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Efficacy of imazethapyr applied alone and mixed with pendimethalin or imazamox in cluster bean (*Cyamopsis tetragonoloba*) and their residual effect on mustard (*Brassica juncea*) in two texturally different soils

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ABSTRACT

An experiment was carried out at two locations, CCS HAU, Hisar and farmer's field in Kheri Batter, Bhiwani to study the efficacy and phytotoxicity of different herbicides/combinations in cluster bean (*Cyamopsis tetragonoloba* L.) during *kharif* 2013 and their carryover effect on mustard [*Brassica juncea* (L.) Czernj. & Coss.] crop in *rabi* season (2013-14). PRE application of pendimethalin 1.0 kg/ha, ready mix (RM) of pendimethalin + imazethapyr (Valor) 1.0 kg/ha and tank mix (TM) at 500 g + 50 g/ha provided 93/83, 98/90 and 100/93 % control of weeds, respectively at Hisar/Kheri Battar locations up to 30 DAS, but at 60 DAS, due to the emergence of new flush of weeds, weed control was reduced to 65/45, 83/80 and 87/87% with the above treatments, respectively at both the locations. Ready/tank mix of pendimethalin + imazethapyr (1000 g and 500+50 g/ha) not only provided satisfactory weed control up to 60 DAS but also exhibited no phytotoxic effect on cluster bean. At 60 DAS, highest weed control (88 and 87%) was recorded with imazethapyr 100 g/ha *fb* propaquizafop 62.5 g/ha 3 *fb* 6 WAS, respectively at Hisar and Kheri Battar locations which was at par with pendimethalin + imazethapyr (RM and TM), imazethapyr + imazamox (Odyssey) 70 g/ha *fb* propaquizafop 62.5 g/ha, 75 and 50 g of imazethapyr *fb* propaquizafop 3 *fb* 6 WAS at Kheri Battar, but the efficacy of Odyssey and imazethapyr 50 and 75 g *fb* propaquifzafop was lower under Hisar conditions due to heavy infestation of *Trianthema portulacastrum*. POE herbicides, except propaquizafop and pendimethalin showed crop phytotoxicity and growth suppression soon after application at higher rates, though plants recovered after 2 weeks and no injury was observed at later stages. Minimum weed dry weight, highest yield attributes and seed yield with maximum net return and B-C ratio was obtained under POE imazethapyr 100 g/ha *fb* propaquizafop 62.5 g/ha, and pendimethalin 0.5 kg + imazethapyr 50 g/ha (TM), but both were statistically similar to each other and to pendimethalin + imazethapyr (RM) 1.0 kg/ha and imazethapyr + imazamox 70 g/ha *fb* propaquizafop 62.5 g/ha as POE at Kheri Batter location, but at Hisar location only pendimethalin + imazethapyr (RM and TM) provided maximum net return and B-C ratio. There was no carry over effect of different herbicides used in cluster bean on succeeding mustard crop, probably due to herbicide detoxification through microbial degradation mediated by high temperature and moisture and possibly by leaching of herbicides because of 594.3 and 500.5 mm of rainfall in the crop growing season at both the locations, respectively.

Key words: Cluster bean, Crop injury, Herbicide mixture, Herbicide efficacy, Mustard, Persistence

There are many constraints for lower yield of cluster bean (*Cyamopsis tetragonoloba* L.), but weed infestation is one of the main constraints (Yadav *et al*. 1993). The first 30-45 days are very critical for cluster bean crop-weed competition.

Major weed flora of cluster bean includes *Trianthema portulacastrum* L.*, Digera arvensis* Forsk.*, Cleome viscosa* L.*, Dactyloctenium aegyptium* Beauv.*, Physallis minima* L.*, Echinochloa colona* (L.) Link*, Cenchrus echinatus* L.*, Corchorus* sp.*, Acrachne racemosa* (Heyne) Ohwi.*, Commelina benghalensis* L.*, Digitaria sanguinalis* (L.) Scop.*, Eragrostis ciliaris* (L.) R. Br*, Leptochloa chinensis* (L.) Nees., *Mollugo nudicaulis* (Lamk)*, Mollugo cerviana* (L.) Ser., *Celosia argentea* (L.)*, Bulbostylis barbata* (Rottb.) Clarke.*, Phyllanthus niruri* L.*, Portulaca oleraceae* L.*, Brachiaria* sp.*, Amaranthus* sp.*, Cyprus* sp.*,* and *Cynodon dactylon* (L.) Pers etc. Crop types and soil properties have greatest influence on the occurrence of weed species (Streibig *et al*. 1984 and Andreasen *et al.* 1991). Some pre-emergence (PRE) and post emergence (POE) herbicides efficacy have been evaluated against weed flora in cluster bean. Imazethapyr applied as PPI, PRE and POE controls monocot and dicot weeds and had a strong residual life (Taylor *et al*. 1988, Punia *et al*. 2011). POE application of imazethapyr at 75 and 100 g/ha reduced the density and dry biomass of broad as well as narrow leaved weeds

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significantly as compared to PPI, PRE and other POE herbicides in soybean (Singh and Kumar 2008, Chandel and Saxena 2001, Kushwah and Vyas 2005). Imazethapyr applied in cluster bean has been observed to show adverse effect on the succeeding crop of mustard in the light soils of South West Haryana where cluster bean is a major crop. Many farmers are resorting to lower use rates of imazethapyr for fear of phytotoxicity in sequential mustard crop. Lower use rates of imazethapyr may kill some weeds of cluster bean notably *D. arvensis*, but in the long run there could be issues of lower use rates stimulating herbicide resistance. Herbicides applied pre-emergence (PRE) or early post-emergence (POE) may not always provide season long weed control necessitating a partner for sequential use for effective control. Grassy weeds notably *Echinochloa colona*, emerges after rainfall and escape mortality from herbicides applied earlier, thus severely affect crop growth. Not only weeds infestation, soil types also have significant influence on herbicides efficacy and their persistence. Therefore, a better and more suitable weed control method is needed for season long effective control of weeds in cluster bean with no adverse effect on succeeding sensitive crops. Keeping these points in view, it was considered to carry out field experiments on the efficacy of imazethapyr applied alone and tank mixed with pendimethalin or imazamox in cluster bean and their residual effect on mustard in two texturally different soils.

MATERIALS AND METHODS

Field experiment in two texturally different soils was conducted to assess the weed control efficacy and residual effect of herbicides applied in cluster bean on succeeding mustard crop at Weed Control Research Area of Department of Agronomy, CCS HAU, Hisar and farmer's field in village Kheri Batter, district Bhiwani (Haryana) during the *kharif* and *rabi* seasons of 2013-14. The Crop received 500.5 and 594.3 mm of rainfall in the crop growing season at both the locations (Kheri Batter and Hisar), respectively. The soils of experimental fields were loamy sand at Kheri Batter (78.27% sand, 18.98% silt and 2.75% clay) and sandy loam at Hisar (63.25% sand, 25.30% silt and 11.45% clay). These soils were low in organic carbon (0.24 and 0.3%), medium in P (12 and 14.4 kg/ha), deficient in N (103.7 and 112 kg/ha) and sufficient in K (240 and 427 kg/ha) at Kheri Batter and Hisar, respectively. Cluster bean variety HG-563 seed was treated with streptocyclin 1.2 g/kg seed and drilled on 22 June and 11 July, respectively at a spacing of 30 × 15 cm R-R and P-P at Hisar and Kheri Battar in a plot size of 5 m × 4.5 m by using 20 kg/ha seed rate. Recommended dose of fertilizers (40 kg P and 20 kg N/ha through SSP and Urea) was applied at sowing and need based irrigation was given to the crop through flooding and sprinkler methods at Hisar and Kheri Battar, respectively. The experiment was laid out in a Randomized Block Design with three replications using 16 treatment combinations (Table 1). POE herbicide, imazethapyr + imazamox (Odyssey) at 43.75, 52.5, 61.5 and 70 g/ha 3 WAS (weeks after sowing) alone and followed by (*fb*) propaquizafop 62.5 g/ha (6 WAS) was compared with imazethapyr (50, 75 and 100 g/ha *fb* propaquizafop 62.5 g/ha applied at 3 fb 6 WAS), PRE pendimethalin + imazethapyr (Valor 1.0 kg/ha, ready mix and 500+50 g/ha, tank mix) and pendimethalin (1.0 kg/ha, PRE) along with weedy and weed free check. Crop was raised as per University package of practices. Fungicide (Blitox) was sprayed twice at 50 and 60 DAS to protect the crop from bacterial blight. Observations on weed density by randomly placing a quadrant (0.25 m^2) in each plot were recorded at 30 and 60 DAS. Dry weight of weeds was recorded after drying the weeds in the sun and later in an oven at 70°C upto 72 hr. Visual crop injury to cluster bean due to different herbicides and rates was quantified visually at 14 and 21 and 28 DAT (days after treatment) on 0-100 scale, where 0 = no effect and 100 = complete mortality. The crop was harvested on 1 and 20 October at Hisar and, Kheri Batter, respectively. After cluster bean harvest, mustard crop (Cv RH-749) was sown to study the carryover effect of different herbicides applied in cluster bean field at both the locations, without disturbing the soil and layout under zero tillage conditions. Emerged weeds at sowing were killed by non-selective and non-residual herbicide prior to planting mustard. Data on number of plants per meter row length, plant height, crop injury, number of leaves and yield were recorded to measure the residual effect of herbicides applied in cluster bean on mustard crop. The data with zero value were subjected to square root transformation and percent data were subjected to arcsine transformation to normalize their distribution. All experimental data were analysed using SPSS version 7.5. The data were subjected to analysis of variance and significant differences among treatments were tested by calculating CD at 5% level of significance differences evaluated by using one-way ANOVA.

RESULTS AND DISCUSSION

Location 1- Kheri Batter

Weed flora

The predominant weed flora of the cluster bean at Kheri Battar location was *Digera arvensis* Forsk., *Dactyloctenium aegyptium* Beauv., *Mollugo cerviana* (L.) Ser., *Trianthema portulacastrum* L., *Cyperus rotundus, Bulbostylis barbata* (Rottb.) Clarke. Other weeds included *Eragrostis ciliaris* (L.) R. Br, *Cleome viscosa* L., *Physallis minima* L., *Cenchrus echinatus* L., *Corchorus* sp., *Acrachne racemosa* (Heyne) Ohwi., *Digitaria sanguinalis* (L.) Scop., *Phyllanthus niruri* L., *Portulaca oleraceae* L., *Tribulus terrestris* L., *Gisekia pharnaciodes* L., *Parthenium hysterophorus* L., *Ipomoea* sp., *Cucumis* sp., *Brachiaria* sp., *Amaranthus* sp. were less and not uniformly distributed in all the plots.

Herbicide efficacy on weeds in cluster bean

Pendimethalin 1.0 kg was not effective against *D. arvensis* which was the dominant weed at Kheri Battar, whereas all other herbicide treatments provided complete

Table 1 Effect of different herbicides on weeds at Kheri Batter location

Treatment	Rate (g/ha)	Time of application	Weed density (No./m^2) at 60 DAS				Weed dry weight (g/m^2)		Visual weed control (%)	
			D. arvensis	*D. aegyptium*	*T. portulacastrum*	*Mollugo sp.*	30 DAS	60 DAS	30 DAS	60 DAS
Pendimethalin	1000	PRE	4.7 (21.0)	7.5 (55.7)	1.0 (0)	4.6 (20.0)	6.3 (40.1)	12.6 (159.1)	66 (83)	54 (65)
Imazethapyr+imazamox (RM)	43.75	3 WAS	1 (0)	7.3 (52.0)	3.0 (8.0)	4.7 (21.0)	9.3 (86.1)	13.2 (175.2)	30 (25)	53 (63)
Imazethapyr+imazamox (RM)	52.5	3 WAS	1 (0)	7.0 (48.0)	2.3 (4.3)	4.6 (20.3)	8.5 (72.1)	13.2 (172.4)	32 (30)	54 (65)
Imazethapyr+imazamox (RM)	61.5	3 WAS	1 (0)	6.1 (36.7)	2.1 (3.7)	2.2 (4.0)	8.3 (68.5)	10.2 (104.4)	35 (33)	60 (75)
Imazethapyr+imazamox (RM)	70	3 WAS	1 (0)	5.2 (26.3)	1.0 (0)	2.7 (6.7)	7.4 (54.7)	8.5 (72.1)	37 (37)	63 (80)
Imazethapyr+imazamox (RM) *fb* propaquizafop	43.75 *fb* 62.5	3 WAS *fb* 6 WAS	1 (0)	2.7 (6.7)	2.4 (5.3)	4.6 (20.7)	9.4 (88.4)	10.5 (110.0)	32(30)	58 (72)
Imazethapyr+imazamox (RM) *fb* propaquizafop	52.5 *fb* 62.5	3 WAS *fb* 6 WAS	1 (0)	2.9 (8.0)	2.2 (4.3)	3.9 (14.3)	8.8 (75.9)	8.4 (70.5)	34 (32)	62 (79)
Imazethapyr+imazamox (RM) *fb* propaquizafop	61.5 *fb* 62.5	3 WAS *fb* 6 WAS	1 (0)	2.4 (5.0)	2.1 (3.7)	2.6 (6.0)	7.9 (62.3)	8.1 (65.7)	35 (33)	65 (82)
Imazethapyr+imazamox (RM) *fb* propaquizafop	70 *fb* 62.5	3 WAS *fb* 6 WAS	1 (0)	1.0 (0)	1.0 (0)	2.3 (4.3)	7.3 (53.3)	6.9 (47.3)	38 (38)	66 (83)
Imazethapyr *fb* propaquizafop	50 *fb* 62.5	3 WAS *fb* 6 WAS	1 (0)	2.2 (4.0)	1.0 (0)	3.4 (10.3)	8.3 (67.5)	8.7 (75.1)	42 (45)	67 (85)
Imazethapyr *fb* propaquizafop	75 *fb* 62.5	3 WAS *fb* 6 WAS	1 (0)	1.0 (0)	1.5 (1.3)	2.2 (4.0)	7.9 (61.5)	8.1 (64.9)	45 (50)	66 (83)
Imazethapyr *fb* propaquizafop	100 *fb* 62.5	3 WAS *fb* 6 WAS	1 (0)	1.0 (0)	1.0 (0)	1.9 (2.7)	6.2 (39.2)	6.1 (36.5)	50 (58)	70 (88)
Pendimethalin+imazethapyr (TM)	500 *fb* 50	PRE	1 (0)	2.5 (5.7)	1.0 (0)	2.6 (6.3)	3.8 (13.5)	7.9 (61.6)	72 (90)	66 (83)
Pendimethalin+imazethapyr (RM)	1000	PRE	1 (0)	2.8 (7.3)	1.0 (0)	2.9 (8.0)	4.0 (15.3)	8.2 (66.6)	75 (93)	69 (87)
Weed free			1 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1 (0)	1 (0)	90 (100)	90 (100)
Weedy check			6.1 (36.3)	17.1 (49.7)	4.3 (18.0)	6.3 (38.3)	12.7 (161.1)	27.7 (768.6)	0 (0)	0 (0)
CD (P=0.05)			0.4	0.9	0.6	0.6	1.5	1.5	4.4	5.8

Original data were subjected to square root $\sqrt{(x+1)}$ transformation and presented in parentheses. RM- Ready mix, TM- Tank mix, fb — followed by, WAS- weeks after sowing, PRE — pre-emergence

control at 60 DAS (Table 1). Efficacy of pendimethalin was reduced significantly at 60 DAS against *Dactyloctenium aegyptium* due to emergence of new flush as it recorded similar population to untreated check. Imazethapyr 75 and 100 g/ha or imazethapyr + imazamox 70 g/ha 3 WAS followed by propaquizafop 62.5 g/ha 6 WAS resulted in complete control of *Dactyloctenium aegyptium* (Table 1). Imazethapyr + imazamox (Odyssey) applied alone was not much effective against *Dactyloctenium aegyptium* particularly at lower rates, whereas all other herbicide treatments reduced its density by 84-92% over control. Pendimethalin applied alone or with imazethapyr (RM and TM), imazethapyr alone at 75 and 100 g/ha and ready mix with imazamox at 70 g/ha *fb* propaquizafop provided effective control of *Trianthema portulacastrum*, whereas imazethapyr + imazamox alone or in sequence with propaquizafop at lower rates had poor efficacy against *Trianthema portulacastrum* (Table 1). *Mollugo* species were less sensitive to the applied herbicides, though higher rates of herbicides reduced the density significantly over weedy check.

Weeds dry weight was reduced by 91-92% by pendimethalin + imazethapyr (RM) 1.0 kg/ha and 500+50g/ha (TM) over control, respectively that was significantly more than pendimethalin alone at 1.0 kg/ha or imazethapyr 100 g/ha (75%) at 30 DAS; effect of other herbicide treatments was less as they were sprayed 3 WAS. At 60 DAS, 95 and 94% lower weed dry weight was recorded over control with imazethapyr 100 g/ha *fb* propaquizafop and imazethapyr + imazamox 70 g/ha *fb* propaquizafop, respectively. Pendimethalin + imazethapyr 500+50 g/ha, imazethapyr 75 g alone or its tank mix with imazamox at 61.5 g/ha *fb* propaquizafop and pendimethalin + imazethapyr (RM) 1 000 g/ha were the next best treatments in reducing weeds dry weight, though statistically similar among themselves (Table 1).

Highest visual per cent mortality of 93 and 90% was observed with PRE application of pendimethalin + imazethapyr (RM and TM) followed by pendimethalin alone (83%) at 30 DAS, but the same was reduced to 87, 83 and 65%, respectively at 60 DAS (Table 1). Imazethapyr at 50, 75 and 100 g/ha and its ready mixture with imazamox at 61.5 and 70 g/ha followed by propaquizafop 62.5 g/ha provided 88-82% control of weeds at 60 DAS and were more effective than other treatments.

Yield attributes and yield

Maximum pods/plant were recorded with weed free treatment that being 2.82 times of weedy check, was significantly higher than all treatments except imazethapyr 75 and 100 g/ha *fb* propaquizafop, tank mix of pendimethalin + imazethaypr 500+50 g/ha and imazethapyr + imazamox 70 g/ha *fb* propaquizafop (Table 3). Number of seeds/pod was highest in tank mix of pendimethalin + imazethapyr which was statistically similar to all treatments except weedy check. Maximum yield observed under weed free that was 56% higher than weedy plot (Table 3). Among the herbicidal treatments, maximum seed yield was obtained with pendimethalin 0.5 kg + imazethapyr 50 g/ha (TM) PRE that was statistically similar to imazethapyr + imazamox 70 g/ha at 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS, weed free treatment, imazethapyr 100 g/ha 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS and pendimethalin + imazethapyr (RM) 1.0 kg/ha PRE. Harvest index had no significant effect of treatments; however, highest B-C ratio was observed under pendimethalin 0.5 kg + imazethapyr 50 g/ha (TM).

Location 2- Hisar

Weed flora

Major weeds infesting Hisar field were *Trianthema portulacastrum, Cyperus rotundus, Convolvulus arvensis* and *Echinochloa colona*. Other weeds, viz. *Cyperus difformis, Digera arvensis, Celosia argentea, Physalis minima, Cynodon dactylon* and *Phyllanthus niruri* were not uniformly present in all the plots.

Herbicide efficacy on weeds in cluster bean

Application of pendimethalin + imazethapyr 1000 g/ha (RM) and 0.5 kg + 50 g/ha (TM) PRE provided complete control of *Trianthema portulacastrum* (Table 2). Other treatments that were effective against this weed were imazethapyr 100 g/ha 3 WAS and pendimethalin 1.0 kg/ha PRE. Ready mix of imazethapyr + imazamox though reduced the *Trianthema portulacastrum* density with increasing rates, but was less effective. Similarly lower rates of imazethapyr failed to completely control *Trianthema portulacastrum*. Complete control of *Echinochloa colona* was recorded at 60 DAS with pendimethalin alone or mixed with imazethapyr (RM and TM), imazethapyr alone and its ready mixture with imazamox *fb* propaquizafop, except its lower rate of 43.75 g/ha. Alone application of imazethapyr + imazamox, though significantly reduced the density of *Echinochloa colona*, but was less effective compared to sequential application of propaquizafop 62.5 g/ha at 6 WAS (Table 2). None of the herbicidal treatments was efficient against *Convolvulus arvensis*, though lower population was recorded with imazethapyr + imazamox 70 g/ha alone and *fb* propaquizafop 62.5 g/ha 6 WAS. Lowest density of *Cyperus rotundus* was recorded with pendimethalin + imazethapyr (RM and TM) and imazethapyr *fb* propaquizafop, but similar density was recorded with imazethapyr at 50, 75 and 100 g/ha, other treatments were less effective except weed free (Table 2).

Pendimethalin + imazethapyr (RM and TM) reduced weed dry weight by 95% over check 30 DAS and were significantly better than all other treatments except weed free (Table 2). However, at 60 DAS the above treatments could not maintain their superiority and lowest weed dry weight was recorded with imazethapyr 75 and 100 g/ha *fb* propaquizafop and imazethapyr + imazamox 70 g *fb* propaquizafop, though statistically similar.

Visual mortality of weeds at 30 DAS was 93-100% in pendimethalin alone and tank or ready mix with imazethapyr followed by imazethapyr alone (70%) at 100 g/ha *fb*

propaquizafop. At 60 DAS; however, pendimethalin alone was less effective (45%) compared to its mixture with imazethapyr (RM and TM) and imazethapyr 100 g/ha *fb* propaquizafop which provided 80 to 87% weed mortality (Table 2).

Yield attributes and yield

There was no crop phytotoxicity with pendimethalin; however, its mixture with imazethapyr (RM and TM) and alone application of imazethapyr exhibited 8% phytotoxicity in cluster bean; the effect was 2-7% with imazethapyr + imazamox treatments 7 DAS, but no injury was visible after two weeks (Table 4). Minimum pods/plant was recorded in weedy check treatment which was 274% less than weed free treatment (Table 4). Among the herbicidal treatments, highest pods/plant were recorded with imazethapyr + imazamox 70 g/ha 3 WAS *fb* propaquizafop 62.5 g at 6 WAS, followed by imazethapyr 100 g/ha *fb* propaquizafop, pendimethalin + imazethapyr 500+50 g/ha and imazethapyr + imazamox 70 g/ha, but statistically similar to weed free and among themselves. Highest seeds/pot were recorded with PRE application of pendimethalin + imazethapyr 500 + 50 g (TM) followed by weed free and minimum in weedy check. Maximum seed yield was recorded with pendimethalin + imazethapyr (RM and TM) which was 65% higher over weedy check. Other treatments with 67 to 37% higher yield over weedy check were weed free, imazethapyr *fb* propaquizafop, imazethapyr + imazamox alone at 70 g/ha and 61.5 and 70 g/ha with sequential application of propaquizafop, in that order (Table 4). Harvest index was non-significant among different treatments, but B-C ratio was highest with pendimethalin + imazethapyr (TM and RM) followed by imazethapyr *fb* propaquizafop application.

Pendimethalin was not effective against *Digera arvensis, Amaranthus* sp., *Commelina* sp., *Parthenium hysterophorus*, *Tribulus terrestris*, *Cucumis* sp., *Cleome viscosa*, *Celosia argentea*, *Phyllanthus niruri, Convolvulus arvensis*, *Cyperus rotundus*, *Mollugo* sp., *Ipomoea* sp., *Bulbostylis barbata*, *Gisekia pharnaceoides*, *Corchorus* sp. and was poor against grasses (*Acrachne racemosa*, *Digitaria sanguinalis*, *Cenchrus echinatus*, *Echinochloa colona*, *Eragrostis* sp. and *Dactyloctenium aegyptium*) at 60 DAS (Table 1 and 2 and observations on individual weeds, not included in Tables). Higher control in pendimethalin alone treatment at 30 DAS could be due to absence of these weed species. This resulted in decreased weed mortality, higher weed dry weight at 60 DAS and lower yield attributes and yield of cluster bean compared to application of imazethapyr as tank mix with imazamox and follow up spray of grass herbicide propaquizafop or its mixture with pendimethalin. Imazethapyr was more effective against *Digera arvensis* and *Amaranthus* sp., but higher rates were required for the control of *Trianthema portulacastrum*. *Cucumis* sp., *Ipomoea* sp., *Celosia argentea* and *Mollugo* sp., though not completely killed by imazethapyr but their growth was significantly checked giving competitive advantage to cluster bean crop. Sequential application of propaquizafop with imazethapyr or imazethapyr + imazamox took care of major grasses and resulted in better growth of cluster bean.

Similarly, lower amount of imazethapyr in Odyssey (imazethapyr + imazamox) alone at lower rates (43.75 to 61.5 g/ha) was less effective against tough weeds like *Trianthema portulacastrum* resulted in lower weed control and cluster bean yield. Sequential application of selective grass herbicides is required to improve the weed control efficacy of PRE or early POE herbicides. Chandel and Saxena (2001) reported effective control of weeds in soybean with post-emergence imazethapyr at 100 g/ha. Similarly, Singh *et al.* (2002), Singh and Kumar (2008), Sumachandrica *et al.* (2003) and Meena *et al*. (2011) reported that POE application of imazethapyr at 75 and 100 g/ha effectively reduced the density and dry weight of broad as well as narrow leaved weeds significantly and recorded higher net return and B:C. Weed dry matter accumulation was reduced in the same order as dose of imazethapyr or imazethapyr + imazamox increased (Table 1 and 2). Similar trend of decreased weed dry weight with increased dose of pendimethalin was reported by Tiwana *et al.* (2002).

No crop phytotoxicity was observed under pendimethalin 1.0 kg/ha PRE (Table 3). At the initial stages, higher rate of imazethapyr + imazamox and imazethapyr alone and *fb* propaquizafop 62.5 g/ha applied POE, pendimethalin 0.5 kg + imazethapyr 50 g/ha (TM) PRE and pendimethalin + imazethapyr (RM) 1.0 kg/ha PRE resulted in chlorosis of leaves, suppression of growth and the plant height which mitigated after 2 weeks and no injury was observed at later stages (Table 3). This corroborates with the findings of Olson *et al.* (2007) who reported that imazethapyr applied at 28 DAT showed no visual injury. Punia *et al*. (2011) also found that POE application of imazethapyr 80 and 100 g/ha caused mild injury to crop up to 7 DAT, but it diminished within 3 weeks without any adverse effect on yield.

Residual effect of herbicides applied in cluster bean on succeeding mustard crop

Location 1-Kheri Batter: No significant effect of the used herbicides at various rates in cluster bean on succeeding mustard crop was observed though some visual crop injury symptoms (<10%) on mustard plants were recorded under imazethapyr + imazamox 61.5 and 70 g/ha at 3 WAS alone and *fb* propaquizafop 62.5 g/ha at 6 WAS, imazethapyr 50, 75 and 100 g/ha 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS, pendimethalin 0.5 kg + imazethapyr 50 g/ha (TM) PRE and pendimethalin + imazethapyr (RM) 1.0 kg/ha PRE, but the effect was transient and not visible at 4 WAS or later stages (Table 5). This may be due to microbial degradation of imazethapyr mediated by higher temperature (36.5°C) observed during the *kharif* season 2013-14) or leaching of these herbicides because of heavy rainfall (500-580 mm) occurred between time of herbicide application and planting of mustard in 2013-14. Growth yield attributes and yield of mustard was not affected by

Table 2 Effect of different herbicides on weeds at Hisar

Treatment	Rate (g/ha)	Time of application	Weed density (No./m²) at 60 DAS				Weed dry weight (g/m²)		Visual weed control (%)	
			T. portulacastrum	*E. colona*	*C. arvensis*	*Cyperus sp.*	30 DAS	60 DAS	30 DAS	60 DAS
Pendimethalin	1000	PRE	2.8 (7.0)	1 (0)	3.5 (12.0)	6.8 (52.0)	6.7 (44.5)	11.6 (133.7)	81 (93)	42 (45)
Imazethapyr+imazamox (RM)	43.75	3 WAS	5.1 (25.3)	4.2 (17.3)	2.9 (8.0)	6.2 (40.0)	9.9 (98.5)	10.8 (115.7)	11 (10)	40 (42)
Imazethapyr+imazamox (RM)	52.5	3 WAS	5.0 (25.0)	3.1 (9.30	2.7 (6.7)	6.2 (40.0)	9.6 (92.0)	10.2 (102.3)	20 (17)	42 (45)
Imazethapyr+imazamox (RM)	61.5	3 WAS	4.6 (20.0)	2.1 (4.0)	2.9 (8.0)	7.2 (53.3)	9.0 (81.7)	9.8 (95.6)	20 (17)	44 (48)
Imazethapyr+imazamox (RM)	70	3 WAS	3.8 (13.3)	1.8 (2.7)	2.2 (4.0)	6.2 (41.3)	7.3 (52.1)	8.6 (72.7)	31 (27)	47 (53)
Imazethapyr+imazamox (RM) *fb* propaquizafop	43.75 *fb* 62.5	3 WAS *fb* 6 WAS	5.0 (24.0)	1.4 (1.3)	2.9 (8.0)	6.2 (40.0)	10.0 (99.9)	9.0 (79.6)	11 (10)	48 (55)
Imazethapyr+imazamox (RM) *fb* propaquizafop	52.5 *fb* 62.5	3 WAS *fb* 6 WAS	4.8 (22.3)	1 (0)	2.5 (5.3)	6.2 (40.0)	9.8 (95.0)	8.4 (69.2)	11 (10)	53 (63)
Imazethapyr+imazamox (RM) *fb* propaquizafop	61.5 *fb* 62.5	3 WAS *fb* 6 WAS	4.4 (18.7)	1 (0)	2.5 (5.3)	7.2 (53.3)	9.4 (87.7)	7.4 (53.6)	20 (17)	54 (65)
Imazethapyr+imazamox (RM) *fb* propaquizafop	70 *fb* 62.5	3 WAS *fb* 6 WAS	4.1 (16.0)	1 (0)	1.8 (2.7)	6.2 (41.3)	8.0 (62.6)	6.7 (43.3)	31 (27)	58 (72)
Imazethapyr *fb* propaquizafop	50 *fb* 62.5	3 WAS *fb* 6 WAS	4.5 (20.0)	1 (0)	3.2 (9.3)	4.1 (16.0)	9.8 (94.4)	7.8 (60.2)	47 (53)	57 (70)
Imazethapyr *fb* propaquizafop	75 *fb* 62.5	3 WAS *fb* 6 WAS	3.6 (12.0)	1 (0)	2.7 (6.7)	4.1 (16.0)	8.0 (63.0)	7.0 (45.5)	53 (63)	61 (77)
Imazethapyr *fb* propaquizafop	100 *fb* 62.5	3 WAS *fb* 6 WAS	2.5 (5.3)	1 (0)	3.2 (9.3)	4.1 (16.0)	7.5 (55.2)	6.3 (39.9)	57 (70)	69 (87)
Pendimethalin+imazethapyr (TM)	500 *fb* 50	PRE	1 (0)	1 (0)	2.9 (8.0)	4.1 (16.0)	3.9 (14.5)	7.3 (51.8)	86 (98)	64 (80)
Pendimethalin+imazethapyr (RM)	1000	PRE	1 (0)	1 (0)	2.7 (6.7)	4.1 (16.0)	4.2 (16.4)	7.3 (52.1)	90 (100)	69 (87)
Weed free			1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	90 (100)	90 (100)
Weedy check			7.1 (49.3)	7.0 (48.0)	3.4 (10.7)	6.3 (44.0)	17.6 (308.8)	21.9 (477.8)	0 (0)	0 (0)
CD (P=0.05)			0.8	0.7	1.0	2.7	1.1	1.0	19.9	5.7

Original data were subjected to square root transformation and presented in parentheses. RM- Ready mix, TM- Tank mix, fb — followed by, WAS- weeks after sowing, PRE — pre-emergence

Table 3 Effect of different herbicides on cluster bean at Kheri Batter

Treatment	Rate (g/ha)	Time of application	Crop phytotoxicity		Pods/plant	Seeds/pod	Seed yield (q/ha)	HI (%)	B C ratio
			1 WAT	2 WAT					
Pendimethalin	1000	PRE	0 (0)	0	85.1	8.0	11.2	22.3	2.4
Imazethapyr+imazamox (RM)	43.75	3 WAS	4.3 (1.7)	0	93.1	7.3	11.0	21.9	2.4
Imazethapyr+imazamox (RM)	52.5	3 WAS	12.9 (5.0)	0	100.7	7.7	11.9	22.6	2.5
Imazethapyr+imazamox (RM)	61.5	3 WAS	14.8 (6.7)	0	108.1	7.7	12.1	21.1	2.6
Imazethapyr+imazamox (RM)	70	3 WAS	16.6 (8.3)	0	123.7	7.7	13.2	21.9	2.8
Imazethapyr+imazamox (RM) *fb* propaquizafop	43.75 *fb* 62.5	3 WAS *fb* 6 WAS	8.6 (3.3)	0	99.9	8.3	11.9	22.0	2.5
Imazethapyr+imazamox (RM) *fb* propaquizafop	52.5 *fb* 62.5	3 WAS *fb* 6 WAS	12.9 (5.0)	0	107.9	8.0	12.4	22.3	2.5
Imazethapyr+imazamox (RM) *fb* propaquizafop	61.5 *fb* 62.5	3 WAS *fb* 6 WAS	14.8 (6.7)	0	120.7	8.0	13.1	22.0	2.7
Imazethapyr+imazamox (RM) *fb* propaquizafop	70 *fb* 62.5	3 WAS *fb* 6 WAS	16.6 (8.3)	0	125.0	8.3	13.8	22.4	2.8
Imazethapyr *fb* propaquizafop	50 *fb* 62.5	3 WAS *fb* 6 WAS	16.6 (8.3)	0	117.2	8.3	12.2	21.1	2.6
Imazethapyr *fb* propaquizafop	75 *fb* 62.5	3 WAS *fb* 6 WAS	16.6 (8.3)	0	125.1	8.3	13.5	22.5	2.7
Imazethapyr *fb* propaquizafop	100 *fb* 62.5	3 WAS *fb* 6 WAS	18.4 (10.0)	0	127.8	8.0	15.8	23.6	3.1
Pendimethalin+imazethapyr (TM)	500 *fb* 50	PRE	16.6 (8.3)	0	127.2	9.0	15.8	23.2	3.2
Pendimethalin+imazethapyr (RM)	1000	PRE	16.6 (8.3)	0	121.8	8.5	14.4	23.2	3.0
Weed free			0 (0)	0	138.0	8.7	15.8	23.2	2.3
Weedy check			0 (0)	0	48.9	6.7	7.2	24.2	1.6
CD (P=0.05)			5.5	NS	13.8	1.4	1.9	NS	

Original data were subjected to arc sin transformation and presented in parentheses. RM- Ready mix, TM- Tank mix, fb — followed by, WAS- weeks after sowing, PRE — pre-emergence

Table 4 Effect of different herbicides on cluster bean at Hisar

Treatment	Rate (g/ha)	Time of application	Crop phytotoxicity		Pods/plant	Seeds/pod	Seed yield (q/ha)	HI (%)	B -C ratio
			1 WAT	2 WAT					
Pendimethalin	1000	PRE	0 (0)	0	87.3	8.3	12.4	23.4	2.5
Imazethapyr+imazamox (RM)	43.75	3 WAS	4.3 (1.7)	0	95.3	7.7	10.2	27.9	1.9
Imazethapyr+imazamox (RM)	52.5	3 WAS	8.6 (3.3)	0	102.9	8.0	11.3	28.7	2.1
Imazethapyr+imazamox (RM)	61.5	3 WAS	12.9 (5.0)	0	110.3	8.0	11.1	22.8	2.3
Imazethapyr+imazamox (RM)	70	3 WAS	14.8 (6.7)	0	125.9	8.0	12.7	24.7	2.5
Imazethapyr+imazamox (RM) *fb* propaquizafop	43.75 *fb* 62.5	3 WAS *fb* 6 WAS	4.3 (1.7)	0	99.9	8.7	11.1	26.3	2.1
Imazethapyr+imazamox (RM) *fb* propaquizafop	52.5 *fb* 62.5	3 WAS *fb* 6 WAS	8.6 (3.3)	0	111.2	8.3	12.0	32.1	2.1
Imazethapyr+imazamox (RM) *fb* propaquizafop	61.5 *fb* 62.5	3 WAS *fb* 6 WAS	12.9 (5.0)	0	122.9	8.0	12.9	25.3	2.4
Imazethapyr+imazamox (RM) *fb* propaquizafop	70 *fb* 62.5	3 WAS *fb* 6 WAS	14.8 (6.7)	0	139.2	8.7	13.8	25.5	2.6
Imazethapyr *fb* propaquizafop	50 *fb* 62.5	3 WAS *fb* 6 WAS	16.6 (8.3)	0	119.4	8.7	12.9	24.6	2.5
Imazethapyr *fb* propaquizafop	75 *fb* 62.5	3 WAS *fb* 6 WAS	16.6 (8.3)	0	127.3	8.7	14.2	25.8	2.7
Imazethapyr *fb* propaquizafop	100 *fb* 62.5	3 WAS *fb* 6 WAS	16.6 (8.3)	0	130.0	8.3	14.7	26.2	2.7
Pendimethalin+imazethapyr (TM)	500 *fb* 50	PRE	16.6 (8.3)	0	129.4	9.3	15.3	26.5	2.9
Pendimethalin+imazethapyr (RM)	1000	PRE	16.6 (8.3)	0	124.0	8.8	15.3	27.4	2.9
Weed free		0 (0)	0	140.2	9.0	15.1	25.3	2.1	
Weedy check			0 (0)	0	51.1	7.0	9.3	27.2	1.9
CD (P=0.05)			6.9	NS	14.0	1.7	2.8	NS	

Original data were subjected to arc sin transformation and presented in parentheses. RM- Ready mix, TM- Tank mix, fb — followed by, WAS- weeks after sowing, PRE — pre-emergence

Table 5 Residual effect of different herbicides applied in cluster bean on succeeding mustard crop at Kheri Batter

Treatment	Rate (g/ha)	Time of application	Crop phytotoxicity (%)		Plant height (cm)		No. of leaves/plant		Branches/ plant	Seed yield (q/ha)
			2 WAS	4 WAS	30 DAS	60 DAS	30 DAS	60 DAS		
Pendimethalin	1000	PRE	0 (0)	0	19.1	122.3	7.7	31.0	9.2	18.9
Imazethapyr+imazamox (RM)	43.75	3 WAS	0 (0)	0	20.0	121.7	8.0	31.4	9.9	19.4
Imazethapyr+imazamox (RM)	52.5	3 WAS	0 (0)	0	19.4	120.8	7.8	34.2	8.6	18.5
Imazethapyr+imazamox (RM)	61.5	3 WAS	6.1 (3.3)	0	19.5	121.6	7.3	31.3	8.9	18.5
Imazethapyr+imazamox (RM)	70	3 WAS	7.6 (5.0)	0	20.1	122.2	7.9	32.9	7.7	18.8
Imazethapyr+imazamox (RM) *fb* propaquizafop	43.75 *fb* 62.5	3 WAS *fb* 6 WAS	0 (0)	0	19.2	121.6	7.9	31.6	8.7	18.8
Imazethapyr+imazamox (RM) *fb* propaquizafop	52.5 *fb* 62.5	3 WAS *fb* 6 WAS	0 (0)	0	21.5	122.9	8.1	35.4	9.8	19.8
Imazethapyr+imazamox (RM) *fb* propaquizafop	61.5 *fb* 62.5	3 WAS *fb* 6 WAS	6.1 (3.3)	0	21.7	124.3	8.1	35.0	9.4	19.6
Imazethapyr+imazamox (RM) *fb* propaquizafop	70 *fb* 62.5	3 WAS *fb* 6 WAS	6.1 (3.3)	0	21.1	122.9	7.9	33.2	9.0	19.4
Imazethapyr *fb* propaquizafop	50 *fb* 62.5	3 WAS *fb* 6 WAS	6.1 (3.3)	0	21.7	121.7	8.2	35.4	9.1	19.5
Imazethapyr *fb* propaquizafop	75 *fb* 62.5	3 WAS *fb* 6 WAS	7.6 (5.0)	0	20.6	124.7	8.1	33.8	8.6	19.1
Imazethapyr *fb* propaquizafop	100 *fb* 62.5	3 WAS *fb* 6 WAS	11.1 (10.0)	0	20.8	124.6	7.7	35.2	9.8	19.4
Pendimethalin+imazethapyr (TM)	500 *fb* 50	PRE	7.6 (5.0)	0	19.2	123.2	8.0	34.7	9.0	18.5
Pendimethalin+imazethapyr (RM)	1000	PRE	6.1 (3.3)	0	19.8	124.1	8.3	35.3	8.7	19.8
Weed free			0 (0)	0	21.2	122.0	7.9	34.9	9.6	20.5
Weedy check			0 (0)	0	19.7	121.6	7.1	33.8	8.9	21.1
CD (P=0.05)			NS	NS	NS	NS	NS	NS	NS	NS

Original data were subjected to arc sin transformation and presented in parentheses. RM- Ready mix, TM- Tank mix, fb — followed by, WAS- weeks after sowing, PRE — pre-emergence

Table 6 Residual effect of different herbicides applied in cluster bean on succeeding mustard crop at Hisar

Treatment	Rate (g/ha)	Time of application	Crop phytotoxicity (%) at 2 WAS	Plant height (cm)		No. of leaves/plant		Branches/ plant	Seed yield (q/ha)
				30 DAS	60 DAS	30 DAS	60 DAS		
Pendimethalin	1000	PRE	0	9.3	110.0	3.6	9.2	5.7	3.0
Imazethapyr+imazamox (RM)	43.75	3 WAS	0	9.3	111.5	3.7	9.7	5.5	2.4
Imazethapyr+imazamox (RM)	52.5	3 WAS	0	9.4	110.5	4.1	9.5	5.7	3.2
Imazethapyr+imazamox (RM)	61.5	3 WAS	0	9.5	109.4	3.7	10.2	5.8	2.9
Imazethapyr+imazamox (RM)	70	3 WAS	0	9.2	109.4	3.8	8.6	5.8	3.0
Imazethapyr+imazamox (RM) *fb* propaquizafop	43.75 *fb* 62.5	3 WAS *fb* 6 WAS	0	9.7	109.6	3.9	9.1	5.7	2.7
Imazethapyr+imazamox (RM) *fb* propaquizafop	52.5 *fb* 62.5	3 WAS *fb* 6 WAS	0	9.3	109.3	3.3	8.9	5.9	2.9
Imazethapyr+imazamox (RM) *fb* propaquizafop	61.5 *fb* 62.5	3 WAS *fb* 6 WAS	0	9.7	110.0	4.0	10.5	5.6	2.6
Imazethapyr+imazamox (RM) *fb* propaquizafop	70 *fb* 62.5	3 WAS *fb* 6 WAS	0	9.4	109.6	3.4	10.6	6.0	2.5
Imazethapyr *fb* propaquizafop	50 *fb* 62.5	3 WAS *fb* 6 WAS	0	9.3	110.1	3.4	10.4	6.1	3.2
Imazethapyr *fb* propaquizafop	75 *fb* 62.5	3 WAS *fb* 6 WAS	0	9.6	111.4	3.9	8.8	5.7	2.5
Imazethapyr *fb* propaquizafop	100 *fb* 62.5	3 WAS *fb* 6 WAS	0	9.6	109.8	3.9	9.1	5.7	3.0
Pendimethalin+imazethapyr (TM)	500 *fb* 50	PRE	0	9.6	109.9	4.2	8.6	5.5	2.7
Pendimethalin+imazethapyr (RM)	1000	PRE	0	9.3	110.2	3.6	9.9	5.6	3.0
Weed free			0	9.7	111.8	3.9	8.9	5.6	2.7
Weedy check			0	9.7	109.8	4.1	9.7	5.7	2.8
CD (P=0.05)			NS	NS	NS	NS	NS	NS	NS

Original data were subjected to arc sin transformation and presented in parentheses. RM- Ready mix, TM- Tank mix, fb — followed by, WAS- weeks after sowing, PRE — pre-emergence

herbicides applied in cluster bean

Location 2-Hisar: There was no crop suppression or injury on mustard crop under Hisar conditions (Table 6). Plant height, number of leaves, branches/plant and yield of mustard was not affected by any herbicidal treatment of cluster bean. Due to heavy rains in October, the field was flooded which might have contributed to no residual effect of persistent herbicide and adverse effect on mustard. Also flooding resulted in delayed planting of mustard under Hisar conditions and the extra time for herbicide degradation. Delayed sowing also resulted in poor plant stand and less yield compared to sandy soil of Kheri Battar field which has six time higher yield of mustard.

Persistence of imazaquin and imazethapyr herbicides has been found to decrease with increased temperature as minimum persistence was recorded between 35 and 45^0C and degradation enhanced when soil moisture increased from 15% to 75% of field capacity (Singh *et al.* 2010 and Flint *et al.* 1997). Similarly, herbicide residues found below 7.5 cm were greater in the clay loam soil than in silt loam soil. As the rainfall amount increased from low to high (75 to 300 mm/month equivalent) imazethapyr bioactivity declined significantly in loamy sand and sandy loam soil (Ayeni *et al.* 1998). Thus no injury symptoms of imazethapyr alone or mixed with imazamox or pendimethalin were observed under Hisar conditions and less than 10% mustard injury only 2 WAS under Kheri Battar seems to be influenced by higher moisture level.

From the present study, it may be concluded that effective control of weeds and improved productivity can be attained with the application of pendimethalin 0.5 kg + imazethapyr 50 g/ha (TM) PRE, pendimethalin + imazethapyr (RM) 1.0 kg/ha PRE, imazethapyr 100 g/ha 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS and imazethapyr + imazamox 70 g/ha at 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS, but imazethapyr + imazamox (Odyssey) was less effective against existing weed flora under Hisar conditions due to predominance of *Trianthema portulacastrum* as compared to above three treatments. PRE pendimethalin + imazethapyr (RM and TM) had the distinct advantage over pre mix of imazethapyr + imazamox because of better weed control early in the season. Persistence was not recorded even at highest use rates which could be due to high moisture and temperature during the current season.

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