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Assessing the efficacy of novel post-emergence herbicides on weed density plant height and yield of mungbean (*Vigna radiata* L. Wilczek) under Arid conditions

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Abstract
The experiment was conducted during 2022-23 at Instructional Farm, College of Agriculture. Jodhpur, Rajasthan to evaluate the impact of different post-emergence herbicides on weed dynamics and mungbean productivity. Field experiment was laid out in randomized block design (RBD) with ten treatment combinations and replicated thrice. The treatments taken in the investigation were W_1- Weedy check, W_2- Weed free, W_3- Imazethapyr 55 g/ha, W_4- Fluazifop-p-butyl 250g/ha, W_5- Pendimethalin + imazethapyr 800 g/ha, W_6- Imazethapyr + imazamox 70 g/ha, W_7- Propaquizafop + imazethapyr 83.3 g/ha, W_8- Aciflourfen sodium + clodinafop- propargyl 210 g/ha, W_9- Fomesafen + fluazifop-p-butyl 220 g/ha, W_{10}- Quizalofop ethyl 60 g/ha. *Digera arvensis* L., *Phyllanthus niruri* L., *Dactyloctenium aegyptium* L., *Portulaca oleracea* L., were the most dominant weeds among identified dicot weed species whereas important monocot weeds included *Cynodon dactylon* L., and *Dactyloctenium aegyptium* L., in the field. Post-emergence application of fomesafen + fluazifop-p-butyl 220 g/ha (W_9) followed by treatment sprayed with sodium acifluorfen + clodinafop-propargyl 210 g/ha (W_8) showed significantly greater plant height & efficacy in reducing total weed density. Ready mix application of (W_9) 220 g/ha can be suggested owing to higher seed yield and profits for farmers while lowering the herbicide dose and expenses in involved in manual weeding and as compared to rest of the treatments tested during field experimentation.

Keywords: Fomesafen, seed yield, post-emergence, ready mix, sodium aciflourfen

Introduction
Mungbean, also known as green gram or moong, is a crop indigenous to India and has become a staple in various global regions. It holds significant nutritional value due to its high protein content, making it a vital food source worldwide. Mungbean is utilized in diverse culinary forms, including dry grains, sprouts, transparent noodles/starch, and paste. Its popularity is especially notable in South and Southeast Asia, where it is integral to traditional dishes. Globally, mungbean is cultivated across about 7.3 million hectares, yielding approximately 5.3 million tonnes. This equates to an average productivity of 721 kg per hectare. India and Myanmar are the leading producers, each responsible for around 30% of the total global production. India is expected to dedicate 5.5 million hectares to mungbean cultivation, yielding 3.17 million tonnes, with an average productivity of 570 kg per hectare. Mungbean represents 10% of total pulse production and occupies 16% of the pulse cultivation area in India. Rajasthan leads in mungbean cultivation, contributing 46% of the area and 45% of the production. (Annual Report-IIPR, 2022-23) [7]. Rajasthan occupied first position with 26 percent contribution in total mungbean production of India. Mungbean are mainly grown in arid and semi-arid tracts of Rajasthan including Nagaur, Jodhpur, Jaipur, Ajmer, Pali, Jalore, Shri-Ganganagar, Tonk, Churu, Barmer and Bikaner. In Rajasthan, mungbean is cultivated on 2.16 million hectares with production 1.32 million tonnes and productivity of 610 kg/ha (DES, 2022) [3]. Mungbean is mostly cultivated in rainfed condition even at low humidity with high temperature (27 to 30 °C).

It has capability to assimilate atmospheric nitrogen in combination with beneficial microbes and efficiently improve soil productivity, the accessibility of other essential elements, reduce soil erosion, ameliorate soil physical properties like water holding capacity, ensure nutritional security and thus play an indispensable role in nurturing sustainable agriculture (Bangar *et al.*, 2019) [1]. Weeds compete with crops for resources such as nutrients, water, light and space, thus reducing their yield. Naturally more-hardy and competitive, they cause significant yield losses if not controlled properly. Due to its low stature of plants, weeds severely reduce mungbean yields and can cause losses of up to 40 to 68%. (Tamang *et al*., 2015) [14]. In addition, Mehriya and Shukla (2015) [9] determined that weed competition for nutrients, moisture, light, and space results in a 23.5 to 45.8 per cent reduction in grain output. Weeding becomes quite laborious during the peak period of sowing and harvesting as traditional methods like hand weeding demands increased drudgery of labour and operation becomes expensive as it is time consuming, affected aberrant weather conditions thus not economical (Vivek *et al*., 2008) [16]. In contrast, chemical weed control offers a more efficient solution. It requires less labor and can manage weed competition more effectively, thereby enhancing yield and productivity. These Novel herbicides include fomesafen, Sodium aciflourfen and propaquizafop which are characterized by broad spectrum weed control with broad window of application, with an environmental advantage deriving from their very low application rates in grams rather than kilograms per hectare which markedly reduce the chemical load in the environment. Thus, an experiment was conducted to determine the effect of novel post-emergence herbicides along with their ready-mix formulations and there is an exigency to recognize the effective and economical weed management practice in mungbean.

Materials and Methods

Present study was carried out during the *kharif* Season of 2022-23 at the Instructional Farm, College of Agriculture, Jodhpur (Rajasthan) which is situated at a distance of about 10 km from Jodhpur railway station. Geographically, it is located between 26^o 15' N to 26^o 45' North latitude and 73^o 00' E to latitude 73^o 29' East longitude at an altitude of 231 meter above mean sea level (MSL). The soil of the experimental field was characterized as was sandy-loam in texture, slightly alkaline in reaction (pH 8.10), non-saline in conductivity (EC 0.12 dS/m), low in organic carbon (0.17%), available nitrogen (165.0 kg/ha), while medium in available phosphorus (22.0 kg P_2O_5/ha) and potassium (310 kg K_2O/ha). However, soil having medium range of pH and EC that favoured better crop management during the year of experimentation. Average daily maximum and minimum temperature varied between 29.20 to 36.67^0 C and 20.59 to 25.31^0 C, respectively during experimentation. The cumulative rainfall during experimentation was 521.5 mm has been received in twenty three rainy days between 29th MW (July) to 39th MW (September), 2022. At initial stage of the crop, heavy pour of rainfall was occurred between 23rd to 29th July, 2022 (30th MW), but it did not affect the crop due to better drainage facilities available at farm. The worthy growth of mungbean was favoured by uniform distribution of rainfall occurred during crop season. The experiment was conducted in a randomized block design (RBD) comprised of 10 treatment combinations, viz. post emergence application of imazethapyr 10% SL (55g/ha), fluazifop-p-butyl (13.4% w/w) 250 g/ha, ready-mix of pendimethalin (30%) + imazethapyr (2%EC) 800 g/ha, Imazethapyr + imazamox (35%WG) 70 g/ha, propaquizafop (2.5%) + Imazethapyr (3.75% w/w ME) 33.3 + 50 g/ha, aciflourfen sodium (16.5%) +clodinafop-propargyl (8% EC) 140 +7 0 g/ha, fomesafen (11.1%) + fluazifop-p-butyl (11.1% SL) 220 g/ha and quizalofop ethyl (5% EC) 60 g/ha was applied at 20 DAS as per the treatments under investigation. Moreover, one weedy check and weed free plot were also kept during crop period by removing weeds as and when these appeared to compare the efficacy of different weed control treatments. All herbicides were sprayed with knapsack sprayer employing flat fan nozzles by making solutions in a required quantity of water per hectares. The spraying was done in backward direction, from top to bottom of the plots in order to maintain herbicidal film intact. 'GM-7' (Gujrat Mung-7) Variety of mungbean has been used for the field experiment. It is an early maturing variety of mungbean which matures uniformly within 75-80 days. Plants height and grains are medium size. This variety is resistant to yellow mosaic virus and tolerance against drought. The field was deep ploughed with tractor drawn disc plough followed by one harrowing and planking. The plot was properly levelled before preparation of layout. The experimental field was demarcated as per plan of layout. A basal dose of 15 kg N and 40 kg P_2O_5 /ha was drilled uniformly before sowing through single super phosphate in individual plot at the depth of 7 to 8 cm below the seed. The seed rate of 15 kg/ha in mungbean was used and sowing was done on July 14, 2022 at spacing of 30 cm × 10 cm with depth of 5-6 cm by "*kera*" method. To assess the biological, seed and stover yields, the plants from all the sides(borders) are removed manually first followed by harvesting of crop on 23rd September, 2022 from each net plot (3.4 m × 2.4 m) and stacked plot wise for sun drying separately, tied in bundles and tagged. These tagged bundled were left for sun drying in the respective plot. After winnowing, cleaned grains were weighed to record grain yield per plot. The moisture percentage in 100 g samples drawn from each treatment were recorded with the help of oven dry method and thereafter the yield, thus obtained was adjusted to 12 per cent moisture and finally the yield of net plot was converted into kg/ha. The stover yield was calculated by deducting the corresponding grain yield from the biological yield of each plot and then converted into kilogram per hectare (kg/ha). The un-threshed produce from net plot area (3.4 m x 2.4 m), excluding root biomass after thorough sun drying was weighed for recording the biological yield and expressed in terms of yield in kilogram per hectare (kg/ha). Similarly, the height of plant is one of major growth attribute and is measured from base of soil to the top leaf. Accordingly, the height of five tagged plants was measured in centimetre (cm) from ground level to the tallest leaf of the plant at 30, 45 DAS and at harvest, and average mean of height was recorded. Moreover, in each plot, species wise weed counts were recorded at 30, 45 DAS and at harvest. For estimating weed density, a quadrate (0.50 m × 0.50 m) was placed randomly at two spots in each plot. Individual species wise counts were taken and expressed as numbers per square meter. The mean data were subjected to square root transformation $\sqrt{(x + 0.5)}$ to normalize their distribution (Gomez and Gomez, 1984) [6], where "x" is the original data. Experimental data recorded in various observations were statistically analyzed in accordance with the "Analysis of Variance" technique as described by Panse and Sukhatme (1985) [10] for randomized block design for testing significance of differences among treatments by 'F' test with 5% level of significance.

Results and Discussion

Effect of different herbicidal treatments on total weed density

Total weed density showed significant reduction in overall density with an advancement of crop, whereas weedy check showed marginal increasing trends with respect to total weed density at all growth stages during course of study. data revealed that post-emergence application of fomesafen + fluazifop-p-butyl 220 g/ha (W_9) significantly reduce total weed density (3.43, 2.95 and 2.32/m^2) followed by the treatment sprayed with sodium acifluorfen + clodinafop-propargyl 210 g/ha (W_8), which also outplayed in reducing total weed density (4.23, 3.54 and 2.92/m^2) at 30, 45 DAS and at harvest stages of mungbean, respectively (Table 1). It was further noticed that both the treatments (W_9 and W_8) showed overall superiority over rest of the treatments studied during experimentation. However, none of the weed counts were recorded under season long weeding *i.e.* weed free (W_2), whereas weedy check recorded significantly higher total weed density (9.42, 10.10 and 10.81/m^2) in comparison to other tested treatments at 30, 45 DAS and at harvest stage of crop, respectively during investigation. The declining trend in the weed population up to harvest stage can be attributed to the completion of life cycle of some weeds emerged during the initial stages of crop, combined with suppression of late flushes of weeds by luxuriant crop growth leading to death of weeds. Moreover, effective control of first flush of weeds by post-emergence herbicides that attributed to check uptake and absorption of nutrients and moisture from the soil in the weed which makes them feeble and eventually also decrease their strength. These trends were also reported by Shah *et al*. 2020 [12], Kadam *et al*. (2018) [8] and Singh *et al.* (2014) [13].

Table 1: Total densities of weeds as influenced by different post-emergence herbicides in mungbean

Treatments	Total weed density (No./m^2)		
	30 DAS	45 DAS	At harvest
Weedy check (W_1)	9.42 (87.91)	10.10 (101.78)	10.81 (115.96)
Weed free (W_2)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Imazethapyr (W_3)	5.33 (27.47)	4.83 (22.38)	4.29 (17.45)
Fluazifop-p- butyl (W_4)	5.22 (26.25)	5.00 (24.01)	4.38 (18.22)
Pendi. + imaza. (W_5)	4.91 (23.97)	4.70 (21.12)	4.19 (16.62)
Imaza. + imazmox. (W_6)	4.73 (21.43)	4.21 (16.74)	3.80 (13.48)
Propa + imaze. (W_7)	4.41 (18.53)	3.84 (13.76)	3.41 (10.69)
Acifluorfen + clodina. (W_8)	4.23 (16.95)	3.54 (11.56)	2.92 (7.55)
Fomesafen + fluazifop (W_9)	3.43 (10.84)	2.95 (7.69)	2.32 (4.38)
Quizalofop-ethyl 5% (W_{10})	5.34 (27.56)	5.07 (24.79)	4.99 (23.93)
S.Em±	0.08	0.06	0.05
CD (P=0.05)	0.25	0.18	0.17

Effect of post-emergence herbicides on Plant Height

The data on mean plant height pertaining to different treatments recorded at 30, 45 DAS and at harvest stage of mungbean are presented in Table 2 and depicted in Fig.1. Marked variations in plant height were observed due to different post-emergence herbicidal treatments tested during crop season. Marked variations in plant height were observed due to different post-emergence herbicidal treatments tested during crop season. Post-emergence application of fomesafen + fluazifop-p-butyl 220 g/ha (W_9) in mungbean recorded significantly taller plants *i.e.* 11.10, 36.21 and 58.3 cm, respectively (Table 2). However, it was at par with sodium acifluorfen + clodinafop-propargyl 210 g/ha (W_8), which also recorded next taller plants 10.6, 36.06 and 57.9 cm at 30, 45 and harvest stage of crop, respectively during experimental year and showed its significant superiority over rest of the treatments. Moreover, increments in plant height due to application of fomesafen + fluazifop-p-butyl 220 g/ha (W_9) were recorded by 35.13%, 21.01% and 17.66 per cent higher over weedy check (W_1) at 30, 45 DAS and at harvest stages of mungbean, respectively during tested year. Significantly taller plant (12.0, 38.54 and 61.5 cm) was recorded under weed free treatment (W_2) treatment at 30, 45 DAS and harvest stage of crop growth, respectively during field trial. However, shorter plant (7.2, 28.60 and 48 cm) was observed under weedy check (W_1). It is further narrated that application of ready-mix herbicides gave plants with taller height, high dry matter accumulation and a greater number of branches might be due to fewer weeds recorded in these plots. A weed free environment at initial stage of crop growth till the critical period of the crop-weed competition facilitated good growth of crop by offering least competition for water, nutrients, light and space with weeds which ultimately reflected on yield. Further, more, the apprehension can be made that up to 45 DAS, weed did not attain much growth and subsequently the crop canopy development was sufficient enough to smother the weeds which emerged at the later stages of crop growth. Reduced weed density may result in lesser competition of mungbean with weeds for nutrients mainly nitrogen, phosphorus and potash and other resources like space, light and water which are needed in ample quantity for proper growth and development and hence produced taller plants of mungbean (Chugh *et al*., 2017 and Dhaker *et al.*, 2009) [2, 4].

Table 2: Plant height at different growth stages of mungbean as influenced by different post-emergence herbicides

Treatments	Plant height (cm)		
	30 DAS	45 DAS	At harvest
Weedy check (W_1)	7.2	28.60	48.0
Weed free (W_2)	12.0	38.54	61.5
Imazethapyr (W_3)	8.5	33.04	53.0
Fluazifop-p-buty (W_4)	8.2	32.47	52.1
Pendi. + imaza. (W_5)	8.8	33.69	53.6
Imaza. + imazmox. (W_6)	9.5	34.04	54.4
Propa + imaze. (W_7)	9.7	34.11	55.0
Acifluorfen + clodina. (W_8)	10.6	36.06	57.9
Fomesafen + fluazifop (W_9)	11.1	36.21	58.3
Quizalofop-ethyl 5% (W_{10})	8.2	31.17	52.0
S.Em±	0.27	0.60	0.84
CD (P=0.05)	0.81	1.79	2.51

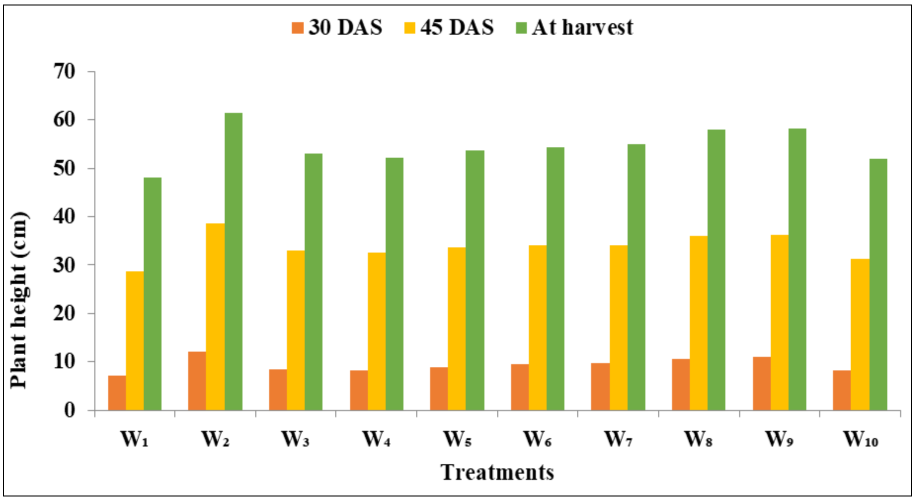

Fig 1: Plant height at different growth stages of mungbean as influenced by different post-emergence herbicides

Effect of post-emergence herbicides on Grain & Stover Yield

Seed yield is the outcome from an interaction between environment and genotypes. It is the most important parameter, which decides the efficiency and superiority of a particular treatment over other treatments. Seed and stover yield of mungbean as influenced by application of different post-emergence herbicides are presented in Table 3 and depicted in Fig. 2. Significantly higher seed yield (1253 kg/ha) and stover yield (2093 kg/ha) was recorded under post-emergence application of fomesafen + fluazifop-p-butyl 220 g/ha (W_9) followed by the treatment sprayed with sodium acifluorfen + clodinafop-propargyl 210 g/ha (W_8). However, these treatments (W_7 and W_6) recorded 30.94 and 26.39 per cent higher grain yield over weedy check (W_1). The magnitude of increments in all these yields over application of W_9 was 37.66 and 28.95 percent over weedy check. Owing to nearly weed free condition observed under post-emergence application of said treatment, which enable the mungbean crop to acquire more nutrients from the soil and same way translocate to the active site where these nutrients accelerate the metabolic function such as cell division and photosynthesis results in more formation of yield attributing parameters in mungbean crop and eventually produces more yield. Similar findings were reported by Patidar *et al.* (2023) [11], Udhaya *et al.* (2023) [15] and Dhayal *et al.* (2022) [5].

Table 3: Seed and stover yield of mungbean as influenced by various post-emergence herbicides

Treatments	Seed yield (kg/ha)	Stover yield (kg/ha)
Weedy check (W_1)	781	1487
Weed free (W_2)	1307	2117
Imazethapyr (W_3)	963	1674
Fluazifop-p-butyl (W_4)	902	1589
Pendi. + imaza. (W_5)	1006	1737
Imaza. + imazmox. (W_6)	1061	1820
Propa + imaze. (W_7)	1131	1923
Acifluorfen + clodina. (W_8)	1190	2008
Fomesafen + fluazifop (W_9)	1253	2093
Quizalofop-ethyl 5% (W_{10})	850	1510
S.Em±	16.8	26.2
CD (P=0.05)	50.10	77.9

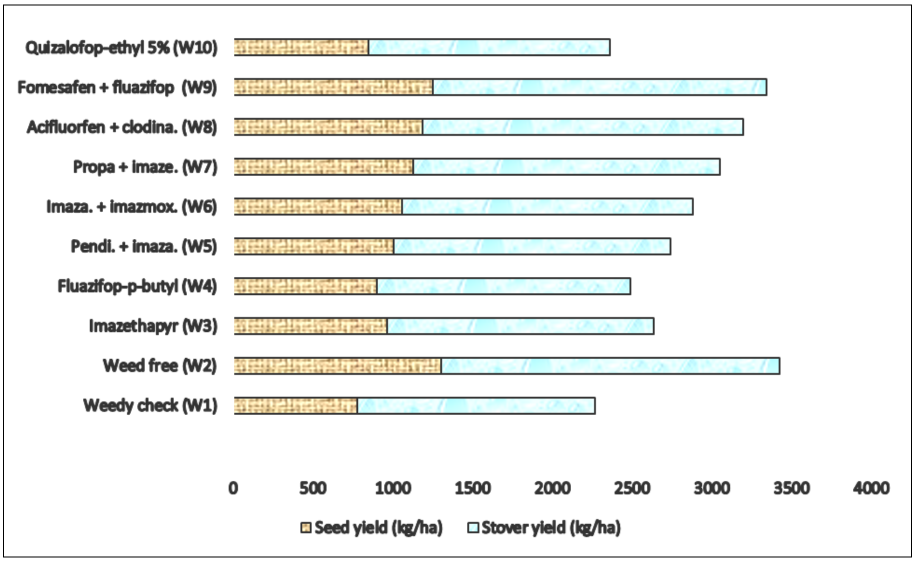

Fig 3: Seed and stover yield of mungbean as influenced by different post-emergence herbicides.

Conclusion

Baes on the experiment results it can be concluded that post-emergence application of fomesafen + fluazifop-p-butyl (220 g/ha) is highly effective in managing weed density, enhancing plant height, and increasing mungbean yield under arid conditions. This treatment, compared to others, significantly reduced the total weed density and achieved higher seed yield, proving to be a beneficial option for farmers. The results also suggest that this ready-mix herbicide can help lower herbicide dosage and reduce manual weeding expenses, making it a more economical and efficient weed control method. The success of fomesafen + fluazifop-p-butyl highlights its potential in improving mungbean productivity in challenging arid climates.

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