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Bio-efficacy of post emergence herbicide mixtures against mixed weed flora, density and weed control efficiency under soybean crop [*Glycine max* (L.) Merril.]

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Abstract
A field experiment was carried out at the Breeder Seed Production Unit, Department of Agronomy, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during the 2019 *Kharif* season, to assess the density and weed control effectiveness, as well as the bio-efficacy of herbicide combinations against mixed weed flora. The findings showed that monocot weeds like *Echinochloa colona* (44.7%) were the most common weeds in the experimental field. However, other monocot weeds like *Cyperus iria* (10.91%), *Commelina benghalensis* (13.36%), and dicot weeds like *Alterenanthera philoxiroides* (15.12%) and *Mollugo pentaphylla* (16.54%) were also associated with soybean in lesser numbers. When Fenoxaprop-p-ethyl 6% + Chlorimuron ethyl was applied post-emergence, the reduction in weed density and dry weight was more noticeable.

Keywords: Weed flora, monocot, dicot, soybean, weed control efficiency, weed control, Fomesafen + Flusifop-p-butyl and weed density

Introduction
Soybean, a native of north-eastern China. It's known as the "Golden Bean" and the miracle crop of the twenty-first century. 40–42% protein, 20–22% oil, 35–40% carbohydrates, 5%–6% minerals, and other nutrients, including vitamins, can be found in soybeans. The biological nitrogen fixation process in soybean allows it to use ambient nitrogen fixation. In comparison to other pulses, it fixes roughly 270 kilograms of biological nitrogen per year as opposed to 58 to 157 kg per year (Hoque, 1978) [3]. It is incredibly hardy and functions even under conditions of acute water stress. According to the USDA (2018) [13], the top soybean producing nations are the United States (34%), Brazil (30%), Argentina (18%), China (4%) and India, which contributes 3.95 percent to global production. In India, 11.48 million tonnes of soybeans are produced on an area of 10.84 million hectares. In Madhya Pradesh, 5.9 million tonnes of soybeans are produced annually on 5.4 million hectares of land, making it one of the top soybean-growing states in India (SOPA, 2018) [11]. As a result, Madhya Pradesh is referred to as the soybean state in the nation. However, soybean productivity is well below its yield potential at approximately 1094 kg ha^{-1}.

It is sown as a *kharif* crop in the state, but weed infestation is the main barrier to soybean production in the rainy season (Vollmann *et al.* 2010) [14]. If weeds are not controlled during the crucial time of crop-weed competition, there will be a noticeable loss in soybean yield of between 58 to 85%, depending on the type and weed intensity (Kewat and Panday, 2001) [4]. According to Vollmann *et al.* (2010) [14], weed infestations are seen as a persistent and complex restraint on soybean growth and development because they compete with the plant for nutrients, water, light, and space in addition to producing substances that are allelopathic. For the management of weeds in soybeans, pre-emergence herbicides such alachlor, fluchloralin, and metolachlor have been suggested and are used by farmers currently. However, new compounds must be discovered in order to manage weeds selectively and successfully as well as to address the issue of some weeds developing resistance to post-emergence advised herbicides (Thirumalaikumar and Kaplan, 2016) [12]. In order to assess chemical weed control strategies, particularly herbicide mixtures used as post-emergence treatments, which may be cost-efficient, highly effective.

Materiel and Methods

The experiment was carried out in Jabalpur, Madhya Pradesh, during the *Kharif* season in 2019. Ten weed control strategies in all were distributed using a randomised block design and triple replication. Depending on the crop cultivated, the management techniques used throughout the study and the soil of the experimental field, a variety of weeds may be present. Table 1 makes it evident that the soil in the experimental field had a clay loam texture, was neutral in reaction (7.2), medium in organic carbon (0.67%), and had accessible nitrogen, phosphorus, and potassium contents of 370.30 kg ha^{-1}, 16.73 kg ha^{-1}, and 310.90 kg ha^{-1}, respectively.

Table 1: Physio-chemical properties of the experimental soil

Texture	Clay loam (Sand: 32.13% Silt 32.80% and Clay 35.14%)
Soil pH	7.20
Electrical conductivity ($dS^{-1}m$)	0.32
Organic Carbon (%)	0.67
Available N (kg/ha)	370.30
Available P_2O_5 (kg/ha)	16.73
Available K_2O (kg/ha)	310.90

The observations were made at 30 DAS, when crop weed competition was at its most critical. In order to count the weeds by species, the weed-infested plots were measured using a quadrate of 0.25 square meters (0.5 m x 0.5 m). The recorded data was converted using the formulas. The percentage composition of the weed flora was calculated from the control plot. According to Mishra's (1968) [16] formula, the relative density of each weed was calculated

$$\text{Density/m}^2 = \frac{\text{Total number of individuals of species}}{\text{Total number of quadrates plotted}}$$

$$\text{Relative Density} = (\%) = \frac{\text{Number of individuals of the same species}}{\text{Number of individuals of all species}} \times 100$$

Weed control efficiency (WCE)

The effectiveness of any weed management method is evaluated in relation to weedy check (Mani et al., 1968) [7]. It might be written mathematically as:

$$WCE = \frac{DWC - DWT}{DWC} \times 100$$

Where,
WCE = Weed control efficiency
DWC = Dry weight of weeds in control plots
DWT = Dry weight of weeds in treated plots

Result and Discussion

Weed flora of soybean

The data on weed flora was shown in Table 2. It is obvious from the data the main weed species recorded in the experimental field were *Echinochloa colona*, *Cyperus iria*, and *Commelina benghalensis* among monocot weeds and *Alterenanthera philoxeroides, Mullogo pentaphylla* among dicot weeds. It is observed from the data that there was dominant of monocot weeds (68.34%) in control plot plots in soybean crop at Jabalpur (MP). Among the monocot weeds, *Echinochloa colona* was major dominant as they contributed 44.07 percent to the relative density of weeds. However, another monocot weeds viz. *Cyperus iria* and *Commelina benghalensis*, and dicot weeds such as *Alterenanthera philoxeroides* and *Mullogo pentaphylla* also marked their presence in less value (10.91, 13.36, 16.54 and 15.12 percent, respectively). Almost similar weed flora associated with soybean was observed by Patidar *et al*., (2019) [10].

Table 2: Weed flora and relative density of weeds in weedy check 15, 30, 45 and 60 DAS during *Kharif season* 2019

Weed flora		Density (m^{-2})				Mean	Relative Density (%)
		15 DAA	30 DAA	45 DAA	60 DAA		
A	Monocot weeds						
1	*Echinochloa colona*	85.00	91.00	95.11	98.74	92.46	44.07
2	*Cypers iria*	18.67	22.00	25.33	25.67	22.91	10.91
3	*Commelina benghalensis*	21.67	28.33	31.00	31.23	28.05	13.36
B	Subtotal					115.38	68.03
	Dicot weeds						
4	*Alterenanthera philoxeroides*	31.33	33.00	36.33	38.27	34.73	16.54
5	*Mullogo pentaphylla*	29.33	31.00	31.67	35	31.75	15.12
	Subtotal					94.54	33.66
	Total	186.00	250.33	219.44	228.91	209.92	100.00

Effect on density and weed dry weight

The various weed management methods shown in Tables 3 and 4 considerably affected weed density and dry weight of weeds at 30 DAA. The findings clearly show that all of these weeds had higher density and dry weight in the control plots due to their continued growth, whereas weed management practices weren't used in the weed control plots. However, weeds were equally reduced in density and dry weight when they were either chemically or manually controlled. Under weedy check plots at 30 DAA, where weeds were not treated in any way, the density and dry weight of weeds were reported at their highest levels. The weed density of monocot weeds like *Echinochloa colona, Cyperus Iria* and *Commelia benghalesis* (9.56 m^{-2}), (4.74 m^{-2}) and (5.36 m^{-2}) respectively and dry weight of *Echinochloa colona*, *Cyperus Iria* and *Commelia benghalesis* (14.63 g m^{-2}), (5.74 g m^{-2}) and (7.92 g m^{-2}) respectively. It was recorded highest under control plots at 30 DAA. Also density of dicot weeds like *Alterenanthera philoxeroides* and *Mullogo pentaphylla* also was recorded highest under control plot. The data presented in Table showed that among all the herbicidal treatment the highest reduction in the density of weed under the application of the Fenoxaprop-p-ethyl 6%+ Chlorimuron ethyl 0.9% + imazethapyr 10% ready mixture @ 200 g *a.i.* ha-1 proved

superior and recorded lowest monocot and dicot weed density *Echinochloa colona*, *Cyperus Iria* and *Commelia benghalesis*, *Alterenanthera philoxeroides* as well as *Mullogo pentaphylla* (1.84 m^{-2}), (1.70 m^{-2}), (1.37 m^{-2}), (1.46 m^{-2}), and (1.37 m^{-2}) respectively. Whereas, lowest dry weight of *Echinochloa colona*, *Cyperus Iria* and *Commelia benghalesis*, *Alterenanthera philoxeroides* as well as *Mullogo pentaphylla* (2.11 g m^{-2}), (1.56 g m^{-2}), (2.22 g m^{-2}), (2.15 g m^{-2}), and (1.34 g m^{-2}) respectively and it is closely followed by the application of Fenoxaprop-p-ethyl 6%+ Chlorimuron ethyl 0.9% + Imazethapyr 10% ready mixture when it is apply @ 170 g a.i. ha^{-1}. But the hand weeding treatments excelled to herbicidal treatments as they curbed the density of weeds and proved significantly superior over all herbicidal treatment. Similar results were also observed by Bedmar (1998) [15]. This might be due to hand weeding reduced the density including of weeds to the maximum extent over herbicidal treatments due to elimination of all sort of weeds during active crop growth and development. Also reported that Kushwaha and Vyas (2005) [6] and Ahirwar *et al.* (2018) [1].

Effect on Weed Control Efficiency (%)

Weed biomass and weed control efficiency (WCE) of a treatment have a strong inverse relationship. Different weed control methods have an impact on the effectiveness of controlling monocot and dicot weeds. The WCE information in Tables 5 and 6 is provided. The statistically it is clearly demonstrate that the ready mixture of Fenoxaprop-p-ethyl 6% + chlorimuron ethyl 0.9% + Imazethapyr 10% at 200 g a.i.ha-1 had a greater efficacy (95.05%), and it was closely followed by Fenoxaprop-p-ethyl 6% + chlorimuron ethyl 0.9% + Imazethapyr 10% @ 170 g a.i. None of the herbicidal methods, however, were better than manual hand weeding, which had a higher WCE of 97.97% for all monocot weeds. When it comes to dicot weeds, it is clear from the data that the administration of Fenoxaprop-p-ethyl in a ready combination provided the most effective weed control among all herbicides.

Table 3: Density of monocot and dicot weeds as influenced by weed control treatments at 30 DAA (m^{-2})

Weed Density (g m^{-2})							
Treatments		**Dose (g/ha)**	***Echinochloa colona***	***Cyperus Iria***	***Commelia benghalesis***	***Alterenanthera philoxeroides***	***Mullogo pentaphylla***
T_1	Fomesafen 11.1%w/w + Flusifop-p-butyl 11.1% w/w SL	220	3.13 (9.33)	2.07 (3.85)	1.77 (2.67)	1.70 (2.40)	1.49 (2.04)
T_2	Fomesafen 11.1%w/w + Flusifop-p-butyl 11.1% w/w SL	260	2.66 (6.67)	1.85 (2.97)	1.67 (2.33)	1.63 (2.15)	1.43 (1.96)
T_3	Imazethapyr 35% +Imazamox 35%	70	3.60 (12.45)	2.30 (5.00)	1.90 (3.18)	1.86 (3.00)	1.87 (3.03)
T_4	Imazethapyr 35% +Imazamox 35%	85	3.50 (11.77)	2.22 (4.51)	1.84 (2.91)	1.77 (2.67)	1.69 (2.38)
T_5	Imazethapyr 30%+Propaquizafop 2%	320	3.89 (14.60)	2.63 (6.84)	2.45 (5.52)	2.16 (4.19)	2.00 (3.50)
T_6	Imazethapyr 30%+Propaquizafop 2%	350	3.69 (13.15)	2.22 (4.45)	2.23 (4.52)	1.88 (3.07)	1.91 (3.15)
T_7	Fenoxaprop-p-ethyl 6%+ Chlorimuron ethyl 0.9% + Imazethapyr 10%	170	2.51 (5.86)	1.84 (2.89)	1.49 (1.74)	1.48 (1.78)	1.41 (1.47)
T_8	Fenoxaprop-p-ethyl 6%+ Chlorimuron ethyl 0.9% + Imazethapyr 10%	200	1.84 (3.00)	1.70 (2.40)	1.37 (1.41)	1.46 (1.67)	1.37 (1.60)
T_9	Hand weeding	20 & 40 DAS	1.32 (1.24)	1.06 (0.78)	1.23 (1.04)	0.93 (0.41)	0.93 (0.41)
T_{10}	Control	-	9.56 (91.00)	4.74 (22.00)	5.36 (28.33)	5.60 (31.00)	5.79 (33.00)
	SEm±		0.13	0.24	0.10	0.15	0.21
	CD (p= 0.05)		0.38	0.72	0.29	0.44	0.61

* = The figures in the parenthesis are the original value and out of parenthesis are in the transformed value (√x+0.5)
DAA = Days after application

Table 4: Dry weight of monocot and dicot weeds as influenced by weed control treatments at 30 DAA (g m^{-2})

Weed Dry weight (g m^{-2})							
Treatments		**Dose (g/ha)**	***Echinochloa colona***	***Cyperus Iria***	***Commelia benghalesis***	***Alterenanthera philoxeroides***	***Mullogo pentaphylla***
T_1	Fomesafen 11.1%w/w + Flusifop-p-butyl 11.1% w/w SL	220	2.55 (6.07)	1.78 (2.70)	2.50 (5.81)	2.34 (5.08)	1.62 (2.14)
T_2	Fomesafen 11.1%w/w + Flusifop-p-butyl 11.1% w/w SL	260	2.27 (4.70)	1.73 (2.54)	2.46 (5.57)	2.26 (4.71)	1.52 (1.82)
T_3	Imazethapyr 35% +Imazamox 35%	70	2.85 (7.67)	2.70 (6.85)	2.52 (5.97)	2.68 (6.70)	1.79 (2.70)
T_4	Imazethapyr 35% +Imazamox 35%	85	2.68 (6.73)	2.09 (4.04)	2.47 (5.70)	2.64 (6.52)	1.72 (2.48)
T_5	Imazethapyr 30%+Propaquizafop 2%	320	2.93 (8.17)	2.89 (7.92)	2.82 (7.55)	3.01 (8.74)	1.89 (3.11)
T_6	Imazethapyr 30%+Propaquizafop 2%	350	2.86 (7.77)	2.82 (7.48)	2.55 (6.06)	2.74 (7.07)	1.83 (2.89)
T_7	Fenoxaprop-p-ethyl 6%+ Chlorimuron ethyl 0.9% + Imazethapyr 10%	170	2.13 (4.11)	1.62 (2.14)	2.37 (5.17)	2.21 (4.44)	1.43 (1.58)
T_8	Fenoxaprop-p-ethyl 6%+ Chlorimuron ethyl 0.9% + Imazethapyr 10%	200	2.11 (3.55)	1.56 (1.97)	2.22 (4.48)	2.15 (4.15)	1.34 (1.33)
T_9	Hand weeding	20 & 40 DAS	2.01 (3.67)	1.21 (0.97)	1.10 (0.77)	1.39 (1.57)	0.80 (0.17)
T_{10}	Control	-	14.63 (215.87)	5.74 (32.67)	7.92 (62.40)	5.61 (31.33)	2.15 (4.14)
	SEm±		0.10	0.15	0.16	0.19	0.08
	CD (p= 0.05)		0.30	0.43	0.49	0.56	0.25

* = The figures in the parenthesis are the original value and out of parenthesis are in the transformed value (√x+0.5)
DAA = Days after application

Table 5: Weed control efficiency of monocot weeds as influenced by weed control treatments

Weed control efficiency (%)						
	Treatment	Dose (g a.i ha^{-1})	*Echinochloa Colona*	*Cyperus iria*	*Commelina benghalensis*	Mean (%)
1.	Fomesafen 11.1%w/w + Flusifop-p-butyl 11.1% w/w SL	220	97.18	91.72	90.68	93.19
2.	Fomesafen 11.1%w/w + Flusifop-p-butyl 11.1% w/w SL	260	97.82	92.22	91.07	93.70
3.	Imazethapyr 35% +Imazamox 35%	70	96.44	79.03	90.43	88.64
4.	Imazethapyr 35% +Imazamox 35%	85	96.88	87.64	90.86	91.79
5.	Imazethapyr 30%+Propaquizafop 2%	320	96.21	75.75	87.90	86.62
6.	Imazethapyr 30%+Propaquizafop 2%	350	96.40	77.08	90.28	87.92
7.	Fenoxaprop-p-ethyl 6%+ Chlorimuron ethyl 0.9% + Imazethapyr	170	98.09	93.44	91.71	94.41
8.	Fenoxaprop-p-ethyl 6%+ Chlorimuron ethyl 0.9% + Imazethapyr	200	98.35	93.97	92.82	95.05
9.	Hand weeding	20&40DAS	98.11	97.04	98.77	97.97
10.	Control	-	-	-	-	-

Table 6: Weed control efficiency of dicot weeds as influenced by weed control treatments

Weed control efficiency (%)					
	Treatment	Dose (g a.i. ha^{-1})	*Alterenanthera philoxeroides*	*Mollugo pentaphylla*	Mean (%)
1.	Fomesafen 11.1%w/w + Flusifop-p-butyl 11.1% w/w SL	220	83.79	48.22	66.01
2.	Fomesafen 11.1%w/w + Flusifop-p-butyl 11.1% w/w SL	260	84.97	55.95	70.46
3.	Imazethapyr 35% +Imazamox 35%	70	78.61	34.78	56.69
4.	Imazethapyr 35% +Imazamox 35%	85	79.19	40.01	59.60
5.	Imazethapyr 30%+Propaquizafop 2%	320	72.10	24.79	48.45
6.	Imazethapyr 30%+Propaquizafop 2%	350	77.43	30.19	53.81
7.	Fenoxaprop-p-ethyl 6%+Chlorimuron ethyl 0.9% + Imazethapyr 10%	170	85.83	53.86	69.85
8.	Fenoxaprop-p-ethyl 6%+Chlorimuron ethyl 0.9% + Imazethapyr 10%	200	86.74	59.74	73.24
9.	Hand weeding	20&40DAS	94.99	95.97	95.48
10..	Weedy-check	-	-	-	

Conclusion

The following conclusions could be derived using data from a single year based on the discussion above. Weeds that predominated in soybean were *Echinochloa colona* (44.7%), it can be said. However, other monocot weeds including *Cyperus iria* (10.91%), *Commelina benghalensis* (13.36%), and dicot weeds like *Alterenanthera philoxiroides* (15.12%) and *Mollugo pentaphylla* (16.54%) were also discovered in lesser numbers cultivated with soybean. The post-emergence application of Fenoxaprop-p-ethyl 6% + Chlorimuron ethyl 0.9% + Imazethapyr 10% ready mixture @ 200 g a.i. ha^{-1} gave effective control of monocot and dicot weeds in soybean and it also gave highest weed control efficiency. The reduction in weed density and dry weight was more pronounced.

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