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Weed management using post-emergence herbicides in chickpea (*Cicer arietinum*) + mustard (*Brassica juncea*) intercropping system

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ABSTRACT

A field study was conducted at Indian Institute of Pulses Research, Kanpur during winter season of 2008-09 and 2009-10 to study the weed control efficiency of different weed management practices including post-emergence herbicides in chickpea (*Cicer arietinum* L.) + mustard (*Brassica juncea* L.) intercropping system. Treatment comprised two different doses of quizalofop-ethyl, imazethapyr and chlorimuron-p-ethyl along with pendimethalin and manual weeding. *Cyperus rotundus*, *Anagallis arvensis*, *Chenopodium album*, *Polygonum plebejum* and *Phalaris minor* were the dominant weeds. *Cyperus rotundus* was the most dominant weeds with highest relative density and relative dry weight. The toxic effect of imazethapyr and chlorimuron was recorded on both chickpea and mustard. Among herbicide treatments, significantly lowest weed density and weed dry weight and highest weed control efficiency, weed control index, nodule specific weight and plant dry matter were recorded in quizalofop-ethyl @ 60 g/ha. Similarly, higher chickpea and mustard yield, system productivity, net return and B/C ratio were recorded in quizalofop-ethyl @ 60 g/ha and manual weeding.

Key words: Chickpea, Economics, Intercropping, Mustard, Post-emergence herbicide, Weed

Intercropping is a system where two or more crop species are grown in the same field at the same time during a growing season (Kumar *et al*. 2008). It can provide numerous benefits to cropping systems through increasing total yield and land use efficiency; improving yield stability of cropping system; enhancing light, water, and nutrient use and controlling weeds, insects, or diseases (Lithourgidis *et al.* 2007, Dhima *et al*. 2007, Kumar *et al.* 2008). India's demand of pulses by 2030 is expected to be as high as 32 million tonnes (IIPR 2011). Among the potential pulse crops in the country, chickpea (*Cicer arietinum* L.) is a leading pulse crop which is grown in 8.3 million ha with annual production of 7.7 million tonnes registering an average productivity of 928 kg/ha. Similarly, the rapeseed and mustard (*Brassica juncea* L.) stands second in edible oil production in the country with an area of 5.9 million ha and production of 6.6 million tonnes with an average productivity of 1 121 kg/ha (Ministry of Agriculture 2013). Chickpea + mustard is an important intercropping system in Indian sub-continent (Kumar *et al.* 2005, Kumar *et al*. 2006, Abraham *et al.* 2011). However, weeds are a serious problem in chickpea + mustard intercropping and reduce system productivity up to 60 %.

Various weed management strategies, such as thorough land preparation, appropriate row spacing and ratio, crop rotations, manual, mechanical and chemical methods are used in this system. For season long weed management, pre-emergence herbicide pendimethalin + manual weeding at 30-35 days after sowing is commonly recommended in chickpea + mustard intercropping (Arya 2004), but its use is decreasing because of labour scarcity at critical time of weeding and increasing cost (Cheema *et al*. 2003). Thus, there is an urgent need to identify an effective post-emergence herbicide to control broad spectrum weeds in chickpea + mustard intercropping system as recommended in many field crops (Kumar 2010 and Kumar and Hazra 2012). Quizalofop ethyl ($C_{17}H_{13}C_1N_2O_4$), Chlorimuron ($C_{15}H_{15}C_1N_4O_6S$) and Imazethapyr ($C_{15}H_{19}N_3O_3$) are new generation post-emergence herbicides used in many leguminous crops. These herbicides provide broad spectrum of weeds control, flexibility in application time, low usage rates and low mammalian toxicity (Tan *et al*. 2005). Quizalofop-ethyl is a phenoxy compound used to control grassy weeds. Chlorimuron is urea derivative and Imazethapyr belongs to the chemical group of imidazolinone which control wide spectrum of weeds. However, till date no systematic study was conducted to see the efficacy of these post-emergence herbicides in chickpea + mustard

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intercropping. Therefore, the present study was conducted to assess the field efficacy of these post-emergence herbicides in management of weeds in chickpea + mustard intercropping.

MATERIALS AND METHODS

A field experiment was conducted during *rabi* season of 2008-09 and 2009-10 at Main Research Farm of Indian Institute of Pulses Research (IIPR), Kanpur, India (26° 27/ N, 80° 14/E and 152.4 m above MSL). The climate is tropical sub-humid, receives annual rainfall of 722 mm and mean annual maximum and minimum temperature is 33.0 and 20.0°C, respectively. The soils of experimental site come under taxonomical class *Typic Usrtochrept* with sandy loam texture having pH 7.8, bulk density 1.43 g/cm^3, low organic carbon content (3.1 g/kg), low in available N (209 kg/ha), and medium in available P (13.2 kg/ha) and K (221 kg/ha).

Treatment comprised of two different doses of quizalofop-ethyl (40 and 60 g/ha), imazethapyr (25 and 40 g/ha) and chlorimuron (3 and 4 g/ha) along with pendimethalin @ 1.25 kg/ha (PE), weedy check and weed free. The experiment was laid out in randomized block design (RBD) with 3 replications. Chickpea variety DCP 92-3 and mustard variety Varuna were used for the study.

Plant to plant distance was maintained ~10 cm in a row spacing of 30 cm for chickpea and 45 cm row spacing for mustard. DAP was applied 100 kg/ha at the time of seedbed preparation and additional top dressing of nitrogen was given to mustard crops as per recommendation. To ensure proper germination, field was prepared after '*palewa*' irrigation and subsequent irrigation was given as per requirement. Quizalofop-ethyl, chlorimuron and imazethapyr were applied at 25 days after sowing (DAS) whereas pendimethalin was applied as pre-emergence within 24 hours of sowing. Other practices were followed as per recommendation for this region.

An iron square of size 0.25 m^2 (side 0.5m) was used to take observations on weed numbers and weed dry weight through random sampling in each plot at 24 DAS (before POE herbicides application) and at 40 DAS (after POE herbicides application). The total number of weeds were counted species wise separately for each plot and analyzed after subjecting the original data to square root transformation ($\sqrt{[x + 0.5]}$). For dry matter, weeds collected from one square meter area were dried under the sun and then in an oven at 70°C for 72 hr, weighed (g/m^2). Five random plants were selected from each plot at 45 and 60 DAS to record observation on nodulation and plant growth parameters. Similarly, 5 random plant samples were collected from each plot at the time of harvest for recording observations on plant growth and yield attributing characters. Weed management indices such as weed control efficiency (WCE), weed control index (WCI), weed index (WI), relative density (RD) and relative dry Weight (RDW) were calculated as per standard procedure and formula (Kumar *et al.* 2013).

The economics of treatments was computed on the basis of prevailing market price of inputs and outputs in Indian rupees under each treatment. The total cost of cultivation of crop was calculated on the basis of different operations performed and materials used for raising the crop including the cost of fertilizers and seeds. The cost of labour incurred in performing different operations was also included.

Statistical analysis of the data was done as per the standard analysis of variance technique for the experimental designs following SPSS software based programme, and the treatment means were compared at $P<0.05$ level of probability using t-test and calculating LSD values. Analysis of variance was performed on all the collected data.

RESULTS AND DISCUSSION

Relative density and relative dry weight of weeds

The common weeds at the experimental sites were *Cyperus rotundus*, *Anagallis arvensis*, *Chenopodiumn album*, *Polygonum plebejum* and *Phalaris minor*. *Cyperus rotundus* was the most dominant weed with relative density of 69% and relative dry weight of 81% during initial crop growth stage (Singh and Singh 1998). However at the time of chickpea harvest highest relative density was recorded in *Cyperus rotundus* and relative dry weight of 39% in *Chenopodium album* (Fig 1). The highest relative dry weight at harvest in *Chenopodium album* was mainly due to higher per plant dry weight.

Weed density and dry weight

Cyperus rotundus was the dominant weed at the experimental site. Under uncontrolled conditions *Cyperus rotundus* population density was almost 5 times higher than next dominant weed *Chenopodium album* (Table 1). Highest weed density was observed under weedy check (544/m^2) which was followed by chlorimuron and imazethapyr treatments and the lowest was recorded in manual weeding (117/m^2) followed by quizalofop-ethyl @ 60 g/ha (288/m^2). At initial crop growth stage (25 DAS) lowest weed biomass was recorded in weed free treatment followed by pendimethalin application (Fig 2). However, maximum weed biomass at flowering (60 DAS) was recorded in chlorimuron (861 and 815 kg/ha at 3 and 4 g/ha dose, respectively) and lowest under weed free (60 kg/ha) and manual weeding (109 kg/ha). In case of post-emergence herbicides, significantly lowest weed biomass was recorded in quizalofop-ethyl @ 60 g/ha (257 kg/ha) and highest in chlorimuron (Table 1). At harvest also among post-emergence herbicides, lowest weed biomass was recorded in quizalofop-ethyl @ 60 g/ha and highest in case of chlorimuron (Fig 2). The toxic effect of chlorimuron was recorded in both chickpea as well as mustard and most of weeds were also killed. But with first irrigation at 40-45 DAS, the emergence and growth of weeds were very fast which resulted in higher weed biomass in chlorimuron. Imazethapyr had also shown toxicity to mustard and chickpea in which all mustard plants were killed, however chickpea had shown bushy growth with narrow leaves. However,

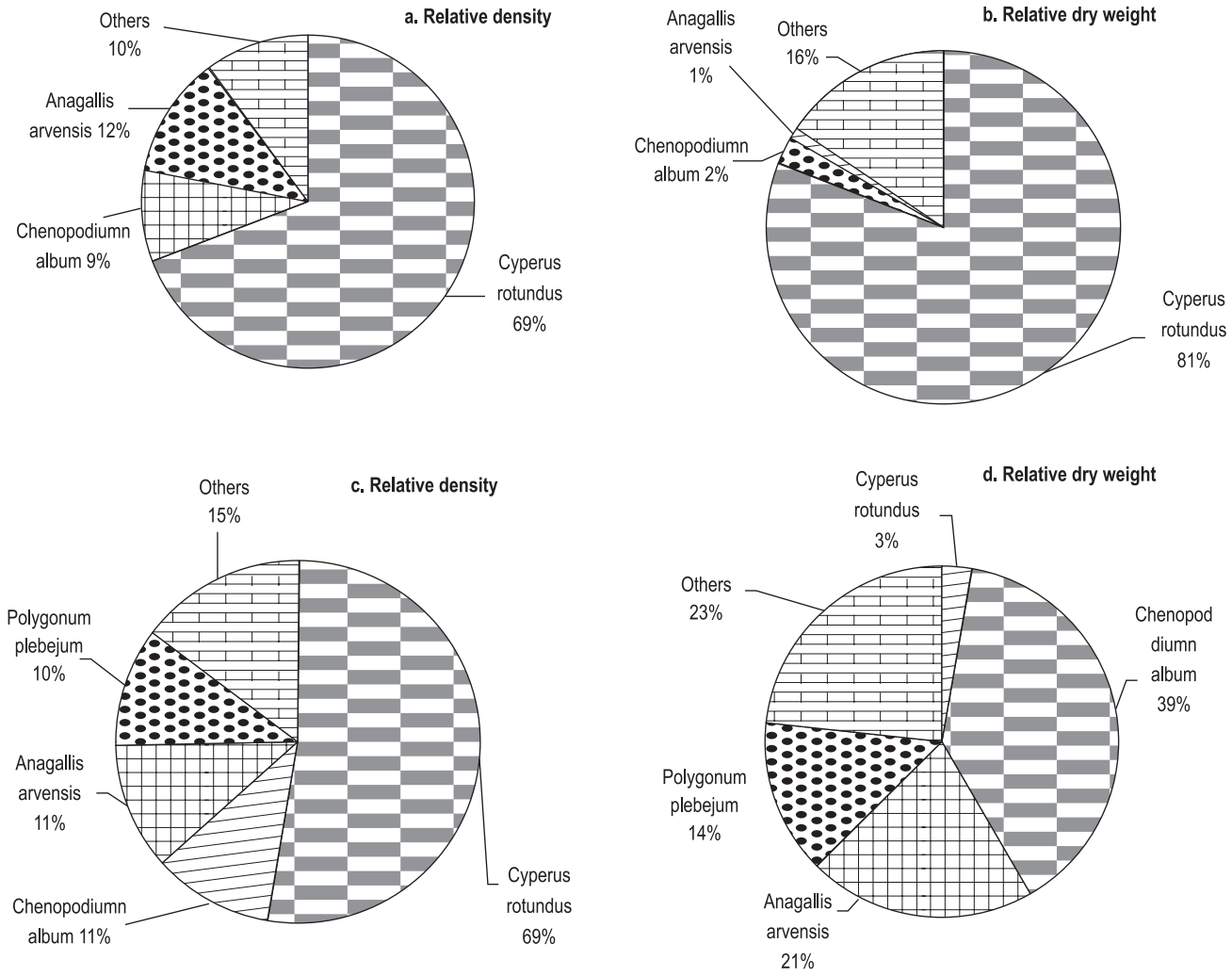

Fig 1 Pie diagram showing relative density and relative dry weight of different weed flora at 30 DAS (a and b) and at harvest (c and d) at experimental site

Table 1 Effect of post-emergence herbicides on weed density and total dry matter (DM) at 60 DAS

Treatment	Weed density (numbers/m^2)				Total weed numbers/m^2	Weed dry matter (kg/ha)
	Cyperus rotundus	*Chenopodium album*	*Anagallis arvensis*	*Polygonum plebejum*		
Quizalofop-ethyl @ 40 g/ha	112	103	31	55	18.1 (328)	465
Quizalofop-ethyl @ 60 g/ha	115	55	49	63	17.0 (288)	257
Imazethapyr @ 25 g/ha	109	77	11	119	20.0 (401)	434
Imazethapyr @ 40 g/ha	164	75	13	97	20.2 (408)	505
Chlorimuron @ 3 g/ha	96	56	31	128	21.0 (439)	861
Chlorimuron @ 4 g/ha	179	87	21	145	22.7 (517)	815
Pendimethalin @ 1.25 kg/ha	260	0	4	0	21.4 (457)	314
Manual weeding (30 DAS)	121	21	11	5	12.5 (157)	109
Weed free	64	12	0	19	10.8 (117)	60
Weedy check	287	59	61	57	23.3 (544)	533
LSD (P = 0.05)	32	9	8	12	2.2	74

quizalofop-ethyl was very effective against most of grassy weeds and non toxic to broad leaved weeds as well as chickpea and mustard.

Nodulation and plant dry matter

Highest nodule numbers/plant was recorded in weed free treatment (16.7 and 13.6/plant at 45 and 60 DAS, respectively) followed by manual weeding (11.3 and 10.4/

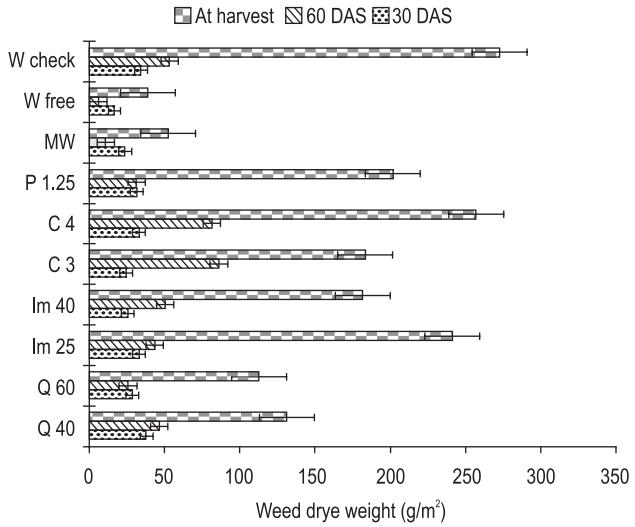

Fig 2 Weed dry matter at 25 and 60 DAS and harvest under different weed management practices in chickpea + mustard intercropping. (Note: Q 40: Quizalofop-ethyl @ 40 g/ha; Q 30: Quizalofop-ethyl @ 40 g/ha; Im 25: Imazethapyr @ 25 g/ha; Imazethapyr @ 40 g/ha; C 3: Chlorimuron @ 3 g/ha; C 4: Chlorimuron @ 4 g/ha; P 1.25: Pendimethalin @ 1.25 kg/ha; MW: Manual weeding; W free: Weed free and W check: weedy check)

plant at 45 and 60 DAS, respectively) (Table 2). The lowest nodules number/plant at 60 DAS was recorded in weedy check (5.8/plant). The greater crop-weed competition may be region behind lowest nodules/plant in case of weedy check. Reduction in nodules/plant was also recorded due to herbicide application in comparison to weed free. Similarly, weight of nodules/plant was highest in weed free treatment (114.2 and 120.9 mg/plant at 45 and 60 DAS, respectively) and lowest in case of weedy check (23.4 mg/plant at 60 DAS). Reduction in nodules dry weight/plant was recorded due to herbicides application. The reduction in nodules dry weight/plant was maximum (72.2%) in case of imazethapyr @ 40 g/ha at 45 DAS. Nodules specific weight was also higher under weed free treatment (6.84 and 8.89 mg/plant at 45 and 60 DAS, respectively) and the lowest was recorded in imazethapyr application. Application of herbicides in general reduced nodules specific weight. Among herbicides, highest specific weight of nodule at 60 DAS was recorded in application of quizalofop-ethyl @ 60 g/ha (7.02 mg). Higher nodule specific weight under weed free and quizalofop-ethyl @ 60 g/ha was mainly due to better weed control and poor crop-weed competition.

Highest value of per plant dry matter was recorded in manual weeding (930 and 1 107 mg/plant at 45 and 60 DAS, respectively) and the lowest in case of imazethapyr @ 40 g/ha (467 and 646 mg/plant at 45 and 60 DAS, respectively). Among post-emergence herbicides, highest plant dry matter was recorded in quizalofop-ethyl @ 60 g/ha (657 and 946 mg/plant at 45 and 60 DAS, respectively). Application of quizalofop-ethyl controlled most of the grassy weeds which might reduce crop-weed competition and resulted in higher plant dry weight.

Productivity

Significant difference in chickpea + mustard productivity was recorded due to different weed management practices. The highest chickpea yield was recorded in weed free treatment (1 759 and 1 312 kg/ha during 2008-09 and 2009-10, respectively) (Table 3). Similarly, significantly highest chickpea equivalent yield was recorded in weed free (2 246 and 2 335 kg/ha during 2008-09 and 2009-10, respectively) and the lowest in chlorimuron. Actually in case of chlorimuron treatment, some of the chickpea plants either partially controlled or not controlled due to non-uniformity in herbicide application, hence some chickpea plants were present scattered in each plot of chlorimuron which resulted in a very less chickpea grain yield (150-200 kg/ha). This was followed by imazethapyr treatment. The poor yield of chickpea was mainly due to toxic effect of imazethapyr on chickpea plants. The toxic effect of imazethapyr was also recorded on mustard in which all mustard plants were killed. Quizalofop-ethyl was non-toxic to both chickpea as well as broad leaved weeds, However, most of grassy weeds were controlled by application of quizalofop-ethyl @ 60 g/ha and thus it might reduced the crop-weed competition which resulted in higher yield of chickpea (1 158 and 833 kg/ha during 2008-09 and 2009-10, respectively) and mustard (401 and 617 kg/ha during 2008-09 and 2009-10, respectively) as well as chickpea

Table 2 Effect of weed management practices on chickpea nodulation and plant dry weight

Treatment	Nodule Numbers/plant		Nodules dry weight(mg/plant)		Nodules specific weight (mg)		Plant dry weight (mg/plant)	
	45 DAS	60 DAS	45 DAS	60 DAS	45 DAS	60 DAS	45 DAS	60 DAS
Quizalofop-ethyl @ 40 g/ha	6.7	7.8	31.7	34.8	4.74	4.46	533	811
Quizalofop-ethyl @ 60 g/ha	8.3	7.0	45.0	49.2	5.42	7.02	657	946
Imazethapyr @ 25 g/ha	10.0	12.4	33.0	55.8	3.30	4.50	577	716
Imazethapyr @ 40 g/ha	3.7	9.6	13.6	42.2	3.67	4.40	467	646
Pendimethalin @ 1.25 kg/ha	8.3	12.0	38.3	65.0	4.60	5.42	367	826
Manual weeding (30 DAS)	11.3	10.4	77.0	83.4	6.80	6.42	930	1 107
Weed free	16.7	13.6	114.2	120.9	6.84	8.89	787	960
Weedy check	10.7	5.8	41.0	23.4	3.83	4.03	638	944
LSD (P = 0.05)	1.1	0.9	6.8	10.2	0.7	0.7	72	68

Table 3 Effect of post-emergence herbicides on productivity (kg/ha) of chickpea + mustard intercropping

Treatment	2008-09			2009-10			Mean CEY
	Chickpea	Mustard	CEY*	Chickpea	Mustard	CEY	
Quizalofop-ethyl @ 40 g/ha	941	278	1 254	525	818	1 445	1 350
Quizalofop-ethyl @ 60 g/ha	1 158	401	1 609	833	617	1 528	1 569
Imazethapyr @ 25 g/ha	1 096		1 096	880		880	988
Imazethapyr @ 40 g/ha	772		772	911		911	842
Chlorimuron @ 3 g/ha	216		216	123		123	170
Chlorimuron @ 4 g/ha	185		185	154		154	170
Pendimethalin @ 1.25 kg/ha	1 485	31	1 520	1 080	62	1 150	1 335
Manual weeding (30 DAS)	1 389	463	1 910	1 096	463	2 190	2 050
Weed free	1 759	432	2 246	1 312	432	2 423	2 335
Weedy check	1 035	270	1 338	602	270	1 383	1 361
LSD (P = 0.05)			315			307	321

CEY: Chickpea equivalent yield

equivalent yield (1 609 and 1 569 kg/ha during 2008-09 and 2009-10, respectively). Poor crop-weed competition and better growth of chickpea and mustard crops under weed free, manual weeding and quizalofop-ethyl @ 60 g/ha might be the reasons for higher productivity under these treatments (Rathi *et al.* 2007, Kour *et al.* 2013).

Weed control indices and economics

Mean values of different parameters were used for calculation of weed control indices. The highest value of weed control efficiency (78.5%) and weed control index (88.7%) were recorded in weed free treatment (Table 4). In case of post-emergence herbicides, highest weed control efficiency (47.1%) and weed control index (51.8%) was recorded in quizalofop-ethyl @ 60 g/ha. The significant control in weed numbers and reduction in weed biomass under weed free, manual weeding and quizalofop-ethyl @ 60 g/ha resulted in higher weed control efficiency and weed control index under these treatments. The highest weed index (92.7%) was recorded in chlorimuron and lowest in manual weeding (12.2%). The weed index was lowest in Quizalofop-ethyl @ 60 g/ha among herbicides applied. This was mainly due to good yield of chickpea and mustard under quizalofop-ethyl @ 60 g/ha (Arya *et al*. 2007).

The highest net return was recorded in weed free (Rs. 36 050/ha) followed by manual weeding. Among herbicides, maximum net return was obtained in quizalofop-ethyl @ 60 g/ha (Rs. 25 370/ha) followed by quizalofop-ethyl @ 40 g/ha (Table 4). However, highest value of benefit:cost ratio (B/C ratio) was recorded in manual weeding (2.31) followed by quizalofop-ethyl @ 60 g/ha (2.17) and lowest in case of chlorimuron. Higher yield and lower cost of production under quizalofop-ethyl @ 60 g/ha resulted in higher net return and B/C ratio, however in case of manual weeding and weed free, higher grain yield of chickpea and mustard resulted in higher net return and B/C ratio**.**

Based on above results, it may be concluded that post-emergence application of quizalofop-ethyl may be used for weed control in chickpea + mustard intercropping system, however some good post-emergence herbicides which can control both broad as well as grassy weeds and non-toxic to chickpea and mustard may be explored.

Table 4 Weed control efficiency indices and economics of different weed management practices in mustard + chickpea intercropping

Treatment	WCE*	WCI*	WI*	Net return (‘/ha)	B:C ratio
Quizalofop-ethyl @ 40 g/ha	39.7	12.8	42.2	19 500	1.93
Quizalofop-ethyl @ 60 g/ha	47.1	51.8	32.8	25 370	2.17
Imazethapyr @ 25 g/ha	26.3	18.6	50.6	14 390	1.71
Imazethapyr @ 40 g/ha	25.0	5.3	55.8	10 490	1.51
Chlorimuron @ 3 g/ha	19.3	-61.5	90.5	-14 040	0.32
Chlorimuron @ 4 g/ha	5.0	-52.9	92.7	-16 100	0.24
Pendimethalin @ 1.25 kg/ha	16.0	41.1	42.8	18 850	1.89
Manual weeding (30 DAS)	71.1	79.5	12.2	34 900	2.31
Weed free	78.5	88.7		36 050	2.06
Weedy check			41.7	21 630	2.13

WCE: Weed control efficiency (%); WCI: Weed control index (%); WI: Weed index (%)

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