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**Research Paper**

# Weed control efficacy of different post-emergence herbicides in mungbean (*Vigna radiata*) in hot arid regions

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## ABSTRACT

A field experiment was carried out during the rainy (*Kharif*) season of 2017 to 2019 at Jodhpur, Rajasthan to find the herbicide effective for mungbean [*Vigna radiate* (l.) R. Wilczek] in arid regions. The treatments comprised pre-emergence and post-emergence herbicides along with hand-weeding, weed-free, and unweeded. Results revealed that, weed-control treatments brought about a 48.9–73.3% reduction in total weeds density and 46.8–80.1% reduction in dry weed weight at harvesting as compared to unweeded control. Post-emergence application of propaquizafop + imazethapyr @125 g a.i./ha, being at par to other imazethapyr treatments and hand-weeding, resulted in significantly lowest total weed density (24.1/m$^2$) and total weed dry weight (66.6 g/m$^2$) with highest weed-control efficiency (80.1%) and showed the lowest values of weed index (18.4). Moreover, post-emergence application of clodinafop-propargyl + sodium acifluorfen @ 312.5 g a.i./ha also exhibited weed-control efficiency (73.2%) and weed index (21.0) at par with other imazethapyr treatments and hand-weeding. Propaquizafop + imazethapyr @ 125 g a.i./ha, being at par with clodinafop-propargyl + sodium acifluorfen @ 312.5 g a.i./ha and weed-free recorded significantly higher crop dry weight (542 g/m$^2$), pods/plant (24.7), 1,000-seed weight (55.2 g), seed yield (840 kg/ha), and stover yield (2,563 kg/ha). Application of propaquizafop + imazethapyr @125 g a.i./ha also registered highest gross returns (₹58.08 × 10$^3$/ha) and net returns (₹42.58 × 10$^3$/ha) which were comparable to returns recorded under clodinafop-propargyl + sodium-acifluorfen @ 312.5 g a.i./ha. Propaquizafop + imazethapyr @ 125 g a.i./ha being comparable with clodinafop-propargyl + sodium-acifluorfen @ 312.5 g a.i./ha was also found superior in terms of impact assessment indices.

***Key words***: Arid regions, economic threshold density, imazethapyr, mungbean, weed indices

Mungbean also known as greengram, is the fourth most-widely produced pulse crop in India. In arid and semi-arid regions of the country, it is primarily grown in the rainy season (*kharif*). The weed infestation in this crop is severe during the rainy season and as a result, the quantity and quality of the seed are reduced substantially. The critical period of crop-weed competition in mungbean is 15–30 days after sowing (DAS) (Kumar *et al*., 2014). Depending on the kind of weed flora and intensity, yield losses in mungbean due to weeds have been estimated between 48 and 75% in Rajasthan (Godara *et al*., 2014). Although manual weeding is a conventional effective weed management practice, but due to higher cost and unavailibility labour, now it becomes expensive and takes away nearly one-third of the total cost of production (Gnanavel, 2015). As an alternative, herbicide application in pulses has emerged as a promising solution for weed control. With the changing scenario of weed management, pre-emergence (PE) herbicides are not very popular among the farmers due to the short period for sowing during *kharif*. Therefore, nowadays use of post-emergence (PoE) herbicides is popular among the farmers. The PoE herbicide like imazethapyr either alone or in combination with other molecules is recommended for the rainy-season pulses. Imazethapyr is both soil-and plant-active herbicide and causes retardation in meristemic cell-division (Khairnar *et al.,* 2014). Several studies reveal that the PoE sole application of imazethapyr 100 g a.i./ha (Ali *et al.,* 2015), 75 g a.i./ha (Khairnar *et al.* 2014), and 40 and 60 g a.i./ha (Godara *et al.,* 2014) resulted in weed suppression at par with hand-weeding. Besides, the combined application of imazethapyr + imazamox @100 g a.i./ha provided very efficient control of annual broadleaf weeds and sedges (Khairnar *et al.,* 2014). The PoE application of imazethapyr either alone or in combination with imazamox, pendimethalin, etc. found to have no adverse effect on plant height, branches and dry-matter accumulation in mungbean (Komal *et al.,* 2015). The PoE

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application of imazethapyr at 75 and 100 g a.i./ha recorded statistically similar pods/plant, test weight, and seed yield compared to 2 hand-weedings (Khairnar *et al.,* 2014). Hence, due to their high herbicidal activity at low application rates and broad-spectrum weed control, imazethapyr and imazamox are now emerging as potent PoE herbicides in mungbean (Singh *et al.,* 2014). However, due to their prolonged residual life, imazethapyr, imazamox etc. can injure successive crops, and continuous use of these herbicides may also lead to weeds resistance. Besides, the application of selective herbicides may control specific weeds species but may not be effective on other weeds. The above facts warrant the use of newer selective broad-spectrum PoE herbicides (combo-packs) like clodinafop-propargyl + sodium-acifluorfen, propaquizafop + imazethapyr. which are found effective in different pulses in different agro-ecological regions. Harithavardhini *et al*. (2016) reported that, clodinafop-propargyl in combination with sodium-acifluorfen @ 300 and 240 g a.i./ha registered higher weed-control efficiency (70.6 and 68.0%, respectively) as against imazethapyr @100 g a.i./ha at 15 and 25 DAS (50.5 and 41.6% respectively) in mungbean. As response to herbicide is location-specific, therefore, before their recommendation for wider use, herbicides should be evaluated for their weed-control efficacy in a particular agro-ecological region. However, there is no information available regarding the suitable dose, time, and effectiveness of these alternative herbicides in the rainy season pulses in arid regions. Hence this research was conducted to find the efficacy of new herbicide molecules over recommended practices and herbicide for effective and economical weed management in the rainy season mungbean under arid conditions of western Rajasthan.

## MATERIALS AND METHODS

The study was conducted at Experimental Field of ICAR-Central Arid Zone Research Institute, Jodhpur (27°18'N, and 73°01'E) under the agro-ecological zone-XIV (Arid Western plains) for 3 years during rainy season 2017–18, 2018–19 and 2019–20. The experiment was conducted to find out the efficacy of new herbicide molecules over recommended practices and herbicide for effective and economic PoE weed management in the the rainy season mungbean. The experimental field was well-drained with loamy sand-textured soil, low in organic carbon (0.18%), and available nitrogen (173 kg/ha), medium in available phosphorus (16.2 kg/ha), and potassium (280 kg/ha), and slightly alkaline in reaction (*p*H 8.3). The average annual rainfall of the region is about 365 mm which is reveived mainly in the rainy season.

In the experiment 11 treatments, viz. $T_1$, pendimethalin pre-emergence (PE) @ 750 g a.i./ha; $T_2$, imazethapyr post-emergence (PoE) @ 50 g a.i./ha; $T_3$, imazethapyr + imazamox PoE @ 60 g a.i./ha; $T_4$, propaquizafop + imazethapyr PoE @ 100 g a.i./ha; $T_5$, propaquizafop + imazethapyr PoE @ 125 g a.i./ha; $T_6$, clodinafop-propargyl + sodium-acifluorfen PoE @ 187.5 g a.i./ha; $T_7$, clodinafop-propargyl + sodium-acifluorfen PoE @ 250 g a.i./ha; $T_8$, clodinafop-propargyl + sodium-acifluorfen PoE @ 312.5 a.i./ha; $T_9$, 1 hand-weeding; $T_{10}$, unweeded control; and $T_{11}$, weed-free (3 hand-weedings), were evaluated in randomized block design with 3 replications. Treatment $T_8$ was applied only during the last 2 years of experimentation. The herbicides were sprayed with a knapsack sprayer, fitted with a flat-fan nozzle using a water volume of 500 L/ha.

Field preparation was done by ploughing in summer and by harrowing, followed by planking after the first showers of monsoon. The rainfed rainy season mungbean was sown during the first fortnight of July with monsoon rainfall and harvested in the second fortnight of September every year. Mungbean 'GM 4' @ 20 kg/ha was sown at 30-cm-row spacing with the help of a seed drill. The recommended dose of fertilizers in mungbean (15 kg N + 40 kg P) was applied als basal dose before sowing through urea and diammonium phosphate (DAP), Need based plant-protection measures were adopted during the crop period. The crop was managed uniformly throughout the growth period, except for weed control.

Observations on weed infestation were recorded after harvesting of crops with a quadrate of 0.5 × 0.5 m (0.25 $m^2$) size, placed at 2 randomly selected places in each plot, leaving an area of 30 cm from the plot borders. Weed density (no./$m^2$) was recorded by categorizing the sampled weeds into grasses, broad-leaf, and sedges. For recording dry matter of weeds (g/$m^2$), the categorized weeds were first air-dried for 5 days and then oven-dried at 65 ± 5°C until constant dry weight (~48 hr). Weed-control efficiency (WCE) and weed index (WI) were calculated by using the standard formula suggested by Mani *et al*. (1973).

The growth (plant height and dry weight/plant) and yield parameters (pods/plant, seeds/pod, 1,000-seed weight) were recorded from 5 randomly selected plants from each plot just before harvesting. Seed and stover yields (kg/ha) were recorded based on the yield obtained from the net plot (2 m × 3 m). Economics was computed based on prevailing market prices of crop produce, agro-inputs, labour, and machinery rent. The economic threshold based on weed density at harvest was worked out as per following equation.

$$Y= [\{(100/He\times Hc)+Ac\}/(Gp\times Yg)] \times 100$$

where Y, yield reduction (%) at a weed density; He, herbicide-control efficiency; Hc, herbicide cost; Ac, application cost; Gp, seed price; Yg, weed-free yield.

Different impact indices, viz. weed-persistence index (WPI), crop-resistance index (CRI), and herbicide/ treatment efficiency index (TEI) were worked out as:

$$WPI = [WDC / WDT] \times [WDMT / WDMC]$$

$$CRI = (CDMT \div CDMC) \times (WDMC \div WDMT)$$

$$TEI = [(YT - YC)/YT] \div (WDMT / WDMC)$$

where YT and YC are the yields in treated and unweeded control plot respectively; WDT and WDC, weed density (no./m$^2$) in treated and unweeded control plot respectively; WDMT and WDMC, weed dry weight (g/m$^2$) in treated and unweeded plot respectively; CDMT and CDMC, crop dry weight (g/m$^2$) in treated and unweeded plot respectively.

Data analysis was done through analysis of variance using the F-test. The collected data for weed and crop parameters were statistically analysed separately using SPSS (version 16.0). Before statistical analysis, the data of weed density and dry weed weight were subjected to square root transformation $[(x+0.5)^{1}/_{2}]$. Means were compared at 5% level of significance as per Tukey's Honest Significant Difference Test. The relationships between seed yield and weed density and dry weight were evaluated using linear regression analysis.

## RESULTS AND DISCUSSION

### *Weed flora distribution*

Weed flora under unweeded control comprised Indian sandbut (*Cenchrus biflorus* Roxb.), browntop millet [*Brachiaria ramosa* (L.) Stapf.], gophertail levegrass [*Eragrostis ciliaris* (L.) R. Br.] and [*Eragrostis poedaisis* (L.)] or grassy weeds; slender amaranth (*Amaranthus viridis* L.), prickly amaranth (*A. spinosis* L.), gale of the wind (*Phyllanthus niruri* L.), (*Boheravia diffusa* L. nom. cons.), bindii plant (*Trianthema portulacastrum* L.), *Tribulus terristris* L., *Euphorbia hirta* L. and common purslane (*Portulaca oleracea* L.) as broad-leaved weeds; and *Cyperus rotundus* L. as sedge. Weed flora composition differed significantly across the treatments having herbicides with different modes of action. Grassy weeds were more dominant, constituting about (47.0–60.7%) of total weed density across the treatments, followed by broad-leaved weeds (31.5–50.0%) and sedges (7.23–11.7%). However, in terms of total weed dry weight across the treatments dominating group was broad-leaved weeds (58.7–87.9%), followed by grassy weeds (11.2–38.0%) and sedges (0.89–5.15%).

### *Weed interference*

The weed management practices differed significantly in terms of density and dry matter of grasses, broad-leaved weeds, sedges, and total weed density at harvest (Table 1). Weed control treatments brought about a 48.9–73.3% reduction in total weeds density and 46.8–80.1% reduction in weed dry weight at harvest compared to unweeded control ($T_{10}$). Pendimethalin (PE 750 g a.i./ha) ($T_1$) controlled initial flushes of weeds. However, late-emerging weeds were effectively controlled by PoE herbicides. Among the PoE herbicides, propaquizafop + imazethapyr (125 g a.i./ha) ($T_5$), being at par to other imazethapyr treatments ($T_2$, $T_3$, and $T_4$) and hand weeding ($T_9$), recorded significantly lower total weed density (24.1/m$^2$) and total weed dry weight (66.6 g/m$^2$) over pendimethalin (PE 750 g a.i./ha) ($T_1$) and unweeded control ($T_{10}$). The broad-spectrum nature of imazethapyr, which acted as an inhibitor of branched-chain amino acids in plants coincided with propaquizafop, killed weed by inhibiting cell division and cell elongation and thus resulted in lesser weed counts and ultimately produced lower weed dry weight. Owing to synergetic enhancement or additive effects, herbicidal combinations, in general, were better than the sole application of

**Table 1.** Weed density and weed dry matter of different categories of weeds in mungbean at harvest under different weed management practices (mean of 3 years data)

| Treatment | Weed density (Nos./m$^2$) | | | | Weed dry matter (g/m$^2$) | | | | WCE (%) | WI |
|---|---|---|---|---|---|---|---|---|---|---|
| | Grassy | Broad-leaved | Sedges | Total | Grassy | Broad-leaved | Sedges | Total | | |
| $T_1$ | 5.2$^{c}$ (26.3) | 3.9$^{bc}$ (14.7) | 2.3$^{cde}$ (5.0) | 6.8$^{d}$ (46.0) | 8.0$^{e}$ (63.7) | 10.3$^{de}$ (107.0) | 2.9$^{fg}$ (7.7) | 13.3$^{d}$ (178.4) | 47.2$^{a}$ | 36.5$^{bc}$ |
| $T_2$ | 3.8$^{b}$ (14.0) | 3.5$^{b}$ (11.7) | 1.6$^{b}$ (2.0) | 5.3$^{b}$ (27.7) | 4.4$^{bc}$ (19.0) | 7.7$^{bc}$ (58.8) | 2.1$^{de}$ (4.1) | 9.1$^{bc}$ (81.8) | 75.6$^{c}$ | 21.3$^{ab}$ |
| $T_3$ | 3.6$^{b}$ (12.3) | 4.0$^{bc}$ (15.7) | 1.9$^{bcd}$ (3.3) | 5.6$^{bc}$ (31.3) | 3.4$^{b}$ (10.9) | 9.2$^{b\text{-}e}$ (85.7) | 1.2$^{ab}$ (0.9) | 9.8$^{bc}$ (97.5) | 71.0$^{bc}$ | 25.0$^{ab}$ |
| $T_4$ | 3.7$^{b}$ (13.3) | 3.4$^{b}$ (11.0) | 1.7$^{bc}$ (2.3) | 5.2$^{b}$ (26.7) | 4.0$^{bc}$ (16.0) | 7.8$^{bcd}$ (61.8) | 1.6$^{bcd}$ (2.0) | 8.9$^{b}$ (79.8) | 76.1$^{c}$ | 19.8$^{ab}$ |
| $T_5$ | 3.4$^{b}$ (11.3) | 3.3$^{b}$ (10.7) | 1.6$^{b}$ (2.0) | 4.9$^{b}$ (24.1) | 3.4$^{b}$ (11.0) | 7.4$^{b}$ (54.3) | 1.3$^{abc}$ (1.2) | 8.2$^{b}$ (66.6) | 80.1$^{c}$ | 18.4$^{a}$ |
| $T_6$ | 5.1$^{c}$ (25.7) | 4.8$^{cd}$ (22.7) | 2.6$^{de}$ (6.3) | 7.4$^{d}$ (54.7) | 6.3$^{d}$ (39.1) | 11.3$^{e}$ (128.2) | 2.4$^{ef}$ (5.2) | 13.1$^{d}$ (172.4) | 48.5$^{a}$ | 32.1$^{ab}$ |
| $T_7$ | 4.6$^{bc}$ (21.3) | 4.2$^{bc}$ (17.3) | 2.3$^{b\text{-}e}$ (4.7) | 6.6$^{cd}$ (43.3) | 5.5$^{cd}$ (30.2) | 9.9$^{cde}$ (97.1) | 1.9$^{cde}$ (3.4) | 11.4$^{cd}$ 130.7) | 60.8$^{ab}$ | 24.1$^{ab}$ |
| $T_8$ | 3.9$^{bc}$ (15.0) | 3.6$^{b}$ (12.3) | 1.9$^{bcd}$ (3.0) | 5.5$^{b}$ (30.3) | 4.1$^{bc}$ (16.0) | 8.4$^{bcd}$ (71.5) | 1.6$^{bcd}$ (2.0) | 9.5$^{bc}$ (89.5) | 73.2$^{bc}$ | 21.0$^{ab}$ |
| $T_9$ | 3.5$^{b}$ (12.0) | 3.3$^{b}$ (10.7) | 1.9$^{bcd}$ (3.0) | 5.1$^{b}$ (25.7) | 5.4$^{cd}$ (28.3) | 8.3b$^{cd}$ (70.0) | 2.4$^{ef}$ (5.3) | 10.2$^{bc}$ (103.7) | 69.3$^{bc}$ | 22.8$^{ab}$ |
| $T_{10}$ | 7.4$^{d}$ (54.7) | 5.4$^{d}$ (28.3) | 2.7$^{e}$ (7.0) | 9.5$^{e}$ (90.0) | 11.3$^{f}$ (127.3) | 14.0$^{f}$ (196.9) | 3.4$^{g}$ (11.1) | 18.3$^{e}$ (335.3) | - | 52.1c |
| $T_{11}$ | 0.7$^{a}$ (0.0) | 0.7$^{a}$ (0.0) | 0.7$^{a}$ (0.0) | 0.7$^{a}$ (0.0) | 0.7$^{a}$ (0.0) | 0.7$^{a}$ (0.0) | 0.7$^{a}$ (0.0) | 0.7$^{a}$ (0.0) | 100.0$^{d}$ | - |

Values in parentheses are the means of original values; Means [the square root transformed ($\sqrt{X}$+ 0.5) values] superscripted with different letters are significant at $p < 0.05$ as per Tukey's HSD test.

herbicides in reducing the total weed dry weight in mung bean. These findings are in line with that of Kumar *et al*. (2018) in soybean and Khairnar *et al. (*2014) in mungbean. Moreover, application of clodinafop-propargyl + sodium-acifluorfen (PoE @312.5 g a.i./ha) ($T_8$) led to weed suppression at par to imazethapyr treatments ($T_2$, $T_3$, $T_4$ and $T_5$) and hand weeding ($T_9$). Further, this treatment combination ($T_8$) caused effective weed control against all categories of weeds. It led to 66.3% and 73.3% reductions in total weed density and total weed dry weight, respectively, over the unweeded control ($T_{10}$). This might be attributed to the broad-spectrum activity of pre-mix herbicides combination against weeds. Harithavardhini *et al*. (2016) reported similar efficacy of clodinafop-propargyl + sodium acifluorfen over imazethapyr on complex weed flora in mungbean.

The significant difference in weed dry weight in different weed management practices was manifested in terms of WCE and WI (Table 1). The better weed control under particular treatment results in higher WCE and lower WI. Amongst PoE herbicides, the maximum value of WCE (80.1%) and minimum values of WI (18.4) were attained with application of propaquizafop + imazethapyr (PoE @ 125 g a.i./ha) ($T_5$). Moreover, clodinafop-propargyl + sodium acifluorfen (PoE @312.5 g a.i./ha) ($T_8$) recorded WCE (73.2%) and WI (21.0) on par with imazethapyr-containing treatments ($T_2$, $T_3$, $T_4$ and $T_5$) and hand weeding ($T_9$). This might have been due to effective control of broad-leaved weeds by imazethapyr in $T_2$, $T_3$, $T_4$ and $T_5$, and higher doses of sodium acifluorfen in clodinafop-propargyl + sodium acifluorfen (PoE @312.5 g a.i./ha) ($T_8$). This also indicates that the imazethapyr has also been effective at lower doses in imazethapyr + imazamox (PoE @ 60 g a.i./ha) ($T_3$).

### *Crop growth and yield*

The different magnitude of weed infestation in different treatments caused competition for resources to crop plants, and it affects the growth and yield of crops accordingly. Data in Table 2 reveals a significant effects of different weed control treatments on the growth parameters, yield attributes, and yield of mungbean. Among the growth parameters, plant height at harvest was not affected significantly. However, propaquizafop + imazethapyr (PoE @125 g a.i./ha) ($T_5$) being at par with other imazethapyr treatments and clodinafop-propargyl + sodium-acifluorfen (PoE @ 312.5 g a.i./ha) ($T_8$) and weed-free ($T_{11}$) recorded significantly higher crop dry weight (542 g/m$^2$) over other treatments. The higher crop dry weight under this treatment indicates lesser weed incidence. The significant difference in crop growth under different treatments resulted in significant differences in yield attributes and yield of mungbean (Table 2). Due to better weed control efficacy, the imazethapyr-containing treatments ($T_2$, $T_3$, $T_4$ and $T_5$) recorded significantly higher values of pods/plant and 1,000-seed weight. Because of its at par weed control efficacy, clodinafop-propargyl + sodium-acifluorfen (PoE @ 312.5 g a.i./ha) ($T_8$) also recorded yield attributes on par with imazethapyr-containing treatments ($T_2$, $T_3$, $T_4$ and $T_5$) and hand weeding ($T_9$). The higher yield attributes under these treatments might be due to reduced weed density, weed dry weight, and higher weed control efficiency leading to effective control of the weeds during the critical crop growth period.

The yield response of mungbean under different weed control treatments varied due to the significant differences in weed dry weight and crop dry weight and yield attributes. (Table 2). Propaquizafop + imazethapyr (PoE @125 g a.i./ha) ($T_5$) produced maximum seed yield (840 kg/ha) and stover yield (2563 kg/ha) that was 69.3% and 101.5% higher over the unweeded control ($T_{10}$), respectively. Further, clodinafop-propargyl + sodium-acifluorfen (PoE @ 312.5 g a.i./ha) ($T_8$) recorded seed and stover yield on par with propaquizafop + imazethapyr (PoE @ 125 g

**Table 2.** Growth parameters, yield attributes, and yield of mungbean as influenced by different weed management practices (mean of 3 years data)

| Treatment | Plant height (cm) | Crop dry weight (g/m$^2$) | Pods/plant (No.) | Seed/pod (No.) | 1000-seed weight (g) | Seed yield (kg/ha) | Stover yield (kg/ha) |
|---|---|---|---|---|---|---|---|
| $T_1$ | $36.5^{NS}$ | $478^{b}$ | $17.5^{abc}$ | $7.1^{NS}$ | $52.1^{ab}$ | $655^{ab}$ | $1622^{ab}$ |
| $T_2$ | $38.1^{NS}$ | $516^{b}$ | $21.3^{bcd}$ | $7.8^{NS}$ | $54.8^{b}$ | $814^{bc}$ | $2164^{bcd}$ |
| $T_3$ | $36.4^{NS}$ | $493^{b}$ | $17.8^{abc}$ | $7.3^{NS}$ | $53.6^{ab}$ | $772^{bc}$ | $1845^{abc}$ |
| $T_4$ | $38.9^{NS}$ | $529^{b}$ | $23.7^{bcd}$ | $8.3^{NS}$ | $54.0^{b}$ | $827^{bc}$ | $2282^{bcd}$ |
| $T_5$ | $35.6^{NS}$ | $542^{b}$ | $24.7^{cd}$ | $8.3^{NS}$ | $55.2^{b}$ | $840^{c}$ | $2563^{cd}$ |
| $T_6$ | $40.1^{NS}$ | $433^{ab}$ | $16.7^{ab}$ | $7.5^{NS}$ | $48.9^{ab}$ | $701^{bc}$ | $1611^{ab}$ |
| $T_7$ | $39.3^{NS}$ | $465^{ab}$ | $19.9^{a-d}$ | $8.6^{NS}$ | $51.5^{ab}$ | $787^{bc}$ | $1942^{abc}$ |
| $T_8$ | $40.4^{NS}$ | $510^{b}$ | $22.3^{bcd}$ | $8.6^{NS}$ | $51.5^{ab}$ | $816^{bc}$ | $2116^{bc}$ |
| $T_9$ | $40.9^{NS}$ | $519^{b}$ | $20.6^{bcd}$ | $7.2^{NS}$ | $53.2^{ab}$ | $799^{bc}$ | $2268^{bcd}$ |
| $T_{10}$ | $42.1^{NS}$ | $327^{a}$ | $12.5^{a}$ | $6.6^{NS}$ | $45.9^{a}$ | $496^{a}$ | $1271^{a}$ |
| $T_{11}$ | $38.4^{NS}$ | $561^{b}$ | $27.6^{d}$ | $8.5^{NS}$ | $54.7^{b}$ | $1035^{d}$ | $2972^{d}$ |

Means superscripted with different letters are significant at $p < 0.05$ as per Tukey's HSD test; NS, Non-significant a.i./ha) ($T_5$). Better weed management at critical growth stages of crop could have minimized the competition between crop and weeds, leading to higher uptake of nutrients resulting in better crop growth and yield attributes, thus contributing to higher seed and stover yield. The results gain support from the findings of Kumar *et al*. (2018) in soybean and Khairnar *et al. (*2014) in mungbean. This indicates that pre-mix herbicides have significant effect on minimizing the weed population, which resulted in increased yield over unweeded control.

Regression analyses revealed that the seed yield of mungbean was negatively associated with weed density and weed dry weight. Regression equations in Fig. 1 indicate that with every unit increase in weed density (per $m^2$) and weed dry weight ($g/m^2$), mungbean seed yield is reduced by 5.17 kg/ha and 2.3 kg/ha, respectively. These linear equations could explain 92.8% and 94.4% of the variations in seed yield (y) due to weed density and weed dry weight (x), respectively, in mung bean. Thus, higher seed yield in herbicide-treated plots may be an outcome of efficient weed control.

### *Economics*

Owing to higher seed and stover yield, the highest gross returns (₹58.08 × $10^3$/ha) and net returns (₹42.58 × $10^3$/ha) were recorded in propaquizafop + imazethapyr (PoE @ 125 g a.i./ha) ($T_5$) (Table 3). Further, the application of clodinafop-propargyl + sodium-acifluorfen (PoE @312.5 g a.i./ha) ($T_8$) found to produce comparable gross returns (₹55.29 × $10^3$/ha) and net returns (₹40.02 × $10^3$/ha) to imazethapyr (PoE @50 g a.i./ha) ($T_4$) and higher than hand-weeding ($T_9$). The superior performance of the above treatments was ascribed to the higher seed and stover yield of the mungbean. Clodinafop-propargyl + sodium-acifluorfen (PoE @312.5 g a.i./ha) ($T_8$) was found comparable to imazethapyr (PoE @50 g a.i./ha) ($T_4$) and higher over hand weeding $T_9$ in terms of $GR_{UWC}$ (21.70 × $10^3$/ha) and $NR_{UWCm}$ (18.82 × $10^3$/ha) and MBCR (3.62). Thus, results endorsed better economic feasibility of treatment linked with higher production potential over unweeded control.

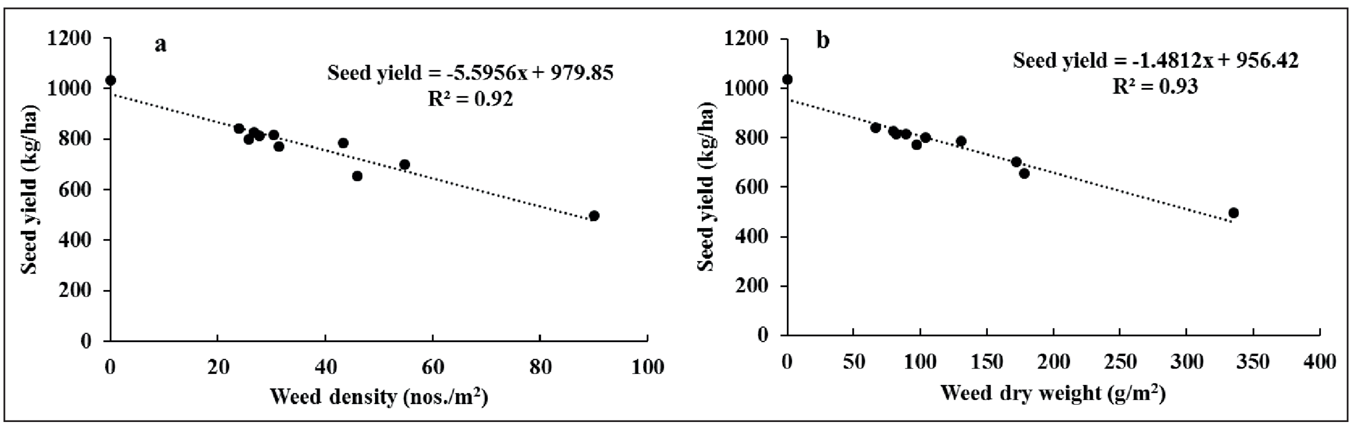


**Fig. 1.** Correlation between a) weed density and b) weed dry weight with seed yield of mungbean under weed-management practices

**Table 3.** Economics of mungbean under weed-management different weed management practices (mean of 3 years data)

| Treatment | Cost of cultivation (×$10^3$ ₹/ha) | Gross returns (×$10^3$ ₹/ha) | Net returns (₹$10^3$ /ha) | $GR_{UWC}$ (×$10^3$ ₹/ha) | $NR_{UWC}$ (×$10^3$ ₹/ha) | MBCR | ET (weeds/$m^2$) |
|---|---|---|---|---|---|---|---|
| $T_1$ | 14.69 | 44.15 | 29.46 | 10.57 | 8.28 | 3.01 | 5.84 |
| $T_2$ | 14.10 | 55.31 | 41.21 | 21.73 | 20.03 | 3.92 | 3.05 |
| $T_3$ | 15.05 | 51.86 | 36.81 | 18.27 | 15.62 | 3.45 | 5.29 |
| $T_4$ | 15.10 | 56.43 | 41.33 | 22.84 | 20.14 | 3.74 | 5.16 |
| $T_5$ | 15.50 | 58.08 | 42.58 | 24.50 | 21.40 | 3.75 | 5.80 |
| $T_6$ | 14.57 | 46.91 | 32.34 | 13.33 | 11.15 | 3.22 | 5.33 |
| $T_7$ | 14.90 | 53.01 | 38.11 | 19.42 | 16.92 | 3.56 | 5.48 |
| $T_8$ | 15.29 | 55.29 | 40.02 | 21.70 | 18.82 | 3.62 | 5.70 |
| $T_9$ | 16.90 | 54.75 | 37.85 | 21.16 | 16.66 | 3.24 | 10.46 |
| $T_{10}$ | 12.40 | 33.58 | 21.18 | 0.00 | 0.00 | 2.71 | |
| $T_{11}$ | 24.40 | 71.00 | 46.60 | 37.41 | 25.41 | 2.91 | |

$GR_{UWC}$- Gross returns over unweeded control; $NR_{UWC}$- Net return over unweeded control; MBCR- Marginal benefit: cost ratio, ET- Economic threshold; Seed price- ₹60/kg; Stover price- ₹3.0/kg

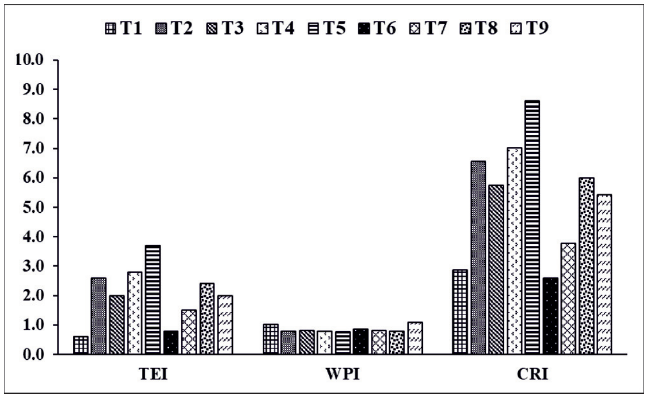


**Fig. 2.** Impact assessment indices of different weed-management practices in mungbean

### *Economic threshold and impact assessment*

Economic threshold *i.e.,* weed density at which cost of weed control equals the economic benefits accrued from that control measure and justifies the adoption of control measure, across the weed control options varied between 3.05–10.46 weeds/m$^2$ (Table 3) during the entire crop duration in mung bean. Economic threshold level increased with the increasing cost of weed control, as in hand weeding ($T_9$) due to higher wages. Contrarily, weed control through herbicides incurred lower costs, resulting in a lower economic threshold level. The economic threshold level at which controlling weeds became economically worthwhile was lower in the case of clodinafop-propargyl + sodium-acifluorfen (PoE @ 312.5 g a.i./ha) ($T_8$) (5.70) than propaquizafop + imazethapyr (PoE @ 125 g a.i./ha) ($T_{10}$) (5.80) and hand weeding (10.46).

The values of different weed indices like TEI, WPI and CRI under different treatments are presented in Fig. 2. The TEI indicates the yield advantage by adopting the treatment over the control concerning reducing weed dry matter over control. Propaquizafop + imazethapyr (PoE @125 g a.i. / ha) ($T_5$) recorded the highest TEI (3.7), indicating the higher yield advantage concerning the reduction in weed dry matter. However, the TEI of clodinafop-propargyl + sodium acifluorfen (PoE @ 312.5 g a.i./ha) ($T_8$) (2.4) was found on par with imazethapyr (PoE @50 g a.i./ha) ($T_4$) (2.6).

The data on WPI indicates the relative weed dry matter accumulation per weeds count in comparison to control. The highest WPI was observed in the case of hand-weeding ($T_9$) (1.09) and pendimethalin (PE @ 750 g a.i./ha) ($T_1$) (1.03), indicating the resistance of escaped weeds to control measures while the rest of the treatments had values much below. The lowest WPI values were observed with propaquizafop + imazethapyr (PoE @125 g a.i./ha) ($T_5$) (0.77). The CRI indicates the increased vigour of crop plants due to weed control measures. The highest CRI was recorded by propaquizafop + imazethapyr (PoE @125 g a.i./ha) ($T_5$), indicating a much less harmful effect of herbicides on the crop to other treatments.

This study showed that the post-emergence applications of propaquizafop + imazethapyr @125 g a.i. /ha resulted in better control of diverse weeds, higher growth, yield, and net returns of mungbean. Therefore, it may be adopted for effective weed control in *Kharif* rainfed mungbean in the western arid regions of India and other areas with similar agro-climatic situations. Furthermore, post-emergence application of clodinafop-propargyl + sodium-acifluorfen @ 312.5 g a.i./ha can also be a profitable alternative for effective weed management in mungbean.

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