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Bio-efficacy of fomesafen + fluazifop-p-butyl mixture against weeds and its effect on productivity and profitability of soybean (*Glycine max*) in Central India

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ABSTRACT

Grassy and broadleaf weeds are simultaneously growing in soybean (*Glycine max* L.) crop and there is a lack of herbicides to control all types of weeds in a soybean crop. Thus, a field experiment was conducted during rainy (*kharif*) seasons of 2017 and 2018 to evaluate efficacy of fomesafen + fluazifop-p-butyl mixture against weeds and consequent improvement in productivity of soybean. Bio-efficacy was evaluated with 10 weed control treatments comprising of 4-doses of fomesafen + fluazifop-p-butyl mixture (90+90, 110+110, 130+130 and 220+220 g/ha), alone application of imazethapyr (100 g/ha), market check – fomesafen + fluazifop-p-butyl (110 + 110 g/ha), combined application of imazethapyr + imazamox (35 + 35 g/ha) as early post-emergence, hand weeding twice at 15 and 30 DAS, weed-free and weedy-check, were laid-out in a randomized complete block design with three replications. Application of premix fluazifop-p-butyl + fomesafen (130+130 g/ha) as early-post-emergence resulted in lower density, dry weight of all individual weeds with 99.2% weed control efficiency (WCE) and higher value of yield parameters and yield (2.01 t/ha) of soybean which was statistically at par with weed-free plots (2.04 t/ha). The higher dose of fomesafen + fluazifop-p-butyl (220+220 g/ha) was found effective against weeds but caused phytotoxicity to soybean crop and reduced seed yield marginally (1.98 t/ha). The fomesafen residues up to 130 g/ha dose were found below the detectable limit in the soil with zero per cent persistence at harvest. However, the highest dose of fomesafen (220 g/ha) resulted in residues in soil (0.016 µg/g) with 4.44% persistence and half-life of 13 days. These results suggested that premix fomesafen + fluazifop-p-butyl at 130+130 g/ha as early-post-emergence can be safe for the application in soybean crop.

Keywords: Fomesafen + fluazifop-p-butyl, Productivity, Soybean, Weeds, Weed control efficiency

Severe weed competition is one of the major constraints for low productivity (about 1 t/ha) of soybean (*Glycine max* L.) (Dass *et al.* 2019). The weeds which invade the crop and affect yield mainly include monocot weeds like *Echinochloa colona, Echinochloa crusgalli, Cyperus rotundus, Cynodon dactylon, Cyperus iria, Dinebra retroflexa* and broad leaved weeds like *Phyllanthus niruri, Euphorbia* spp.*, Commelina benghalensis, Eclipta alba, Mollugo pentaphylla, Corchorus acutangulus,* etc. which compete for essential nutrients, moisture, sunlight and space during early period of crop growth (critical period of crop-weed competition) and cause identical reduction in crop yields. Bhimwal *et al.* (2019) noted that monocot weeds were predominant (55.1%) in the experimental field, as compared with dicot weeds (44.9%). *Echinochloa colona* (41.6%) and *Trianthema portulacastrum* (33.2%) were predominant in soybean but other weeds like *Cyperus rotundus*, *Cynodon dactylon*, *Commelina benghalensis*, *Digera arvensis*, *Amaranthus viridis*, *Physalis minima*, *Corchorus spp. etc.* also marked their presence in the experimental field. Zandona *et al.* (2018) observed 73–94% reduction in soybean yield in the weedy-check plots where weeds were allowed to grow with crop throughout the growing season.

Frequent weather events like uneven heavy rainfall during the rainy (*kharif*) season coupled with unavailability of labour during peak periods of demand reduced the scope of manual weeding. In such circumstances, the only alternative method to control weeds is the use of dominant herbicides. The proper contact of herbicide with weeds is very difficult in case of post-emergence application in soybean due to quick cover of ground and attaining the proper height of crop. Beside this, the use of single herbicide has not been found effective as some weeds escape due to their selectivity. Therefore, the use of pre-mix herbicides may wider the window of weed management by the way of broad-spectrum weed control (Bineet *et al.* 2001, Malik *et al.* 2006, Dass *et al.* 2019, Pratap *et al.* 2023) and help delay resistance in weeds.

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Fomesafen is a new herbicide of diphenyl ether group, used as early post-emergence herbicide with unique selectivity and herbicidal activity against broad-leaved weeds in soybean. Fomesafen controlled broadleaved weeds successfully at 240 and 480 g/ha to beans in Ontario (Soltani *et al.* 2017). But, very meagre information is available about its efficacy and their residue in soil when applied in combination with fluazifop-p-butyl as ready mixture. Pundas *et al.* (2018a) reported lower weed density (12.7/m^2) and dry weight (14.26 g/m^2) with 85.6% weed control efficiency with the application of fomesafen + clodinafop at 219 + 156 g/ha as post emergence. Oliveira *et al.* (2017) found that application of fomesafen + imazethapyr mixture controlled broad-leaved weeds and grassy weeds in more than 90 and 80% with higher yield of soybean. These all combinations are used to control weeds in soybean but require much higher doses for effective control of weeds.

Hence, it is of utmost importance to judge ready to use mixture efficacy for broad-spectrum weed control in soybean crop. Therefore, the present investigation was conducted to evaluate the efficacy and persistence of fomesafen in the soil to provide a base on the number of applications of the herbicide with various dosages that might be helpful to recommend the suitable dose in terms of possibly least residue contamination in soil.

MATERIALS AND METHODS

A two-year field experiment was conducted at the research farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh during rainy (*kharif*) seasons of 2017 and 2018. Soil of the experimental field was clayey loam in texture. It was medium in organic carbon (0.6 %), available nitrogen (369.5 kg/ha), available phosphorus (15.6 kg/ha) and high in available potassium (322.1 kg/ha) contents and neutral in reaction (7.2). The concentration of salt was below toxic limit (0.3 dS/m).

The experiment was laid out with 10 weed control treatments comprising four doses of fomesafen 11.1% + fluazifop-p-butyl 11.1% SL mixture (90+90, 110+110, 130+130 and 220+220 g a.i/ha), alone application of imazethapyr 10% SL (100 g a.i/ha), market check – fomesafen 11.1% + fluazifop-p-butyl 11.1% SL (110 + 110 g a.i/ha), combined application of imazethapyr 35% + imazamox 35% WG (35 + 35 g a.i/ha) as early post-emergence (10 DAS), hand weeding twice at 15 and 30 DAS, weed free and weedy check in randomized complete block design with 3 replications. Sowing of soybean variety JS 20-69 was sown manually with seed rate of 80 kg/ha. The major weed flora in the experimental field consisted of monocot weeds, viz. *Echinochloa colona, Cyperus iria* and dicot weeds, viz. *Mollugo pentaphylla, Cichorium intybus, Phyllanthus urinaria* and *Eclipta alba* in main crop season.

Observations on main crop (Soybean): The observations on weeds in main crop (soybean) under different treatments were made at 30 days after application (DAA) of herbicidal treatments and mechanical weed control by using quadrat of 0.25 m^2 and the same was placed at four places in each plot. Individual weeds were collected separately from the same area at 30 DAA. Weed samples were oven dried before weighing at 60±2°C till the constant weight was achieved. The data on density and dry weight of weeds were subjected to square root transformation ($\sqrt{x+1}$). Weed control efficiency (WCE) and weed index (WI) was computed by using the following formula (Lal *et al.* 2017, Singh *et al.* 2017):

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

Where, WCE, Weed control efficiency; DWC, Dry weight (g) of weeds in control plots and; DWT, Dry weight (g) of weeds in treated plots.

$$WI = \frac{X - Y}{X} \times 100$$

Where, WI, Weed index; X, Seed yield of weed free plot and; Y, Seed yield of the treated plot for which weed index is to be worked out. The number of pods per plant and seed index (100 seed weight) were recorded at harvest from 5 randomly selected plants. The seed and stover yield of soybean were recorded at harvest from net plot by threshing manually then yield was converted from kg/plot to t/ha by multiplying with appropriate conversion factor. The economic analysis of treatments was determined on a per hectare area basis and cost of cultivation was worked out based on the labour and market price of various common and variable agro-inputs input cost incurred towards soybean cultivation in different treatments. Gross monetary return was worked out based on the minimum support price for soybean (₹30.5 and 33.9/kg) and for stover (₹1.5 and 1.5/kg) in 2017 and 2018, respectively and B:C was calculated.

Residue analysis: Soil samples were collected from each plot at harvest. Approximately 2.5 kg of soil was dug out from a depth of 15 cm with the help of soil auger from randomly selected five places out of each treated plot. The samples were bulked together from each plot, powdered and mixed uniformly before analysis. In the laboratory, residue was extracted using a mixture of acetonitrile and hydrochloric acid in 98:2 proportions. After the complete extraction process, residue was collected in HPLC grade acetonitrile (2 ml) for further analysis by Ultra Fast Liquid Chromatography (UFLC). Residue concentration was determined by using UFLC. Half-life was calculated by using following formula:

$$t_{1/2} = \frac{0.693}{K}$$

Where $t_{1/2}$, half life of herbicide and; K, rate constant.

RESULTS AND DISCUSSION

Associated weed flora: On the basis of mean data (2017 and 2018) the density of monocot weeds was higher (55.8%) as compared to dicot weeds (44.2%) in weedy check plot. Among the monocot weeds, *Echinochloa colona*

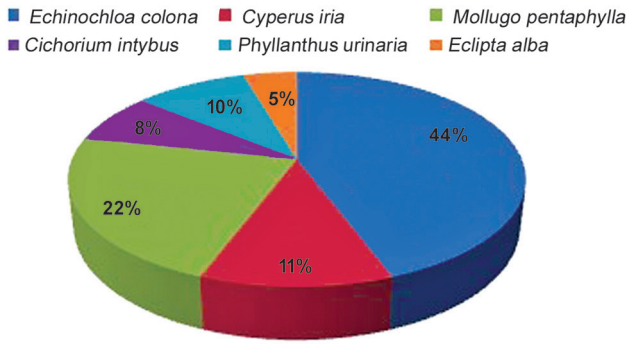

Fig 1 Relative density of monocots and broadleaf weeds.

was more rampant constituting 44.3% relative density, whereas, *Mollugo pentaphylla* wasdominant among the dicots (22.5%) due to higher seed bank in soil coupled with continuous germination of these weed seeds in the experimental field. However, other monocot weeds like *Cyperus iria* (11.5%) as well as dicot weeds *Cichorium intybus* (7.6%), *Phyllanthus urinaria* (9.5%) and *Eclipta alba (*4.5%) also marked their presence in lesser numbers in soybean (Fig 1). Lodha (2018) also reported presence of above biomass in the soybean field.

Density, dry weight of weeds and weed control efficiency (WCE): The density and dry weight of all individual species of weeds were maximum under weedy check plots due to uninterrupted growth during critical period of crop-weed competition (Table 1 and 2). Fomesafen + fluazifop-p-butyl mixture at the lowest dose (90+90 g/ha) caused approximately 80% reduction in the density and dry weight of almost all weeds over weedy-check plots.

However, the activity of fomesafen + fluazifop-p-butyl mixture at lower dose was poor against *Cyperus iria* as compared to other weeds and it could control only 29.5% weed density and 45.2% dry weight. The higher reduction in dry weight was found when fomesafen + fluazifop-p-butyl was applied at 130+130 g/ha (>94–97%) or higher dose 220+220 g/ha except *Cyperus iria* (88.6 and 92.7% reduction, respectively) and proved significantly effective over other treatments. Similar results were also found by Kadam *et al.* (2018). Singh *et al.* (2014) reported an effective control of grassy and non-grassy weeds with fomesafen + fluazifop-p-butyl 250+250 g/ha.

Lower WCE (75.3%) was recorded with application of Imazethapyr (100 g/ha) due to poor control of weeds. The activity of fomesafen + fluazifop-p-butyl at lower dose (90+90 g/ha) was poor against all weeds (83.9%). The efficiency was further increased with increasing the application rates being higher at 130+130 (99.2%) or 220+220 g/ha (99.6%) which was nearly the same as hand weeded plots (99.9%) and proved superior over the check herbicides. Similarly, Yadav *et al.* (2022) reported 87.4%

Table 1 Effect of different weed control treatments on density of weeds species in soybean at 30 days after application (DAA) [mean data of *kharif* 2017 and 2018]

Treatment	Dose (g/ha)	Density of weeds/m^2 at 30 DAA					
		Echinochloa colona	*Cyperus iria*	*Mollugo pentaphylla*	*Cichorium intybus*	*Phyllanthus urinaria*	*Eclipta alba*
Fomesafen + fluazifop-p-butyl	90+90	5.93 (35.17) de	4.91 (23.50) g	2.58 (6.00) c	2.36 (6.00) c	3.69 (13.00) f	2.13 (3.67) d
Fomesafen + fluazifop-p-butyl	110+110	3.53 (11.83) c	3.46 (11.17) ef	1.45 (1.17) ab	1.82 (2.50) b	2.95 (8.17) e	1.63 (1.83) bc
Fomesafen + fluazifop-p-butyl	130+130	2.16 (3.83) b	3.04 (8.33) de	1.21 (0.50) ab	1.26 (0.67) a	2.66 (6.33) de	1.21 (0.50) ab
Fomesafen + fluazifop-p-butyl	220+220	1.59 (1.67) ab	2.53 (5.67) cd	1.00 (0.00) a	1.21 (0.50) a	2.09 (3.50) cd	1.00 (0.00) a
Imazethapyr	100	6.30 (39.33) e	2.90 (7.37) de	4.85 (23.67) e	3.85 (13.83) d	2.51 (5.50) de	2.85 (7.33) e
Market check (fomesafen + fluazifop-p-butyl)	110+110	4.15 (16.83) c	3.76 (13.33) f	1.59 (1.67) b	1.69 (2.00) b	3.04 (8.50) e	1.94 (3.00) cd
Imazethapyr + imazamox	35 + 35	5.44 (29.33) d	2.11 (3.67) bc	3.58 (12.67) d	2.65 (6.17) c	1.84 (2.67) bc	2.35 (4.67) d
Hand weeding	15 and 30 DAS	1.87 (2.67) b	1.97 (3.17) b	3.01 (8.50) c	1.62 (1.67) b	1.40 (1.17) ab	1.90 (2.67) cd
Weed free	-	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a
Weedy check (control)	-	11.30 (128.33) f	5.84 (33.33) h	8.12 (65.33) f	4.75 (22.00) e	5.32 (27.67) g	3.73 (13.17) f
SEm±	-	0.30	0.21	0.17	0.15	0.18	0.14
CD (P=0.05)	-	0.87	0.61	0.50	0.42	0.53	0.39

*Figures in parenthesis are the original values and others are transformed values (√x+1). *Common letters are non-significant according to Duncan's multiple range test where P < 0.05.

Table 2 Effect of different weed control treatments on dry weight of weed species and weed control efficiency (WCE) in soybean at 30 days after application (DAA) [mean data of *kharif* 2017 and 2018]

Treatment	Dose (g/ha)	Dry weight of weeds (g/m^2) at 30 DAA						Total weed control efficiency (%) at 30 DAA
		Echinochloa colona	*Cyperus iria*	*Mollugo pentaphylla*	*Cichorium intybus*	*Phyllanthus urinaria*	*Eclipta alba*	
Fomesafen + fluazifop-p-butyl	90+90	10.59 (111.83) d	4.62 (20.75) a	1.14 (0.30) b	1.23 (0.53) bc	1.70 (1.95) c	1.34 (0.81) b	83.89
Fomesafen + fluazifop-p-butyl	110+110	3.16 (9.14) b	2.68 (6.31) d	1.02 (0.04) a	1.07 (0.15) ab	1.42 (1.06) bc	1.15 (0.32) ab	97.93
Fomesafen + fluazifop-p-butyl	130+130	1.65 (1.77) a	2.30 (4.33) c	1.01 (0.01) a	1.02 (0.05) a	1.27 (0.63) ab	1.00 (0.01) a	99.19
Fomesafen + fluazifop-p-butyl	220+220	1.11(0.24) a	1.91(2.78) b	1.00 (0.00) a	1.02 (0.04) a	1.15 (0.33) ab	1.00 (0.00) a	99.59
Imazethapyr	100	14.35 (208.47) e	1.69 (1.92) b	1.51 (1.33) d	1.83 (2.39) d	1.44 (1.10) bc	1.44 (1.12) b	74.25
Market check (fomesafen + fluazifop-p-butyl)	110+110	3.33 (10.45) b	2.83 (7.12) d	1.02 (0.05) a	1.09 (0.18) ab	1.50 (1.28) bc	1.23 (0.54) ab	97.61
Imazethapyr + imazamox	35 + 35	9.23 (87.41) c	1.25 (0.57) a	1.25 (0.57) c	1.38 (0.93) c	1.13 (0.30) ab	1.20 (0.47) ab	89.35
Hand weeding	15 and 30 DAS	1.01(0.03) a	1.02 (0.05) a	1.11 (0.23) b	1.01 (0.02) a	1.01 (0.01) a	1.02 (0.05) a	99.96
Weed free	-	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	100.00
Weedy check (control)	-	27.98 (793.05) f	6.21(37.88) f	3.69 (12.64) e	2.64 (6.17) e	3.50 (11.68) d	2.03 (3.33) c	-
SEm±	-	0.50	0.15	0.09	0.08	0.10	0.08	-
CD (P=0.05)	-	1.45	0.43	0.26	0.24	0.29	0.23	-

*Figures in parenthesis are the original values and others are transformed values (√x+1). *Common letters are non-significant according to Duncan's multiple range test where P < 0.05.

WCE in greengram with the application of fomesafen + fluazifop-p-butyl at 220 + 220 g/ha.

Yield attributes, yield and weed index of soybean: The mean value of two rainy seasons (2017 and 2018) demonstrated that application of fomesafen + fluazifop-p-butyl at 130+130 g/ha recorded more number of pods per plant and was found significantly superior over its lower doses 90+90, 110+110 g/ha and check herbicides being at par with highest dose of fomesafen + fluazifop-p-butyl (220+220 g/ha), hand weeding and weed free plots (Table 3). Seed index of soybean did not vary due to different weed control treatments as it is governed by genetic factors to a great deal.

Seed and stover yield were recorded as minimum (0.70 and 2.03 t/ha, respectively) in the weedy check plot receiving no weed control measure throughout the growing season. However, the seed and stover yield was further increased with corresponding increase in dose of fomesafen + fluazifop-p-butyl mixture when it was applied at 130+130 g/ha (2.03 and 4.19 t/ha, respectively) and proved significantly superior over the check herbicides imazethapyr 100 g/ha (1.07 and 2.68 t/ha), imazethapyr + imazamox 35+35 g/ha (1.48 and 3.33 t/ha) and market sample of fomesafen + fluazifop-p-butyl mixture 110+110 g/ha (1.73 and 3.75 t/ha). But, it was found at par to hand weeding twice (2.02 and 4.16 t/ha) and weed free (2.06 and 4.24 t/ha, respectively). The highest dose of fomesafen + fluazifop-p-butyl (220+220 g/ha) caused slight phytotoxicity to crop plants and thereby produced inferior yield attributing traits leading to marginal reduction in seed and stover yields (1.99 and 4.15 t/ha, respectively). Similarly, Singh *et al.* (2014) observed phytotoxicity on soybean when fomesafen + fluazifop-p-butyl was applied at higher dose (250+250 g/ha) and obtained inferior seed yield than lower doses 125+125. Kashyap *et al.* (2022) also reported severe phytotoxicity on chickpea with the application of fomesafen + fluazifop-p-butyl at higher dose (220+220 g/ha).

The maximum reduction in seed yield (66.2%) occurred in weedy check plots, where weeds were allowed to grow throughout the crop season. However, the lowest weed index (1.65%) was recorded with fomesafen + fluazifop-p-butyl at 130+130 g/ha as the yield losses were minimum followed by hand weeding twice (2.3%) and highest dose of fomesafen + fluazifop-p-butyl 220+220 g/ha (3.36%). Kadam *et al.* (2018) also found that post-emergence application of fomesafen + fluazifop-p-butyl at 125+125 g/ha recorded higher seed yield of soybean (2.42 t/ha) and proved superior over check herbicides. Similarly, Pundas

Table 3 Effect of weed control treatments on yield attributes, seed and straw yield, weed index and economics of soybean (mean data of *kharif* 2017 and 2018)

Treatment	Dose (g/ha)	Pods/plant (no.)	Seed index (g)	Seed yield (t/ha)	Stover yield (t/ha)	Weed index (%)	Cost of cultivation (₹/ha)	Gross monetary returns (₹/ha)	Net monetary returns (₹/ha)	B:C ratio
Fomesafen + fluazifop-p-butyl	90 + 90	38.43 d	8.01 a	1.25 e	2.97 cd	39.32	30937	44847	13910	1.45
Fomesafen + fluazifop-p-butyl	110 + 110	55.22 bc	8.58 a	1.81 bc	3.87 ab	12.14	31229	64361	33131	2.06
Fomesafen + fluazifop-p-butyl	130 + 130	63.63 ab	8.71 a	2.03 ab	4.19 a	1.46	31522	71711	40189	2.27
Fomesafen + fluazifop-p-butyl	220 + 220	61.29 abc	8.55 a	1.99 ab	4.15 a	3.40	32840	70511	37671	2.15
Imazethapyr	100	32.09 d	7.94 a	1.07 e	2.68 d	48.06	31063	38601	7538	1.24
Market check (fomesafen + fluazifop-p-butyl)	110 + 110	53.32 c	8.38 a	1.73 c	3.75 ab	16.02	31205	61455	30250	1.97
Imazethapyr + imazamox	35 + 35	40.12 d	8.31 a	1.48 d	3.33 bc	28.16	30969	52794	21825	1.70
Hand weeding	15 and 30 DAS	62.19 ab	8.72 a	2.02 ab	4.16 a	1.94	41019	71266	30247	1.74
Weed free	-	64.71 a	9.13 a	2.06 a	4.24 a	-	47019	72907	25888	1.55
Weedy check (control)	-	22.34 e	7.84 a	0.70 f	2.03 e	66.02	29019	25587	-3432	0.88
SEm±	-	2.36	0.28	0.07	0.15	-	-	-	-	-
CD (P=0.05)	-	6.76	NS	0.21	0.43	-	-	-	-	-

*Common letters are non-significant according to Duncan's multiple range test where $P < 0.05$.

et al. (2018b) also reported that application of fomesafen + clodinafop at 219 + 156 g/ha recorded significantly higher seed and stover yields.

Economics: The mean data of two rainy seasons (2017 and 2018) shows that higher gross monetary returns (₹72907/ha) were fetched with weed free followed by application of fomesafen + fluazifop-p-butyl at 130+130 g/ha (₹71711/ha) closely followed by hand weeding twice (₹71266/ha) and highest dose of fomesafen + fluazifop-p-butyl at 220+220 g/ha (₹70511/ha). But, net monetary returns and B:C ratio were maximum (₹40189/ha and 2.27) with early post-emergence application of fomesafen + fluazifop-p-butyl at 130+130 g/ha (Table 3). Similarly, higher gross returns, net returns and B:C ratio of groundnut with the application of fomesafen + fluazifop-p-butyl at 125+125 g/ha were reported by Shah and Premanik (2020).

Residue concentration and persistence of fomesafen: At harvest, fomesafen residues degraded below the detection limit (0.001 µg/g) and no residues (zero persistence) were found in the soil except when it was applied at the highest dose (220 g/ha) in which 0.009 µg/g residue of fomesafen was found in the soil with 4.44% persistence. The highest dose (220 g/ha) recorded a half life of 13 days. The half-life value was nearly similar to the previous observations made by Cobucci *et al.* (1998). Whereas, Johnson and Talbert (1993) reported that the degradation of fomesafen was less than 3 weeks in anaerobic conditions and 6 to 12 months under aerobic conditions.

The application of premix fomesafen + fluazifop-p-butyl at 90+90, 110+110 and 130+130 g/ha as early post-emergence gave effective control of diverse weed flora, attained higher value of yield attributing traits, yield and was more remunerative in terms of net monetary returns and B:C ratio without any phytotoxicity on soybean crop plants. The fomesafen residues were found below detectable limit in the soil with 0% persistence at harvest. However, the highest dose of fomesafen at 220 g/ha was having some residues in soil (0.016 µg/g) with 4.44% persistence. Thus, it could be concluded that premix fomesafen + fluazifop-p-butyl at 130+130 g/ha as early post-emergence can be recommended in soybean without any residual effect on soil.

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