 × 200 × 400
Herbicide tank capacity, litres	:	80
Spray pump	:	Single action piston pump of 9 L/min capacity
Spray tip type	:	Flat fan nozzle
Number of spray nozzle tips	:	Six

the whole system for banded mode application of herbicide. Similarly, a discharge rate of 1.125 L/min per nozzle tip and a total discharge rate of 6.75 L/min at pressure 2.0 kg/cm^2 was determined for the whole system for the application of herbicide in broadcast mode. Considering the determined information in the preliminary calculations, a single-action pump having a liquid delivery capacity of 9 L/min was selected. For herbicide applications, flat fan-type spray tips are primarily used (Bindra and Singh 1977). Therefore, the flat fan type of nozzles meeting the desired requirement and commercially available in the market, were selected for the herbicide application during field experiments.

Field experiment

A field experiment was conducted in the *Kharif* 2019 and 2020 for evaluation of the efficacy of the developed PREHAP in *Kharif* soybean crop (variety JS 9560) at ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India. The experimental farm used in the present study has been under a soybean-wheat cropping system for the last five years, with even topography and a good drainage facility. The study site (Bhopal) is situated at 23.26° N latitude, 77.41° E longitude, and altitude of about 527 m above mean sea level in a humid subtropical climate. The soil of the experimental field was clayey loam in texture with 47-54% clay content, alkaline in nature (pH 7.7), and 0.24 dS/m EC. The field experiments were laid out in a randomized complete block design (RCBD) with three replications and seven treatments of weed control. Each plot size was 100 m^2. The treatments included in the field experiments were: control *i.e.* no herbicide application, no manual/mechanical weeding; intercultivation (hoeing) once between the crop rows; hand weeding once after 30 days after seeding (DAS); banded application of pre-emergence herbicide by PREHAP; broadcast application of pre-emergence herbicide over the entire field by PREHAP; band application of pre-emergence herbicide by PREHAP followed by (*fb*) one manual weeding after 30 DAS; broadcast application of pre-emergence herbicide over the entire field by PREHAP *fb* one manual weeding after 30 DAS.

In the treatments involving no herbicide application, only the planter system of PREHAP was used for seeding of the soybean crop. The developed PREHAP was set at 450 mm of row-to-row spacing between the seed boxes for the soybean crop. The seed metering plates suitable for sowing soybean seeds were mounted in the seed boxes. To operate the

PREHAP, a two-wheel drive tractor (3630 New Holland, CNH Industrial Pvt. Ltd., India) was used as a prime mover for laying down the treatments. During banded and broadcast herbicide application treatments, the pre-emergence application (PE) of herbicide (pendimethalin) at a rate of 1 kg/ha was done using the developed PREHAP, simultaneously with the seeding operation. In banded herbicide application treatments, the pre-emergence herbicide in the band of 200 mm was applied by adjusting the spray nozzle setting. In the case of broadcast herbicide application treatments, spray nozzle tips were adjusted to apply herbicide over the entire field. In order to maintain the weed free experimental plots, the hand weeding was done at 30 DAS using *khurpi*. The nutrients dose of 100 kg/ha of DAP with 18% nitrogen and 46% phosphorous basal recommended for soybean crop in Bhopal region was applied at the time of sowing using PREHAP.

The observations on the weed flora (grasses, broad-leaved and sedges) and weed density were recorded at 60 DAS. The efficacy of the weed management of the different treatments was assessed by weed density in the inter- and intra-row and weed infestation. For the intent of determining the intra-row weed density, segments of crop rows measuring 5 m in length were selected randomly. The weeds emerged in 100 mm of distance on either side along the selected segment of crop row, were measured. Similarly, the 4 m long and 250 mm wide strips between the two subsequent crop rows were randomly selected and measured the inter row weed density. Weed infestation refers to the percentage of weeds in the composite population of weed and crop plants. Weed infestation was calculated using following formula:

$$\text{Weed infestation (\%)} = \frac{\text{(Total number of weeds in unit area)}}{\text{(Total no. weed and crop plants in the same area)}} * 100$$

The data on soybean plant height and the number of pods were also recorded for each treatment prior to the harvesting of the crop. The seed and straw yield data for the different treatments was measured using the standard yield measurement protocol. Weed index for each treatment was determined based on the yield data (Prachand *et al*. 2015). Weed index was computed using the formula given below-

$$\text{Weed index (\%)} = \frac{(X - Y)}{X} * 100$$

Where, X = seed weight (t/ha) in the treatment which has highest yield and Y= seed weight (t/ha) in treatment for which weed index is to be calculated.

The cost incurred for production of soybean for different treatments was estimated. The economic benefit in terms of net return and benefit cost ratio were also determined for each treatment in soybean. The statistical analysis of the recorded data was done using SAS 9.3 software (SAS Institute, Cary, N. C.). The least significant difference (LSD) test was used as post hoc mean separation test ($p<0.05$).

RESULTS AND DISCUSSION

Effect on weeds

The predominant weed flora in the experimental field during both the years of study was: *Brachiaria reptans, Chloris inflata, Dactyloctenium aegyptium, Digitaria lingifora, Eleusine indica* among the grasses, *Acalypha indica, Aerva lanata, Aerva tomentosa, Amaranthus viridis, Chrozophora rottlery, Corchorus olitorius, Euphorbia geniculate* among the broad-leaved weeds and *Cyperus rotundus, Cyperus difformis, Cyperus iria* were among the predominant sedges. Of these, *Cyperus rotundus* was the most dominant weed followed *by Amaranthus viridis* and *Eleusine indica.*

The highest weed density and weed infestation was recorded in untreated control (T1) for both intra- and inter-row of the crop (**Table 2**). The intra-row weed density was higher than the inter-row weed density in one inter cultivation between the crop rows (T2) as mechanical intercultural operations in the intra-row of the crop are difficult. Hand weeding once (T3), banded pendimethalin PE using PREHAP (T4), broadcast pendimethalin PE using PREHAP (T5), banded pendimethalin PE using PREHAP *fb* one hand weeding (T6) and broadcasted pendimethalin PE using PREHAP *fb* one hand weeding (T7) had insignificant effect on the intra-row weed density. The pendimethalin PE using PREHAP controlled broad-leaved weeds and grasses completely but did not control *Cyperus rotundus* (Singh *et al*. 2019). Inter-row weeds were found to be the most abundant in treatments T1 and T4, whereas the inter-row weed densities observed in the treatments T2, T3, T5, T6 and T7 were not significantly different. During both years of field experiments, the treatments T7, T6, T5 and T3 showed good weed control. *Cyperus rotundus* was the most common weed in both the intra-row and inter-row treatments.

The significantly highest weed infestation of 80% was recorded for untreated control (T1), followed by 69% for the banded pre-emergence herbicide application (T4) and 58.6% for the inter cultivation between crop rows (T2) during *Kharif* 2019. Similar results were observed during *Kharif* 2020 with weed infestation of 78.5, 67.5, and 58.1% for the treatments T1, T4, and T2, respectively. The weed control treatments, broadcast pendimethalin PE using PREHAP (T5), banded pendimethalin PE using PREHAP *fb* one hand weeding (T6), and broadcast pendimethalin PE using PREHAP *fb* one hand weeding (T7), had no significant effect on the weed infestation during the field experiments for both years. The lowest weed infestation of 24.2% was observed for the broadcast pendimethalin PE using PREHAP *fb* one hand weeding (T7) during *Kharif* 2019. While during *Kharif* 2020, the lowest weed infestation of 27.9% was observed for broadcasted pendimethalin PE using PREHAP (T5) and might be due to the heavy infestation of the *Cyperus rotundus* weed in other treatment plots. However, the results of weed infestation for the treatments T5, T6, and T7 were found to be similar.

The lowest weed index of 14.3% and 11.9% was observed for the banded pendimethalin PE using PREHAP *fb* one hand weeding (T6) during the *Kharif* of 2019 and 2020, respectively (**Table 2**). The highest weed index of 85.7% in *Kharif* 2019 and 78.4% in *Kharif* 2020 was found in unweeded treatment (T1), followed by the inter cultivation between crop rows (T2) and banded pendimethalin PE using PREHAP (T4). The reason for the highest weed index for the treatments T1, T2 and T4 is the presence of heavy weeds in the intra-row and inter row of the crop during both the *Kharif* seasons. The banded pendimethalin PE using PREHAP and inter-row cultivation of weeds once were not found to be effective measures for controlling weeds. The lower infestation of weeds in the herbicide-applied locations indicated that the herbicide spraying system of the PREHAP performed satisfactorily.

Effect on the crop growth parameters and crop yields

The highest plant height and number of pods per plant was observed with broadcast application of pre-emergence herbicide using PREHAP *fb* one hand weeding (T7) during *Kharif* 2019 and 2020, respectively (**Table 3**). Whereas the lowest plant height of the crop was observed in the unweeded control (T1) during both the crop seasons. However, the plant height and number of pods per plant observed with pendimethalin PE in T5, T6 and T7 was not significantly different. This might be due to lower crop weed competition provided healthy environment during the early stages of the crop's growth. The highest seed yield of 1.40 and 1.34 t/ha was observed for the broadcast application of pendimethalin PE using PREHAP *fb* one hand weeding (T7) during kharif 2019 and 2020, respectively, followed by the banded application of pendimethalin PE using PREHAP *fb* one hand weeding (T6) and broadcast application of pendimethalin PE using PREHAP (T5). However, the seed yield observed in the broadcast application of pendimethalin PE using PREHAP *fb* one hand weeding (T7) and followed by the banded application of pendimethalin PE using PREHAP *fb* one hand weeding (T6) was not significantly different. Similar results were observed in the case of straw yield as in

Table 2. Effect of different weed control treatments on weed parameters in soybean crop at 60 DAS

Treatment	*Kharif* 2019				*Kharif* 2020			
	Weed density (no./m^2)		Weed infestation (%)	Weed index (%)	Weed density (no./m^2)		Weed infestation (%)	Weed index (%)
	Intra-row	Inter-row			Intra-row	Inter-row		
T_1	175^a	271^a	80.0^a	85.7	186^a	296^a	78.5^a	78.4
T_2	142^b	21^c	58.6^c	59.9	134^b	36^d	58.1^c	59.7
T_3	54^c	66^b	51.1^c	39.5	48^c	59^c	48.2^d	39.6
T_4	31^d	254^a	69.0^b	42.9	39^{cd}	218^b	67.5^b	41.8
T_5	24^d	35^c	28.4^d	35.4	27^d	24^d	27.9^f	29.9
T_6	28^d	20^c	27.6^d	14.3	34^d	25^d	33.1^e	11.9
T_7	17^e	23^c	24.2^d	-	31^d	27^d	32.0^{ef}	-
LSD (p=0.05)	14	24	7.8		11	18	4.3	

T_1: control *i.e.* no herbicide application, no manual/mechanical weeding; T_2: intercultivation (hoeing) once between the crop rows; T_3: hand weeding once after 30 days after seeding (DAS); T_4: banded application of pre-emergence herbicide by PREHAP; T_5 : broadcast application of pre-emergence herbicide over the entire field by PREHAP; T_6: band application of pre-emergence herbicide by PREHAP *fb* one manual weeding after 30 DAS; T_7: broadcast application of pre-emergence herbicide over the entire field by PREHAP *fb* one manual weeding after 30 DAS.

the case of seed yield. The lower crop weed competition in the early stages of crop growth resulted in higher soybean seed and straw yield.

Techno-economic feasibility

The broadcast application of pendimethalin using PREHAP with one hand weeding (T7) recorded highest net returns and was followed by the banded application of pendimethalin using PREHAP *fb* one hand weeding (T6) and broadcast application of pendimethalin using PREHAP (T5) (**Table 3**). The treatments without pre-emergence herbicide application fetched lower net returns. The broadcast application of pre-emergence herbicide using PREHAP alone (T5) and *fb* one hand weeding gave the highest B:C and was followed by banded application of pendimethalin using PREHAP (T4) during both the years. The broadcast application of pendimethalin using PREHAP *fb* one hand weeding (T7) proved to be more economical due to better B:C ratio resulted due to better weed control. Due to poor weed control with one inter cultivation between the crop rows (T2) and one hand weeding (T3) resulted in lower B:C ratio and was not found to be cost effective. The results of weed attributes, net returns, and B:C showed that applying a pre-emergence herbicide along with the sowing operation with one-hand weeding results in better weed control and seed yield in a soybean crop. Kushwah and Kushwaha (2001) reported similar results, that pendimethalin PE using PREHAP *fb* one hand weeding resulted in higher weed control efficiency and B:C. Thus, the developed machine PRAHEP can be successfully used for the application of pre-emergence herbicides along with the crop sowing operations.

Conclusion

The designed and developed PREHAP (pre-emergence herbicide applicator-cum-planter) with a band and broadcast herbicide-spraying capability was proven to be useful for applying pre-emergence herbicide along with seeding the soybean. The field capacity and operating cost of the developed system was found to be 0.4 ha/h and ₹ 1650/ha, respectively. It can be concluded that broadcast application of the pre-emergence herbicide pendimethalin 1.0 kg/ha using PREHAP combined with one hand weeding gave optimum weed management in soybean with higher soybean yield and economic return.

Table 3. Effect of different weed control treatments on various crop growth and yield attributing characters, yield and economics of soybean

Treatment	Plant height at 60 DAS (mm)	No. of pods per plant	Seed yield (t/ha)	Straw yield (t/ha)	Cost of cultivation ($x10^3$ `/ha)	Net return ($x10^3$ `/ha)	B:C
Kharif 2019							
T_1	472^{c}	15.4^{c}	0.21^{d}	0.29^{d}	13.1	0.0013	1.01
T_2	528^{b}	22.1^{bc}	0.59^{c}	0.81^{c}	17.1	20.07	2.17
T_3	523^{b}	27.3^{b}	0.89^{b}	1.17^{b}	24.6	31.47	2.28
T_4	546^{ab}	26.5^{b}	0.84^{b}	1.08^{b}	14.5	38.42	3.65
T_5	552^{ab}	33.7^{ab}	0.95^{b}	1.19^{b}	15.6	44.25	3.84
T_6	561^{ab}	36.8^{a}	1.26^{a}	1.68^{a}	24.0	55.38	3.31
T_7	572^{a}	40.2^{a}	1.40^{a}	1.84^{a}	24.1	68.51	3.84
LSD (p=0.05)	38.4	8.11	0.15	0.22			
Kharif 2020							
T_1	481^{c}	18.1^{c}	0.29^{d}	0.41^{c}	13.1	0.5170	1.4
T_2	512^{b}	23.4^{bc}	0.54^{c}	0.71^{c}	17.1	16.92	1.99
T_3	527^{ab}	25.2^{b}	0.81^{b}	1.10^{b}	24.6	26.43	2.07
T_4	534^{ab}	29.0^{b}	0.78^{b}	1.09^{b}	14.5	34.64	3.39
T_5	528^{ab}	33.2^{ab}	0.94^{b}	1.26^{b}	15.6	43.62	3.8
T_6	536^{ab}	34.0^{ab}	1.18^{a}	1.51^{ab}	24.0	50.34	3.1
T_7	548a	36.3^{a}	1.34^{a}	1.74^{a}	24.1	60.32	3.5
LSD (p=0.05)	33.1	6.9	0.18	0.31			

T_1: control *i.e.* no herbicide application, no manual/mechanical weeding; T_2: intercultivation (hoeing) once between the crop rows; T_3: hand weeding once after 30 days after seeding (DAS); T_4: banded application of pre-emergence herbicide by PREHAP; T_5 : broadcast application of pre-emergence herbicide over the entire field by PREHAP; T_6: band application of pre-emergence herbicide by PREHAP *fb* one manual weeding after 30 DAS; T_7: broadcast application of pre-emergence herbicide over the entire field by PREHAP *fb* one manual weeding after 30 DAS.

REFERENCES

Bindra OS and Singh H. 1977. *Pesticide-application Equipment.* Oxford & IBH.

Chethan CR, Dubey RP, Chandar S, Pawar DV, Ghosh D and Singh PK. 2022. Harnessing the full potential of low-dose high-potency (LDHP) herbicide molecules by standardized spraying technique in rice and wheat. *Indian Journal of Weed Science* **54**(2): 146–150.

Dixit A and Varshaney JG. 2009. *Herbicide use in field crops.* Directorate of Weed Science Research [Indian Council of Agricultural Research].

Gharde Y, Singh PK, Dubey RP and Gupta PK. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection* **107**: 12–18.

Gite LP, Agrawal KN, Mehta CR, Potdar RR and Narwariya BS. 2020. *Handbook of Ergonomical Design of Agricultural Tools, Equipment and Work Places.* Jain Brothers, New Delhi.

Kalkhoff SJ, Lee KE, Porter SD, Terrio PJ and Thurman EM. 2003. Herbicides and herbicide degradation products in upper Midwest agricultural streams during August base flow conditions. *Journal of Environmental Quality* ***32***(3): 1025–1035.

Kumar SP, Roul AK, Nandede BM, Jyoti B and Chethan CR. 2021. Development of small tractor operated boom sprayer for effective control of weeds in maize. *Indian Journal of Weed Science* **53**(2): 173–178.

Kumar SP, Tewari VK, Chethan CR, Mehta CR, Nare B and Chandel AK. 2019. Development of non-powered self-propelling vertical axis inter row rotary weeder. *Indian Journal of Weed Science* **51(**3): 284–289.

Kushwah SS and Kushwaha HS. 2001. Influence of weed-control methods on growth, yield and economics of rainfed soybean (Glycine max) at farmer's field. *Indian Journal of Agronomy* **46**(3): 511–515.

Malik RS, Yadav A and Malik RK. 2006. Integrated weed management in soybean (*Glycine max*). *Indian Journal of Weed Science* **38**(1&2):65–68.

Niazmand AR, Shaker M and Zakerin AR. 2008. Evaluation of different herbicide application methods and cultivation effect on yield and weed control of corn (*Zea mays*). *Journal of Agronomy* **7** (4): 314–320.

Prachand S, Kalhapure A and Kubde KJ. 2015. Weed management in soybean with pre-and post-emergence herbicides. *Indian Journal of Weed Science* **47**(2): 163–165.

Rao AN and Nagamani A. 2010. Integrated Weed Management in India–Revisited. *Indian Journal of Weed Science* **42**(3): 1–10.

Sankula S, VanGessel MJ, Kee WE, Beste CE Kee and Everts Jr KL. 2001. Narrow row spacing does not affect lima bean yield or management of weeds and other pests. *HortScience* **36**: 884–888.

Singh G, Virk HK and Khanna V. 2019. Pre-and post-emergence herbicides effect on growth, nodulation and productivity of greengram. *Indian Journal of Weed Science* **51**(3): 257–261.

Swanton CJ, Shrestha A, Clements DR, Booth BD and Chandler K. 2002. Evaluation of alternative weed management systems in a modiûed no-tillage maize-soybean-winter wheat rotation: weed densities, crop yield, and economics. *Weed Science* **50:** 504–511

Swanton CJ and Weise SF. 1991. Integrated weed management: The rationale and approach. *Weed Technology* **5**: 657–663.

Talnikar AS, Kadam GL, Karande DR and Jogdand PB. 2008. Integrated weed management in Pigeonpea [Cajanus Cajan (L.) Millsp.]. *International Journal of Agricultural Science* **4**(1): 363–370.