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Effect of Weed Management on Weed Interference, Nutrient Depletion by Weeds and Production Potential of Long Duration Pigeonpea (*Cajanus cajan* L.) under Irrigated Ecosystem

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A B S T R A C T

Timely weed management is important to increase productivity in s long-duration crop like pigeonpea. A field study to evaluate the effect of weed management on weed interference, nutrient depletion by weeds and production potential of long duration pigeonpea under irrigated ecosystem was conducted at Agricultural Research Farm, IAS, BHU, Varanasi during 2009-10 and 2010-11. Results revealed that use of imazethapyr @ 0.15 kg ha^{-1} followed by (*fb*) paraquat @ 0.4 kg ha^{-1} 40 days after sowing (DAS) significantly ($P \leq 0.05$) reduced the weed density, total weed density and total weed dry weight being statistically at par with two hand weeding (HWs) at 25 and 50 days after sowing (DAS). Weed control index, weed persistence index and weed index were the highest in weed- free, 2- HWs and imazethapyr applied @ 0.15 kg ha^{-1} *fb* paraquat 0.4 kg ha^{-1}. However, weed-free treatment resulted in per cent higher yield attributes like pods plant^{-1} (32.0 and 29.5%), grains pod^{-1} (34 and 32.6%), 1000-grain weight (25.8 and 21.5%), grain yield (48.7 and 47.5%), gross returns (46.0 and 45.0%), net returns (54.6 and 53.0%) and benefit-cost ratio (40.7 and 38.5%), being significantly higher than weedy check but remained at par with 2-HWs, imazethapyr @ 0.15 kg ha^{-1} *fb* paraquat @ 0.4 kg ha^{-1}. The highest nutrient depletion by weeds was recorded in weedy check, whereas, the lowest was in imazethapyr @ 0.15 kg ha^{-1} *fb* paraquat 0.4 kg ha^{-1}.

Introduction

Pigeonpea is the fifth major food grain-legume crop in the world and occupies the second position in India after chickpea (Kumawat *et al.*, 2013a,b and 2015; Singh *et al.*, 2017a,b). In Asia, it is grown in 4.3 m ha with a production of 3.8 m t. India has the largest area (3.4 m ha) followed by Myanmar, China and Nepal. The Indian subcontinent alone contributes nearly 92% of the total pigeonpea production of the world (Kumar *et al.*, 2014, Kumar and Kumawat, 2014, Kumar *et al.*, 2016, 2017a). In 2013-14, productivity was around 25% lower (730 kg ha^{-1}) than the world average (910 kg ha^{-1}) (Singh *et al.*, 2018). Productivity of pigeonpea, however, continues to be low, as this crop are generally grown in rainfed areas under the poor management and face various kinds of biotic and abiotic stresses (Kumar *et al.*, 2010, Kumar *et al.*, 2015a,b and Choudhary *et al.*, 2013). Weed infestation is one of the major constraints in realizing the potential of pigeonpea. Weeds are a severe problem at the initial period (6-8 weeks) due to wider spacing, slow initial growth and harsh climate. Weed control by chemical method is the most promising, even there are cultural practices like intercropping, crop rotation, closer spacing, tillage, which could reduce weed infestation in crop (Kaur *et al.*, 2015 and Kumar *et al.*, 2019). The extent of damage caused by weeds depends largely on composition of weed flora, their population and growth habits. Due to slow initial growth with wider spacing pigeonpea is unable to compete with weeds and fully utilize sunlight and available soil moisture at early growth stage provides an ample scope for emergence and growth of many annual weeds, which compete with crops. Weeds pose a serious problem in pigeonpea during the first 6-8 weeks after sowing, affects crop growth and result in 32-68 % reduction in yield (Kumar *et al.*, 2008, 2010 and Talnikar *et al.*, 2008). Hand weeding is old and effective practice of weed control; however, untimely and continuous rainfall and unavailability of labour at peak period are important constraints (Kumar *et al.*, 2017b, Paswan *et al.*, 2017, Yadav *et al.*, 2018, Kumawat *et al.*, 2018, Mishra *et al.*, 2019 and Kumawat *et al.*, 2019).

Herbicides can suppress weeds from initial growth stages and enhance crop productivity. These not only save valuable time, energy and money, but also permit coverage of more area in short period and carry out the timely weeding. Herbicides like fluchloralin as pre-plant incorporation (PPI) and pendimethalin as pre-emergence (PE) are recommended for weed control to effective control of weeds throughout cropping season, use of post emergence herbicide like imazethapyr has been found safe and effective. Combined application of cultural, mechanical and chemical methods and integration of pre and post-emergence herbicides yielded higher weed control index and monetary benefits than alone application (Kumari *et al.*, 2010, 2012, 2014 and Singh *et al.*, 2006). Taking into consideration the above facts, it becomes imperative to find out the suitable herbicide for weed control in pigeonpea under irrigated ecosystem of India.

Materials and Methods

A field experiment was carried out at the Research Farm, Banaras Hindu University, Varanasi, Uttar Pradesh, India during rainy (*kharif*) season of 2009-10 and 2010-11 under irrigated condition. The study area lies between 25°18′N and 83°03′ E with an altitude of 129 m. The minimum and maximum temperature ranges were 7.1 to 28.5 °C, 4.8 to 29.6 °C and 14.4 to 43.0 °C, 14.2 to 38.2°C, while total rainfall received was 481.5 mm and 734.3 mm, during 2009-10 and 2010-11, respectively. The soil was sandy loam (type *Ustrochrept*) with 53.6 and 52.1% sand, 22.8

and 23.4 % silt, 23.6 and 24.5% clay, bulk density 1.44 and 1.48 Mg m^{-3} in both the respective years. The soil was having low in soluble salts (EC 0.27 and 0.28 dS m^{-1}), organic C (3.4 and 3.8 g kg^{-1}), and slightly alkaline pH (7.42 and 7.57), respectively in both the years. Experimental plot was having available N (203.7 and 214.2 kg ha^{-1}), medium available P (19.2 and 22.4 kg ha^{-1}), available K (218.3 and 231.8 kg ha^{-1}) and available S (21.6 and 24.5 kg ha^{-1}) during both the years, respectively. Eight weed management treatments comprising of weedy check, two hand weeding (25 and 50 DAS), pendimethalin @ 0.75 kg ha^{-1} as pre-emergence, pendimethalin @ 0.75 kg ha^{-1} at pre-emergence *fb* hand weeding at 50 DAS, imazethapyr @ 0.15 kg ha^{-1} as post-emergence, pendimethalin @ 0.75 kg ha^{-1} as pre-emergence *fb* paraquat @ 0.4 kg ha^{-1} as post-emergence, imazethapyr @ 0.15 kg ha^{-1} as post-emergence *fb* paraquat @ 0.4 kg ha^{-1} as post-emergence (Table 1) in combination with each other and with hand weeding were laid out in a randomized complete clock design with three replications with a net plot size of 6 x 5 m. Weed-free and weedy check controls were also included for comparison. Field was prepared using rotary tiller, cultivator and planking was done to make the soil leveled and pulverized. Pigeonpea cv. 'Malviya Arhar-6' was on 3 and 6 July; and. Harvested on 24 March, 2 April in 2010-11 and 2011-12. Pendimethalin was sprayed within 24 hours of sowing and while imazethapyr and paraquat were sprayed in between the crop rows (direct sprays) 30 days after sowing. The knap sack hand sprayer with flat fan nozzle and hood was use for spraying of herbicides. Hand weeding (HW) was done according to treatment and weed- free control plots were maintained by manual weeding. The recommended dose fertilizers i.e. N, P_2O_5, K_2O and S were applied @ 30, 60, 40 and 30 kg ha^{-1} at the time of sowing as a basal through urea (46 % N), di-ammonium phosphate (46 % P_2O_5 and 18 % N), muriate of potash (60 % K_2O) and elemental sulphur (80% S), respectively.

Plant yield attributes, yields and economics analysis

Yield attributes were recorded from five tagged plants. The grain yield was recorded after threshing. Economic analysis was done prevailing market price of produce and cost of inputs and field operations.Net return, benefit: cost ratio, production and economic efficiency was calculated as: Net return (Rs. ha^{-1}) = Gross return (Rs. ha^{-1}) – Cost of cultivation (Rs. ha^{-1}) and benefit: cost ratio= Net return (Rs. ha^{-1})/ cost of cultivation (Rs. ha^{-1}).

Weed density (m^{-2})

At 90 days of crop growth weed density species-wise was measured randomly. Weeds were uprooted and fresh weight was calculated. The collected weeds were oven-dried at 70 ^{o}C ± 2 for about 48 hours for calculating dry weight.

Weed indices

Weed control index (WCI), weed persistence index (WPI) and weed index (WI) were calculated by following formulae (Jaya Suria *et al.*, 2011). Weed control index (%) = [(WDC-DMT)/DMC] x 100 and Weed persistence index = (DMT/DMC) x (WDC/WDT) Where, DMT = Dry biomass of weeds (g m^{-2}) in the treated plot, DMC = Dry biomass of weeds (g m^{-2}) in weedy check plot (control plot), WDT = Weed density (No. m^{-2}) in the treated plot, WDC = Weed density (No. m^{-2}) in weedy check plot (control plot). Weed index (%) = (X-Y/X) x 100, Where, WI = Weed index was expressed in percentage, X = Grain yield in weed free plots, Y = Grain yield in treatment plot for which weed index is to be calculated

Nutrient depletion/uptake by weeds

Nutrient depletion/uptake by weeds was calculated by following formula suggested by Kumawat *et al.,* (2015): Nutrient depletion/ uptake (kg ha^{-1}) = [Nutrient concentration in weeds (%)/100] x Weed dry weight (kg ha^{-1})

Microbial population

Microbial population was determined by following method Pikovskaya's agar medium (Sundra Rao and Sinha, 1963).

Statistical tools and techniques

The collected data at different growth phases were analyzed by using appropriate advanced statistical technique "DMRT" in order to check the effectiveness of treatments at probability level of 5% through Randomized Block Design (RBD as per the procedure suggested by Cochran and Cox (1957) and significance was tested by F-test.

Results and Discussion

Weed interference

Echinochloa crusgalli (L.) Beauv. and *Cynodon dactylon* (L.) Pers. were the potent grassy weeds; *Digera arvensis* Forsk., *Trianthema monogyna* L. and *Eclipta alba* (L.) Hassk. were dominant broad- leaved weed; and *Cyprus rotundus* L. was less dominant weed. Maximum relative percentage was recorded for grasses (46.5%), followed by broad-leaved weeds (29.5%) and sedges (14.9%) (Table 2). Application of imazethapyr @ 0.15 kg ha^{-1} *fb* paraquat @ 0.4 kg ha^{-1} significantly reduced the grasses density; *E. crusgalli* (72.3 and 78.8%) and *C. dactylon* (61.9 and 66.8%), broad leaved weeds; *Digera arvensis* (75.3 and 76.7%), *T. monogena* (71.2 and 74.8%), *E. alba* (71.6 and 78.3 %) and *C. rotundus* (65.7 and 70.0%) density over weedy check, but it was statistically at par with remaining weed management treatments (Table 2). The BLWs was managed by integration of mechanical and chemical weeding techniques. Application of imazethapyr @ 0.15 kg ha^{-1} *fb* paraquat @ 0.4 kg ha^{-1} significantly reduced total weed density and dry biomass of weeds, which led to reduced weed competition for crop establishment at initial stages of crop growth (Table 3). This might be due to application of early and late post-emergence herbicide, which managed weed density quite well and reduce crop weed competition up to 50 days, resulting in vigorous crop growth (Ahmad *et al.,* 2008; Singh *et al.,* 2014). Application of pre-emergence pendimethalin @ 1.0 kg ha^{-1} *fb* imazethapyr @ 0.10 kg ha^{-1} at 30-35 DAS was found promising to control weeds in pigeonpea (Padmaja *et al.,* 2013). Pre-emergence application of pendimethalin and HW at 50 DAS resulted in maximum control of monocot and dicot weeds. Post-emergence application of either imazathapyr or quizalofopethyl followed by HW at 50 DAS resulted in very good control of both dicot and monocot weeds (Rao *et al.,* 2015).

Weed indices

Weed control index followed the order: 2-HWs ≥ imazethapyr *fb* paraquat ≥ pendimethalin ≥ HW ≥ pendimethalin *fb* paraquat as compare to pendimethalin and imazethapyr alone application. Minimum weed persistence index (WPI) (0.04) was recorded 2-HWs followed by in imazethapyr @ 0.15 kg ha^{-1} *fb* paraquat @ 0.4 kg ha^{-1} (0.08) (Table 3). Weed index (WI) indicated that maximum yield loss by weeds was found in weedy check (94.8 and 90.5%) and minimum in 2-HWs and application of imazethapyr *fb* paraquat (5.7%). Integration of pre and post-emergence herbicides showed better performance over weedy check and alone use of herbicides (Table 4). This could be due to the different action of pre- and post-emergence herbicides applied in crop and their mode of action on weeds like primary mode of action of pendimethalin is to inhibit microtubule formation in cells of susceptible monocot and dicot weed, which are an important part of cell division process (Padmaja *et al.,* 2013). As a result of restricted cell division, growth of emerging weed was prevented. Similarly, post-emergence application of imazethapyr was responsible for inhibition of acetolactate synthase (ALS) or acetohydroxy acid synthase (AHAS) in broad leaved weeds, which caused destruction of these weeds at 3-4 leaf stage and finally reduced the density and population of weeds in the field (Rathod *et al.,* 2016). Initial control of weeds by HW provided favourable environment to the crop for growth and development, and after 2-HWs crop grow better due to the least crop-weed competition under irrigated conditions (Meena *et al.,* 2011).

Nutrients depletion by weeds and microbial population

Depletion of nutrients (N, P and K) by weeds differed significantly ($P \leq 0.05$) due to weed management treatments (Table 5). In weedy check, weeds removed significantly higher N (6.22 and 5.76 kg ha^{-1}), P (3.97 and 3.74 kg ha^{-1}) and K (4.57 and 4.24 kg ha^{-1}) over weed-free control, 2- HWs, respectively. Lower depletion of nutrients by weeds was recorded under imazethapyr *fb* paraquat, this treatment performance better over rest of different herbicidal treatments. The highest nutrient depletion by weed was recorded in weedy check plots. The main reason for this kind of behaviour was that the weeds in weedy check were not controlled effectively. Therefore increased weeds per unit area enabled them to absorb more nutrients. The less nutrient removal by weeds with imazethapyr *fb* paraquat was due to better control of weeds (Vyas *et al.,* 2003). Further data showed on microbial populations were influenced by weed management practices. The maximum microbial population (1.80 and 1.86 x 10^4 cfu g^{-1} soil) was recorded in weed-free control treatment being significantly higher than various weed management treatment, but it was statistically at par with 2- HW at 25 and 50 DAS.

Table.1 Herbicide treatments in the *kharif* season of 2009-10 and 2010-11

Treatment	Rate of application	Time of application
Weedy check	-	Up to harvest
Two hand weeding	-	25 DAS *fb* 50 DAS
Pendimethalin	0.75 kg a.i. ha^{-1}	1 DAS
Pendimethalin *fb* one hand weeding	0.75 kg a.i. ha^{-1}	1 DAS *fb* 50 DAS
Imazethapyr	0.15 kg a.i. ha^{-1}	20 DAS
Pendimethalin *fb* paraquat	0.75 kg a.i. *fb* 0.4 kg a.i. ha^{-1}	1 DAS *fb* 40 DAS
Imazethapyr *fb* paraquat	0.15 kg a.i. *fb* 0.4 kg a.i. ha^{-1}	20 DAS *fb* 40 DAS
Weed free	-	10 DAS to 180 DAS

DAS: Days after sowing, *a.i.*: active ingredient and *fb*-followed by

Table.2 Relative composition (%) of weed species occurring in experimental field

Treatment	***Echinochola crusgalli***	***Cynodon Dactylon***	***Digera arvensis***	***Trianthema monogyna***	***Eclipta Alba***	***Cyprus rotundus***	**Other weeds**
2009-10							
Weedy check	31.13	15.34	8.34	9.45	11.73	14.90	9.11
Two hand weeding at 25 and 50 DAS	30.93	20.36	7.22	10.31	8.76	14.95	7.47
Pendimethalin @ 0.75 kg ha^{-1} (PE)	32.85	15.74	7.26	9.93	11.23	14.59	8.40
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* one hand weeding at 50 DAS	27.50	19.10	7.24	10.42	11.58	14.46	9.70
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	31.60	16.73	6.51	10.69	10.78	15.33	8.36
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	25.85	19.74	7.29	10.57	11.52	16.45	8.58
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	28.76	19.48	6.86	9.09	11.13	17.07	7.61
Weed free	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010-11							
Weedy check	32.47	15.80	8.27	9.18	12.36	13.93	7.99
Two hand weeding at 25 and 50 DAS	32.39	22.54	7.05	9.86	7.04	14.08	7.04
Pendimethalin @ 0.75 kg ha^{-1} (PE)	33.66	15.54	6.69	9.50	11.22	15.02	8.37
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* one hand weeding at 50 DAS	29.86	17.71	7.47	9.55	10.94	14.05	10.42
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	34.09	16.88	6.31	9.52	11.07	13.28	8.85
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	27.07	18.92	6.99	9.91	11.35	16.30	9.46
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	27.23	20.80	7.67	9.16	10.64	16.58	7.92
Weed free	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PE-Pre-emergence, Data with different letters show significant difference in column data in randomized block design test at $p < 0.05$ under Duncan's multiple range test

Table.3 Effect of weed management on species wise weed density in pigeonpea

Treatment	*Echinochola crusgalli*	*Cynodon dactylon*	*Digera arvensis*	*Trianthema monogyna*	*Eclipta alba*	*Cyprus rotundus*	Other weeds
2009-2010							
Weedy check	7.5^{a} (56.0)	5.2^{a} (27.6)	5.3^{a} (15.0)	3.9^{a} (17.0)	4.2^{a} (21.1)	4.6^{a} (26.8)	4.1^{a} (16.4)
Two hand weeding at 25 and 50 DAS	3.5^{f} (12.0)	2.5^{e} (7.9)	2.9^{d} (2.8)	1.8^{e} (4.0)	2.1^{d} (3.4)	1.9^{f} (5.8)	1.8^{f} (2.9)
Pendimethalin @ 0.75 kg ha^{-1} (PE)	6.6^{b} (43.0)	4.4^{b} (20.6)	4.6^{b} (9.5)	3.2^{b} (13.0)	3.7^{b} (14.7)	3.9^{b} (19.1)	3.4^{b} (11.0)
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* one hand weeding at 50 DAS	4.4^{de} (19.0)	3.2^{d} (13.2)	3.7^{c} (5.0)	2.4^{d} (7.2)	2.8^{c} (8.0)	2.9^{d} (10.0)	2.7^{d} (6.7)
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	5.8^{c} (34.0)	4.1^{bc} (18.0)	4.3^{b} (7.0)	2.7^{c} (11.5)	3.5^{b} (11.6)	3.5^{c} (16.5)	3.1^{c} (9.0)
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	4.7^{d} (22.0)	3.8^{c} (16.8)	4.2^{b} (6.2)	2.6^{cd} (9.0)	3.1^{c} (9.8)	3.2^{cd} (14.0)	2.8^{cd} (7.3)
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	4.0^{ef} (15.5)	3.1^{d} (10.5)	3.3^{cd} (3.7)	2.1^{e} (4.9)	2.3^{d} (6.0)	2.6^{e} (9.2)	2.1^{e} (4.1)
Weed free	0.7^{g} (0.0)	0.7^{f} (0.0)	0.7^{e} (0.0)	0.7^{f} (0.0)	0.7^{e} (0.0)	0.7^{g} (0.0)	0.7^{g} (0.0)
LSD (P=0.05)	0.70	0.39	0.43	0.28	0.33	0.33	0.30
2010-2011							
Weedy check	7.3^{a} (52.0)	4.8^{a} (25.3)	5.1^{a} (13.3)	3.7^{a} (14.7)	3.9^{a} (19.8)	4.5^{a} (22.3)	3.6^{a} (12.8)
Two hand weeding at 25 and 50 DAS	3.1^{e} (9.2)	2.1^{e} (6.4)	2.6^{e} (2.0)	1.6^{f} (2.8)	1.8^{e} (2.0)	1.6^{f} (4.0)	1.6^{f} (2.0)
Pendimethalin @ 0.75 kg ha^{-1} (PE)	6.3^{b} (39.0)	4.2^{b} (18.0)	4.3^{b} (7.8)	2.8^{b} (11.0)	3.4^{b} (13.0)	3.7^{b} (17.4)	3.2^{b} (9.7)
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* one hand weeding at 50 DAS	4.2^{d} (17.2)	2.9^{d} (10.2)	3.3^{d} (4.3)	2.2^{d} (5.5)	2.5^{d} (6.3)	2.6^{d} (8.1)	2.5^{d} (6.0)
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	5.6^{c} (30.8)	3.5^{c} (15.3)	3.9^{bc} (5.7)	2.5^{c} (8.6)	3.0^{c} (10.0)	3.2^{c} (12.0)	2.9^{bc} (8.0)
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	4.4^{d} (18.6)	3.4^{c} (13.0)	3.7^{c} (4.8)	2.3^{cd} (6.8)	2.7^{d} (7.8)	2.9^{d} (11.2)	2.6^{cd} (6.5)
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	3.4^{e} (11.0)	2.7^{d} (8.4)	2.9^{de} (3.10)	1.9^{e} (3.7)	2.1^{e} (4.3)	2.2^{e} (6.7)	1.9^{e} (3.2)
Weed free	0.7^{f} (0.0)	0.7^{f} (0.0)	0.7^{f} (0.0)	0.7^{g} (0.0)	0.7^{f} (0.0)	0.7^{g} (0.0)	0.7^{g} (0.0)
LSD (P=0.05)	0.55	0.34	0.39	0.25	0.29	0.29	0.28

Table.4 Effect of weed management on weed density and weed control efficiency

Treatment	Total weed density (m^{-2})	Total weed dry weight (g)	Weed control efficiency (%)	Weed persistence index (WPI)	Weed index (%)
2009-2010					
Weedy check	13.43^{a} (179.9)	12.77^{a} (162.7)	0.00^{e}	1.00^{a}	94.83^{a}
Two hand weeding at 25 and 50 DAS	6.27^{f} (38.8)	5.43^{e} (29.0)	82.18^{b}	0.04^{g}	5.72^{e}
Pendimethalin @ 0.75 kg ha^{-1} (PE)	11.46^{b} (130.9)	10.43^{b} (108.2)	33.50^{d}	0.48^{b}	69.81^{b}
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* one hand weeding at 50 DAS	8.34^{de} (69.1)	7.34^{cd} (53.4)	67.18^{c}	0.13^{e}	32.43^{d}
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	10.40^{c} (107.6)	9.72^{b} (94.0)	42.22^{d}	0.35^{c}	45.77^{c}
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	9.25^{d} (85.1)	7.45^{c} (55.0)	66.20^{c}	0.16^{d}	44.71^{c}
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	7.38^{e} (53.9)	6.53^{d} (42.1)	74.12^{bc}	0.08^{f}	31.21^{d}
Weed free	0.71^{g} (0.0)	0.71^{f} (0.0)	100.00^{a}	0.00^{h}	0.00^{f}
LSD (P=0.05)	0.98	0.87	10.47	0.02	3.82
2010-2011					
Weedy check	12.67^{a} (160.2)	12.26^{a} (149.7)	0.00^{f}	1.00^{a}	90.54^{a}
Two hand weeding at 25 and 50 DAS	5.38^{f} (28.4)	4.39^{f} (18.8)	87.44^{b}	0.02^{g}	5.99^{e}
Pendimethalin @ 0.75 kg ha^{-1} (PE)	10.79^{b} (115.8)	10.22^{b} (104.0)	30.53^{e}	0.50^{b}	68.18^{b}
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* one hand weeding at 50 DAS	7.62^{d} (57.6)	6.64^{d} (43.6)	70.88^{cd}	0.10^{e}	32.31^{d}
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	9.53^{c} (90.4)	7.71^{c} (59.0)	60.59^{d}	0.22^{c}	45.36^{c}
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	8.32^{d} (68.7)	6.85^{d} (46.4)	69.00^{cd}	0.13^{d}	43.92^{c}
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	6.40^{e} (40.4)	5.58^{e} (30.6)	79.56^{bc}	0.05^{f}	31.72^{d}
Weed free	0.71^{g} (0.0)	0.71^{g} (0.0)	100.00^{a}	0.00^{g}	0.00^{f}
LSD (P=0.05)	0.87	0.74	11.14	0.02	3.79

Table.5 Effect of weed management on nutrient depletion by weeds and microbial population

Treatment	Nutrient depletion by weeds (kg ha^{-1})			Microbial population (x 10^4 cfu g^{-1} soil)
	N	P	K	
2009-2010				
Weedy check	6.22[a] (38.17)	3.97[a] (15.27)	4.57[a] (20.42)	1.16[f]
2 HW at 25 and 50 DAS	2.36[d] (5.08)	1.59[d] (2.03)	1.92[d] (3.19)	1.68[ab]
Pendimethalin @ 0.75 kg ha^{-1} (PE)	4.98[b] (24.30)	3.20[b] (9.72)	3.67[b] (13.00)	1.29[ef]
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* 1 HW at 50 DAS	3.59[c] (12.36)	2.33[c] (4.95)	2.67[c] (6.62)	1.52[cd]
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	4.56[b] (20.27)	2.93[b] (8.11)	3.37[b] (10.84)	1.41[de]
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	3.63[c] (12.67)	2.36[c] (5.07)	2.70[c] (6.78)	1.46[cd]
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	3.14[c] (9.37)	2.06[c] (3.75)	2.35[c] (5.01)	1.58[bc]
Weed free	0.71[e] (0.00)	0.71[e] (0.00)	0.71[e] (0.00)	1.80[a]
LSD (P=0.05)	0.55	0.35	0.41	0.15
2010-2011				
Weedy check	5.76[a] (32.66)	3.74[a] (13.51)	4.24[a] (17.47)	1.25[e]
2 HW at 25 and 50 DAS	1.89[e] (3.06)	1.26[e] (1.10)	1.66[d] (2.26)	1.75[ab]
Pendimethalin @ 0.75 kg ha^{-1} (PE)	4.71[b] (21.72)	3.00[b] (8.52)	3.48[b] (11.62)	1.43[d]
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* 1 HW at 50 DAS	3.14[c] (9.39)	2.00[cd] (3.48)	2.35[c] (5.02)	1.60[bcd]
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	3.51[c] (11.83)	2.29[c] (4.77)	2.61[c] (6.33)	1.52[cd]
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	3.23[c] (9.94)	2.08[c] (3.85)	2.41[c] (5.32)	1.56[cd]
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	2.61[d] (6.34)	1.70[d] (2.38)	1.97[d] (3.39)	1.69[abc]
Weed free	0.71[f] (0.00)	0.71[f] (0.00)	0.71[e] (0.00)	1.86[a]
LSD (P=0.05)	0.50	0.32	0.37	0.16

Table.6 Effect of weed management on yield attributes, yield and economics of pigeonpea

Treatment	Pods plant^{-1} (no.)	Grains pods^{-1} (no.)	1000-grain weight (g)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Cost of cultivation (Rs.x10^3 ha^{-1})	Gross return (Rs.x10^3 ha^{-1})	Net return (Rs.x10^3 ha^{-1})	B:C ratio
2009-2010									
Weedy check	86.4^d	3.1^e	88.0^c	1025^d	4030^c	20.3^c	52.0^d	31.7^e	1.56^d
2 HW at 25 and 50 DAS	120.9^{ab}	4.4^{ab}	114.4^{ab}	1889^a	6180^a	25.3^{ab}	90.8^a	65.6^a	2.59^a
Pendimethalin @ 0.75 kg ha^{-1} (PE)	100.2^{cd}	3.4^{de}	99.7^{bc}	1176^{cd}	4048^c	20.6^c	57.4^{cd}	36.7^{de}	1.78^{cd}
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* 1 HW at 50 DAS	116.5^{ab}	4.0^{bc}	109.0^{ab}	1508^b	5014^b	23.1^{bc}	72.8^b	49.7^{bc}	2.15^b
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	106.0^{bc}	3.7^{cd}	102.8^{bc}	1370^{bc}	4121^c	20.7^c	64.4^{bc}	43.7^{cd}	2.11^{bc}
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	109.7^{bc}	3.8^{bcd}	107.2^{ab}	1380^{bc}	4200^c	20.7^c	65.1^{bc}	44.4^{cd}	2.14^b
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	118.8^{ab}	4.2^{bc}	111.5^{ab}	1522^b	5180^b	20.8^c	74.0^b	53.2^b	2.56^a
Weed free	127.6^a	4.7^a	118.6^a	1997^a	6605^a	26.5^a	96.3^a	69.8^a	2.63^a
LSD (P=0.05)	16.1	0.58	15.17	232.70	761.87	3.24	11.19	7.97	0.33
2010-2011									
Weedy check	93.1^d	3.3^d	94.5^c	1068^d	4153^c	20.3^c	54.0^d	33.7^e	1.66^d
2 HW at 25 and 50 DAS	126.7^{ab}	4.6^{ab}	117.0^{ab}	1920^a	6424^a	25.3^{ab}	92.9^a	67.6^a	2.68^a
Pendimethalin @ 0.75 kg ha^{-1} (PE)	106.8^{cd}	3.7^{cd}	102.0^{bc}	1210^{cd}	4183^c	20.6^c	59.1^{cd}	38.5^{de}	1.87^{cd}
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* 1 HW at 50 DAS	120.5^{abc}	4.2^{bc}	112.0^{ab}	1538^b	5140^b	23.1^{bc}	74.4^b	51.3^{bc}	2.22^b
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS	109.2^{cd}	4.0^{bc}	104.0^{bc}	1400^{bc}	4250^c	20.7^c	66.0^{bc}	45.3^{cd}	2.19^{bc}
Pendimethalin @ 0.75 kg ha^{-1} (PE) *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	113.7^{bc}	4.1^{bc}	108.0^{abc}	1414^{bc}	4325^c	20.7^c	66.8^{bc}	46.1^{cd}	2.22^b
Imazethapyr @ 0.15 kg ha^{-1} at 20 DAS *fb* paraquat @ 0.4 kg ha^{-1} at 40 DAS	122.5^{abc}	4.5^{ab}	115.2^{ab}	1545^b	5294^b	20.8^c	75.3^b	54.5^b	2.62^a
Weed free	132.0^a	4.9^a	120.4^a	2035^a	6737^a	26.5^a	98.2^a	71.7^a	2.70^a
LSD (P=0.05)	16.7	0.60	15.51	236.84	785.66	3.24	11.43	8.21	0.34

Yield attributes and Yield

Yield attributing characters, yield and production efficiency were influenced significantly due to weed management treatments (Table 6). Application of imazethapyr *fb* paraquat gave maximum pods plant^{-1} (118.8 and 122.5), grains pod^{-1}(4.2 and 4.5), 1000-grain weight (111.5 and 115.2) in comparision to other treatment. The highest grain yield (1522 and 1545 kg ha^{-1}) and stover yield (5180 and 5294 kg ha^{-1}) were also recorded with imazethapyr *fb* paraquat, respectively. However it was found statistically at par with pendimethalin @ 0.75 kg ha^{-1} *fb* HW at 25 DAS during both the years study. The per cent increases the grain yield by 32.7, 30.9 and stover yield 22.2 and 21.6, respectively over the unweeded control. Higher production efficiency was gave alone application of imazethapyr and lowest was recorded weedy check (Table 5). This may be due to fact that with favourable condition in absence of weeds, process of tissue differentiation from stomatic to reproductive, meristematic activity and development of floral primordial have been enhanced causing greater number of flowers, which later developed in pods (Rathod *et al.,* 2016). Similarly, application of imazethapyr *fb* paraquat recorded higher growth and yield attributes as compared to different weed management practices. This might be due to effect of different herbicides that controlled the weeds and reduced the competition of crop with weeds for growth resources like space, air, sunlight, moisture and nutrients (Vyas *et al.,* 2003; Ram *et al.,* 2011).

Economics

The gross return, net returns, benefit: cost, production and economic efficiency were noted minimum for weedy check (Table 6). Among the weed management treatments, the highest gross returns (x10^3 74.0 and 75.3 Rs. ha^{-1}), net returns (x10^3 53.2 and 54.5 Rs. ha^{-1}) and benefit: cost ratio (2.56 and 2.62), were recorded in imazethapyr *fb* paraquat but it was found significantly superior to other weed management practices. This might be due to this treatment gave better control of weeds resulting into higher yield attributes and yield of crop. Padmaja *et al.,* (2013) reported that higher net return was realized with pendimethalin followed by paraquat at 42 DAS, which was statistically higher than those with other treatments except imazethapyr followed by paraquat at 56 DAS.

In conclusion, the result of the present investigation that application of herbicides in comparison to hand weed weedings are better under lack of availability of labours and continues rains. For maximum weed reduction and productivity as well as profitability of long duration pigeonpea were achieved with imazethapyr @ 0.15 kg ha^{-1} *fb* paraquat @ 0.4 kg ha^{-1} under irrigated ecosystem of India.

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