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Long-term weed management effect on weed dynamics, weed shift and productivity of direct-seeded rice-chickpea cropping system

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ABSTRACT

A long-term experiment was conducted on Inceptisol at Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh during 2010 to 2015 in direct-seeded rice (DSR)-chickpea cropping system to study the effect of continuous and rotational use of weed management practices on weed shift and productivity. No remarkable weed shift was visualized due to continuous or rotational application of combination of herbicides or manual weeding or its integration. However, appearance of *Celosia argentea* in unweeded plot was noticed in sixth year of DSR mainly due to its aggressive growth habit and non-submergence of rice field during *Kharif* 2015. The appearance of *Celosia argentea* suppressed the *Alternanthera triandra*. The *Celosia argentea* produced 8430 seeds/plant as against 1564 seeds/plant by *Alternanthera triandra.* Significantly higher seed yield of rice was registered under two hand weedings followed by oxadiargyl 80 g/ha *fb* bispyribac 25 g/ha. Seed yield of chickpea was higher under conventional tillage and continuous application of pendimethalin 1000 g/ha. Studies on weed seed bank suggested that although, there was no effect of different weed management treatments on seed bank up to 15 cm soil depth neither in DSR nor in chickpea at initial stage, but in unweeded control plot, there was perceptible variation in number of weed seeds of different annual weed species. The dominant weeds species were *Celosia argentea* (37.7%), *Echinochloa colona* (19.6%), *Ischaemum rugosum* (14.7%) and *Cyperus iria* (9.8%) over initially dominant species of *Alternanthera triandra.*

INTRODUCTION

Rice-chickpea is one of the important cropping systems in India including Chhattisgarh. Rice is major *Kharif* crop occupies an area of around 3.67 million hectare (mha) while during *Rabi* season, chickpea is an important pulse crop in Chhattisgarh, covering an area of 0.40 mha with an annual production of 0.43 metric tons. In recent years, due to severe water and labour scarcity, farmers are changing their rice establishment method from transplanting to direct-seeding (Walia *et al*. 2012), therefore, there has been a continuous shift from transplanted rice to direct-seeded rice (DSR) cultivation in several countries of South-East Asia (Pandey and Velasco 2002). The Chhattisgarh state traditionally has an area of nearly 70% under direct-seeding. The DSR has several advantages over puddle transplanted rice like easier planting, timely sowing, less drudgery, early crop maturity by 7-10 days, less water requirement, better soil physical condition for next crop and low production cost with more profit (Kumar and Ladha 2011). The additional benefits of DSR would be water conservation, soil temperature moderation and built up of soil organic carbon status due to residue retention at the surface (Singh *et al.* 2014). However, heavy weed infestation is one of the major constraints in DSR cultivation causing severe yield losses (Rao *et al*. 2007). Yield losses due to weeds varied from 40-100% in direct-seeded rice (Choubey *et al*. 2001). The chickpea is also a poor competitor of weeds because of slow growth rate and limited leaf development during early stage of crop growth and lack of proper weed management which resulted in yield loss of 40-87% (Chaudhary *et al*. 2005). Although, tillage and herbicides are used for weed control, but the degree of control achieved may vary widely depending on weed species present, soil type, climatic conditions, tillage methods *etc*. Thus, herbicide use becomes more important in rice-chickpea cropping system because weeds and rice seedling emerge simultaneously in DSR and starts crop weed competition (Raj *et al.* 2013). Herbicides offer most effective, economical and practical way to weed management and are considered an alternative

supplement to hand weeding. Considering the weed flora and its density, combination of different herbicide molecules may work better than over-dosing of a single recommended herbicide. Continuous use of the same herbicide year after year may also lead to problem of shift in weed flora. Weed population dynamics depends on weed management practices of both crops of cropping system along with tillage practices in chickpea crop. With this background, the present study was conducted to explore the long-term use of herbicides either continuously or in rotation in comparison with manual weeding in DSR and chickpea along with different tillage practices in succeeding crop on weed dynamics, weed shift and productivity of rice-chickpea cropping system.

MATERIALS AND METHODS

Experiment was initiated in *Kharif* 2010 on Inceptisols type of soil at Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh and continued from rainy seasons of 2010 to 2015 in DSR as first crop and chickpea as second crop in rice-chickpea cropping system under mid land ecosystem. During *Kharif*, five treatments comprised of oxadiargyl 80 g/ha at 3 days after sowing (DAS) *fb* bispyribac Na 25 g/ha 25 DAS, fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha 20 DAS; pyrazosulfuron 25 g/ha at 3 DAS *fb* hand weeding at 35 DAS, hand weeding twice at 20 and 35 DAS and unweeded control were assigned in a randomized block design with three replications. Of these five treatments, three plots, *viz*. oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha, hand weeding twice and un-weeded control remained fix continuously for five years on same piece of land, whereas, fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha and pyrazosulfuron 25 g/ha *fb* hand weeding were rotated with each other in every two years. In case of follow-up crop of chickpea, each plot of *Kharif* rice was divided into two treatments, one with conventional tillage and another with zero tillage which again sub-divided into three sub-sub plots consisting weed management practices; namely farmers' practice (hand weeding and interculture at 20 DAS), pendimethalin 1.0 kg/ha as pre-emergence (PE) and unweeded control in split-split plot design replicated thrice. The soil was sandy-loam with low organic carbon and available nitrogen but medium in phosphorus and high in potassium with neutral soil reaction. Medium duration rice cultivar '*MTU 1010*' and chickpea cultivar '*JG-130*' were taken as test crop. The sowing of rice at 80 kg/ha was done with the help of seed cum fertilizer drill in third week of June during all the five years at a spacing of 20 cm row to row with recommended dose of fertilizer *i.e.* 100:50:30 kg/ha of N:P:K. The crop did not suffer with any kind of incidence like drought, insect, disease *etc*. during its entire growth period, however, during 2015 *Kharif*, there was no submergence as rain water was not available throughout the crop period and the survival was only on the basis of irrigation water.

Sowing of chickpea crop was done in the third week of November every year with a seed rate of 75 kg/ha and row spacing of 30 cm with the help of seed cum fertilizer drill in conventional tillage, whereas, it was sown with zero-till seed cum fertilizer drill in zero tillage plots. The recommended fertilizer dose of 20:50:30 kg/ha N:P:K was applied to chickpea as basal. The observations, *viz*. weed flora, weed density, weed biomass and their effect on yield of rice and chickpea and economic viability of different treatments were analyzed as per the standard procedure. All other agronomic practices were kept normal and uniform for all the treatments of the experiment. Effect of continuous use of herbicides and herbicide-tillage combination on weed shift in rice and chickpea was recorded in the initial and final year. The herbicides were applied by using knapsack sprayer with 375 liters of spray volume per hectare as per treatment. The species and category wise weed density and dry weight was recorded using quadrate of 50 × 50 cm in all the seasons. Weed seed bank studies were conducted to see the changes in weed flora over initial status. Soil samples from a depth of 0-15 cm were collected treatment wise from 3 random spots in each treatment after the harvest of rice and chickpea in the initial year 2010-11 and concluding year 2015. The soil samples weighing 500 g were put in small pots followed by a regular watering to facilitate early emergence of weeds. Species wise weed emergence was recorded at 30 DAS.

RESULTS AND DISCUSSION

Weed flora

Rice: Major weed flora observed in the experimental field of rice during rainy seasons of 2010 to 2015 were *Echinochloa colona, Ischeamum rugosum* among grasses; *Alternanthera triandra, Cyanotis axillaris* among broad-leaved and *Cyperus iria* among sedges. Other weeds present in lower density were *Commelina benghalensis, Croton bonplandianus, Spilanthus acmella, Ludwigia parviflora.* In the initial years, *Alternanthera triandra* was the dominant weed but became gradually insignificant later.

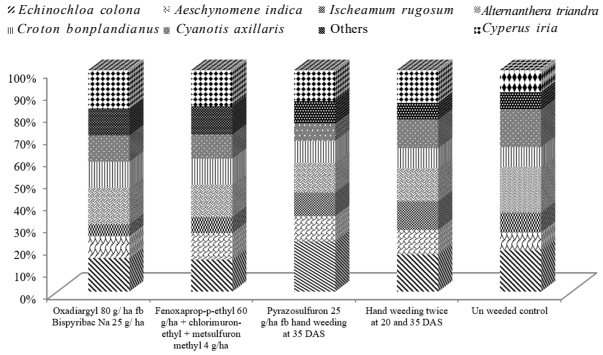

Figure 1. Relative weed density in the initial year, *Kharif* 2010 under direct seeded rice

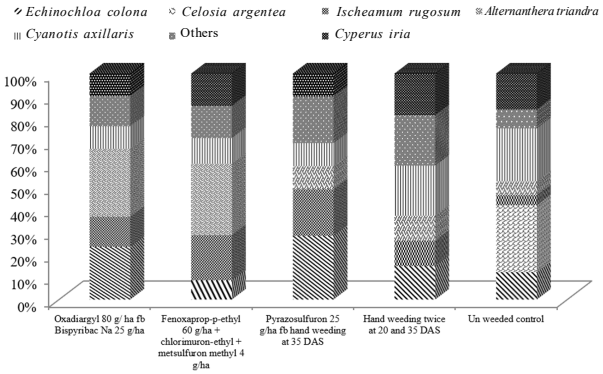

Figure 2. Relative weed density in the concluding sixth year, *Kharif* 2015 under direct seeded rice

Chickpea: Major weed flora observed in the chickpea field during winter seasons of 2010-11 to 2014-2015 was *Medicago denticulata* and *Chenopodium album*. Other weeds in lower density were *Anagalis arvensis, Melilotus alba, Echinochloa colona, Cyperus iria.* Sekhon and Singh (1993) has also reported the similar weed flora as problematic weeds in pulses.

Weed density and dry weight

Rice: The data of weed densities in rice recorded at 60 DAS in the initial year (**Figure 1** and **2**) revealed that density of grassy weed mainly *Echinochloa colona* was higher with pyrazosulfuron 25 g/h *fb* one hand weeding at 35 DAS due to the fact that pyrazosulfuron is more effective on broad-leaves than grasses. The density of broad-leaves and sedge was slightly more under oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac-Na 25 g/ha 25 DAS in the first year. However, in the concluding year *i.e.* sixth, there was shift in weed flora except for *E. colona* which remained unchanged and was found higher under pyrazosulfuron 25 g/ha *fb* one hand weeding. Density of *I. rugosum* was also found higher under this treatment. The relative density of *A. triandra* was recorded to be the highest under fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha at 20 DAS. It was mainly due to the lesser effect of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha against *A. triandra*. The remarkable change in weed densities was noted under untreated control plot where density of *A. triandra* reduced drastically from 20.5% in the initial year to 5.6% in the sixth year. This was mainly due to suppressive effect of *C. argentea,* which emerged as the most dominating weed species at the sixth year and contributed the share of 27.5%. Another weed density increased over initial year was *C. axillaris,* which contributed for 28.9% in the control plot.

Significantly lower weed dry matter was recorded at 60 DAS under all the treatments over un-weeded control plot in all the years (**Table 1**). Among different weed management treatments, significantly lower weed dry matter was registered under two hand weeding at 20 and 35 DAS in all the years, which was closely followed by oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS. Weed dry matter was also found significantly low under rotational treatments than unweeded control.

Chickpea: There was no change in weed species either due to weed management practices or tillage practices. *M. denticulata* and *C. album* were the most dominant weeds. Out of these two, *M. denticulata* proved to be more serious weed of chickpea and contributed for 70.7 and 78.5%, respectively in the initial and concluding year under conventional tillage whereas it was to the tune of 60.6 and 80.3% in zero tillage for the same period. The relative density of *M. denticulata* was 76.5 and 80% in the initial and concluding year under unweeded control (**Figure 3 and 4**).

Table 1. Weed dry weight at 60 DAS of direct-seeded rice as influenced by long term weed management practices under rice-chickpea cropping system

Treatment	Weed dry weight (g/m^2)						
	2010	2011	2012	2013	2014	2015	Mean
Oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha	6.79(45.6)	6.70(44.4)	3.78(13.8)	4.69(21.7)	6.08(26.5)	4.33(18.2)	5.37(28.4)
Fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha	6.53(42.1)	7.33(53.2)	6.55(42.4)	6.15(37.6)	6.64(43.9)	5.40(28.7)	6.47(41.3)
Pyrazosulfuron 25 g/ha *fb* HW at 35 DAS	6.44(41.0)	9.19(83.9)	4.56(20.3)	5.27(27.5)	6.42(40.9)	5.09(25.4)	6.35(39.8)
Hand weeding (HW) twice at 20 and 35 DAS	6.50(41.8)	5.57(30.5)	4.24(17.5)	4.25(17.7)	4.70(21.7)	4.09(16.2)	4.97(24.2)
Unweeded control	11.86(140.2)	12.61(158.6)	9.27(85.5)	9.74(94.6)	11.80(139.1)	15.44(237.9)	11.96(142.6)
LSD (p=0.05)	0.36	0.52	0.40	0.22	0.65	0.78	-

*Data in parentheses is original and transform by ($\sqrt{x+0.5}$)

The treatments of weed management applied during *Kharif* to DSR had no significant impact on weed dry matter in *Rabi* at 60 DAS, though, there was slightly higher dry matter of weeds was recorded under unweeded control plot of *Kharif* season than other practices (**Table 2**). However, there was significant impact in previous two years *i.e.* 4th and 5th year. The impact of previous season treatments on weed dry matter was seen in 4th and 5th year where weed dry matter was significantly lower under permanent plots of two hand weeding treatment and this was closely followed by oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS than un-weeded control. Tillage also had no significant impact on weed dry matter at 60 DAS in chickpea except during 2014-15. Though, there was slightly higher weed dry matter obtained under conventional than zero tillage during entire period of expermentation. Among weed management treatments, significantly higher weed dry matter was recorded under un-weeded control plot. However, in the initial two years, significantly lower weed dry matter was recorded under farmers' practice than others, but in the later part, higher density was seen in the entire experiment and significantly lower weed dry matter was registered under pre-emergence application of pendimethalin 1.0 kg/ha had better control of wide spectrum of weeds in chickpea.

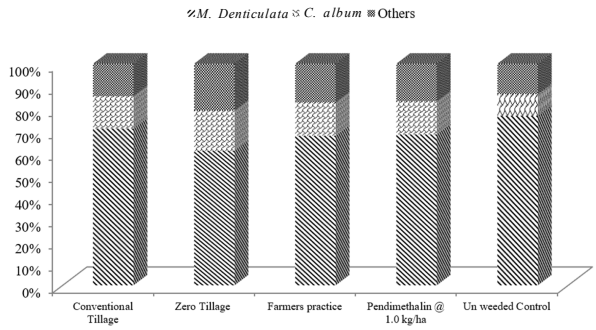

Figure 3. Relative weed density during 1st year of *Rabi* 2010-11 under rice-chickpea cropping system

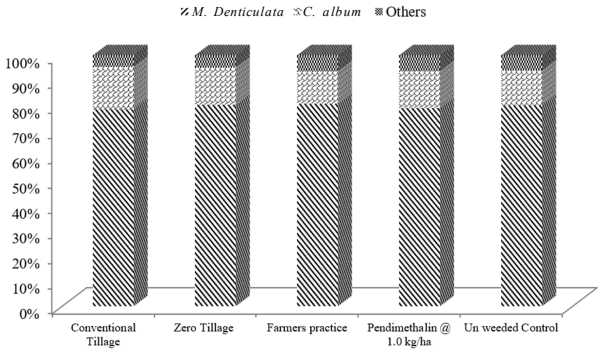

Figure 4. Relative weed density during fifth year of *Rabi* 2014-15 under rice-chickpea cropping system

Weed seed bank

Rice: The annual weed species emerged during *Kharif* were *E. colona, I. rugosum, A. indica* among grasses; *A. triandra, C. bonplandianus, C. argentea* among broad-leaved and *C. iria* among sedges. *E. colona* and *A. triandra* dominated the flora to the tune of 27.9 and 24.4%, respectively, at the start of experiment in 2010 (**Table 3**). The status of weed seed bank up to a soil depth of 15 cm studied at concluding year (**Table 3**) during *Kharif* (sixth year in case of direct-seeded rice) revealed that continuous or rotational application of combination of herbicides

Table 2. Weed dry weight at 60 DAS of chickpea influenced by long term weed management practices under rice-chickpea cropping system

Treatment	Weed dry weight (g/m^2)					
	2010-11	2011-12	2012-13	2013-14	2014-15	Mean
Weed management (Kharif)						
Oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha	2.55 (6.0)	3.98(15.4)	4.02(15.7	7.96(62.8)	4.01(15.6)	4.86(23.1)
Fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha	2.63(6.4)	4.09(16.2)	4.26(17.6)	7.96(62.9)	4.91(23.6)	5.08(25.3)
Pyrazosulfuron 25 g/ha *fb* hand weeding at 35 DAS	2.74(7.0)	4.02(15.6)	4.13(16.5)	7.96(62.8)	4.67(21.3)	5.02(24.7)
Hand weeding twice at 20 and 35 DAS	2.82(7.4)	3.73(13.4)	3.37(10.9)	7.47(55.3)	4.35(18.4)	4.65(21.1)
Unweeded control	2.67(6.6)	4.60(20.7)	4.61(20.7)	8.35(69.1)	4.35(29.9)	5.47(29.4)
LSD (p=0.05)	NS	NS	NS	5.99	0.32	-
Tillage						
Conventional	2.69(6.8)	3.99(15.5)	4.30(18.0)	8.55(72.6)	4.99(24.4)	5.28(27.4)
Zero	2.68(6.7)	4.12(16.5)	4.16(16.8)	7.10(49.9)	4.43(19.1)	4.72(21.8)
LSD (p=0.05)	NS	NS	NS	NS	0.28	-
Weed management (Rabi)						
Farmers practice	2.15(4.1)	3.86(14.4)	3.85(14.4)	8.01(63.7)	4.54(20.1)	4.88(23.3)
Pendimethalin 1.0 kg/ha	2.49(5.7)	3.03(8.7)	3.47(11.5)	6.18(37.7)	4.22(17.3)	4.08(16.2)
Unweeded Control	3.28(10.3)	4.84(22.9)	4.88(23.3)	9.32(86.4)	5.32(27.8)	5.89(34.1)
LSD (p=0.05)	0.65	0.51	0.47	0.95	0.31	-

*Data in parentheses is original and transform by $(\sqrt{x+0.5})$^0.5

or integration of herbicide and one hand weeding or purely two hand weedings did not show remarkable variation in weed seed bank of different annual weed species like *E. colona, I. rugosum* (among grasses), *A. triandra* (among broad-leaved) and *C. iria* (among sedges). However, in unweeded control plot, there was remarkable variation in number of weed seeds of different annual weed species. The dominant weeds species were *Celosia argentea* (37.7%), *E. colona* (19.6 %), *I. rugosum* (14.7%), *C. iria* (9.8 %), whereas, initially dominant species *A. triandra* registered its presence by a reduced tune of 1.6% only. This indicated that intra-weed competition in long term which causes the the appearance or disappearance of particular weed species.

Chickpea: During *Rabi* season, annual weeds like *M. denticulata* and *C. album* were the dominant weed species. *M. denticulata* alone contributed 41.5% of the total share of seed bank, of which 25.7% shared by conventional tillage and 15.8% seed bank was shared by conservation tillage. Share of *C. album* was next in order. Weed seeds of other weeds like *A. arvensis, M. alba, E. colona, C. iria* also emerged in meager number (**Table 4**).

During concluding years' *i.e. Rabi* 2014 -15 from a soil depth of 15 cm revealed that there was no change in weed flora either due to long-term application of pendimetalin as PE, or farmers' practice or no weeding in control plot as well as conventional/zero tillage in chickpea sown after direct-seeded rice (**Table 5**). The dominant annual dicotyledonous weeds observed during *Rabi* were *M. denticulata* and *C. album* along with seeds of some other weed species but in a very meager number and irregular appearance. However, the number of seeds of different weed species varied remarkably due to tillage as well as un-weeded conditions. It is obvious that tillage systems disturb the vertical distribution of

Table 3. Weed seed bank in initial year 2010 and sixth year 2015 *Kharif* at 0-15 cm in long term weed management practices under rice-chickpea cropping system

Treatment	*E. colona*	*A. indica*	*I. rugosum*	*A. triandra*	*C. bonplandianus*	*C. argentea*	*C. rotundus*	Others	Total
Weed seed bank (initial) year 2010									
Oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha	3.2(10)	1.6(2)	1.9(3)	2.9(8)	2.1(4)	1.9(3)	1.9(3)	1.9(3)	6.04(36)
Fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha	2.9(8)	1.2(1)	2.1(4)	3.1(9)	1.9(3)	1.2(1)	1.9(3)	1.9(3)	5.70(32)
Pyrazosulfuron 25 g/ha *fb* hand weeding at 35 DAS	3.1(9)	1.2(1)	1.9(3)	2.7(7)	1.6(2)	1.6(2)	2.1(4)	1.6(2)	5.52(30)
Hand weeding twice at 20 and 35 DAS	3.2(10)	1.2(1)	2.1(4)	2.9(8)	1.9(3)	1.9(3)	1.9(3)	1.6(2)	5.87(34)
Unweeded control	3.2(10)	1.2(1)	2.1(4)	3.1(9)	1.6(2)	1.6(2)	2.1(4)	1.6(2)	6.04(36)
Weed seed bank (at last) year 2015									
Oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha	2.1(4)	-	1.6(2)	1.9(3)	-	-	1.6(2)	1.9(3)	3.8(14)
Fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha	1.9(3)	-	2.6(6)	2.9(8)	-	-	1.9(3)	2.6(6)	5.2(26)
Pyrazosulfuron 25 g/ha *fb* hand weeding at 35 DAS	3.1(9)	-	2.7(7)	1.9(3)	-	-	1.6(2)	2.1(4)	5.1(25)
Hand weeding twice at 20 and 35 DAS	1.9(3)	-	2.4(5)	1.9(3)	-	-	1.2(1)	1.6(2)	3.8(14)
Unweeded control	4.1(16)	-	3.1(9)	1.2(1)	-	4.2(17)	2.6(6)	3.2(10)	7.7(59)

Table 4. Weed seed bank (0-15 cm) at harvest of chickpea in 2010-11 under long term weed management practice under rice-chickpea cropping system

Treatment main plot (*Kharif*)	Sub-plot (*Rabi*)	*Medicago denticulata*		*Chenopodium album*		*Cyperus iria*		Others	
		CT	ZT	CT	ZT	CT	ZT	CT	ZT
Oxadiargyl 80 g/ha *fb*	Framer's practice	3.94(15)	2.74(7)	1.58(2)	-	-	1.58(2)	-	1.22(1)
bispyribac-Na 25 g/ha	Pendimethalin 1.0 kg/ha	3.54(12)	2.35(5)	1.22(1)	-	1.58(2)	-	-	1.22(1)
	weed check	5.79(33)	3.08(9)	1.87(3)	1.58(2)	1.58(2)	1.58(2)	1.58(2)	1.22(1)
Fenoxaprop-p-ethyl 60 g/ha +	Framer's practice	2.55(6)	2.35(5)	-	-	-	-	1.87(3)	1.87(3)
chlorimuron-ethyl +	Pendimethalin 1.0 kg/ha	2.35(5)	1.87(3)	1.58(2)	1.58(2)	-	-	-	-
metsulfuron-methyl 4 g/ha	Weed check	5.52(30)	2.92(8)	2.35(5)	1.58(2)	1.87(3)	-	-	2.12(4)
Pyrazosulfuron 25 g/ha *fb*	Framer's practice	2.55(6)	2.55(6)	1.58(2)	1.22(1)	1.58(2)	-	-	-
hand weeding at 35 DAS	Pendimethalin 1.0 kg/ha	2.12(4)	2.35(5)	1.22(1)	-	1.58(2)	1.87(3)	-	-
	Weed check	3.94(15)	2.92(8)	1.87(3)	-	2.12(4)	1.87(3)	1.22(1)	-
Hand weeding twice at 20	Framer's practice	3.94(15)	2.55(6)	1.58(2)	1.58(2)	-	-	-	-
and 35 DAS	Pendimethalin 1.0 kg/ha	3.39(11)	1.87(3)	-	-	-	1.22(1)	1.22(1)	-
	Weed check	5.34(28)	12.0	1.58(2)	1.22(1)	1.58(2)	1.22(1)	1.22(1)	-
Unweeded control	Framer's practice	3.67(13)	1.87(3)	1.58(2)	1.87(3)	1.58(2)	-	1.58(2)	1.58(2)
	Pendimethalin 1.0 kg/ha	3.24(10)	1.87(3)	-	-	-	-	1.58(2)	1.22(1)
	Weed check	5.79(33)	2.74(7)	1.58(2)	1.87(3)	2.12(4)	-	1.87(3)	1.58(2)
Total		15.38(236)	12.0(144)	5.34(28)	4.06(16)	4.85(23)	3.54(12)	3.67(13)	3.94(15)

CT- Conventional tillage, ZT - Zero tillage

Table 5. Weed seed bank (0-15 cm) at harvest of chickpea in 2014-15 under long term weed management practice under rice-chickpea cropping system

Treatment Main plot (*Kharif*)	Sub-plot (*Rabi*)	*M. denticulata*		*C. album*		Others	
		CT	ZT	CT	ZT	CT	ZT
Oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha	Framer's practice	2.92(8)	2.35(5)	1.22(1)	1.22(1)	1.22(1)	1.22(1)
	Pendimethalin 1.0 kg/ha	2.35(5)	1.58(2)	1.22(1)	-	1.22(1)	-
	Weed check	6.04(36)	5.43(29)	1.58(2)	1.58(2)	1.87(3)	1.22(1)
Fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron- methyl 4 g/ha	Framer's practice	3.08(9)	2.35(5)	1.22(1)	-	1.58(2)	1.22(1)
	Pendimethalin 1.0 kg/ha	2.55(6)	1.58(2)	1.22(1)	1.22(1)	1.22(1)	-
	Weed check	6.04(36)	5.43(30)	1.87(3)	1.58(2)	1.58(2)	1.22(1)
Pyrazosulfuron 25 g/ha *fb* hand weeding at 35 DAS	Framer's practice	3.24(10)	2.74(7)	1.22(1)	1.22(1)	1.58(2)	-
	Pendimethalin 1.0 kg/ha	2.35(5)	1.87(3)	1.22(1)	1.22(1)	1.22(1)	-
	Weed check	5.52(30)	5.52(30)	2.12(4)	1.58(2)	1.58(2)	1.22(1)
Hand weeding twice at 20 and 35 DAS	Framer's practice	3.39(11)	3.08(9)	1.58(2)	-	1.22(1)	1.22(1)
	Pendimethalin 1.0 kg/ha	2.55(6)	2.12(4)	1.58(2)	-	1.22(1)	1.22(1)
	Weed check	5.96(35)	5.15(26)	2.12(4)	1.87(3)	1.87(3)	1.87(3)
Unweeded control	Framer's practice	4.06(16)	3.39(11)	1.22(1)	1.87(3)	1.87(3)	1.58(2)
	Pendimethalin 1.0 kg/ha	2.92(8)	2.35(5)	1.87(3)	1.22(1)	1.58(2)	1.58(2)
	Weed check	7.97(63)	7.04(49)	2.55(6)	1.87(3)	2.12(4)	1.58(2)
Total		17.13(293)	14.75(217)	5.96(35)	4.53(20)	5.43(29)	4.06(16)

CT- Conventional tillage, ZT - Zero tillage

weed seeds in the soil in different ways. Size and composition of seed bank as well as above ground weed flora reflect past and present weed, crop and soil management. Similarly in the present investigation, the number of weed seeds was more under conventional tillage than zero tillage system, due to vertical soil disturbance. Tillage practices also alter distribution of weed seeds vertically within the soil profile (Buhler, 1995). The number of weed seed emergence of weed species, *M. denticulata* and *C. album* was 26 and 42% higher under conventional tillage than zero tillage. The studies of Buhler (1995) and Buhler *et al*. (1996) also reported changes in weeds due to tillage practices The number of weed emergence was considerably high under un-weeded plots than plots where pendimethalin as PE, or farmers' practice was adopted continuously for weed management irrespective to tillage system, which suggests that weed management practices are quite effective in controlling weeds in chickpea.

Weed shift

Rice: At the beginning of the study in 2010-11, the major weed flora observed in the beginning was *E.colona* and *I. rugosum* (among grasses), *A. triandra, C. axillaris, C. benghalensis, C. bonplandianus* and *C. argentea* (among broad-leaved) and *C. iria* (as sedge). Continuous and rotational use of cultural, chemical as well as integrated weed management practices in rice for six years lowered the density of all the weed species. There was no major or noticeable weed shift or change in weed flora due to continuous use of combination of pre- and post-emergence application of herbicide oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac-Na 25 g/ha 25 DAS and cultural practice of hand weeding twice at 20 and 35 DAS. Similarly, there was no remarkable weed shift due to rotational application of combination of fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha 20 DAS and integration of PE pyrazosulfuron 25 g/ha at 3 DAS *fb* hand weeding at 35 DAS, with each other in every two years. But in untreated control plot, densities of *A. triandra* and *E. colona* progressed with each year might be due to aggressive nature of both of these weeds as well as ability to tolerate continuous submergence. However, *C. benghalensis* and *C. bonplandianus* got disappeared mainly due to intra-weed competition, whereas density of *C. argentea* remained at lower level up to fifth year. However, in sixth year of experimentation, *C. argentea* abruptly emerged as one of the most dominant weed and did not allow *A.triandra* to grow at all. Similarly, it suppressed the density of *E. colona* considerably. This might be due to favourable environments for *C. argentea* in *Kharif* 2015 in terms of lesser rains, longer dry spells, nil submergence in the entire season as well as sufficiency of seed bank. Thus, *A.triandra* got disappeared due to aggressive appearance of *Celosia argentea* in the concluding year. The comparative biology of *A. triandra* and *C. argentea* is given in **Table 6** for better understanding of reasons behind appearance or disappearance of any particular weed species. Tillage practices also alter distribution of weed seeds vertically within the soil profile (Buhler, 1995). Application of herbicide

Table 6. Comparative biology of *Alternanthera triandra* and *Celosia argentea, Kharif* 2015

Characters \ Weed species	*A. triandra*	*C. argentea*
Height, cms	89	165
Branches/plant	11	4
Fruits/plant	527	15
Total no. of seeds/plant	1564	8430
Weight of 1000 seeds, g	0.33	0.43

was found effective to reduce weed seed numbers. It is obvious from the **Table 6** that height and number of seeds per plant in *C. argentea* were 46 and 81.4% higher over *A. triandra,* respectively, which proved the aggression of *C. argentea* against *A. triandra* in the favourable environments like *Kharif* 2015.

Chickpea: No remarkable effect of weed management and tillage practices on weed shift was found. *M. denticulata* was observed to the most dominant weed during winter followed by *C. album*. The manual and chemical weed management in chickpea did not make any change in the weed flora. However, there was manifold increase in density of both the above weeds in last two years. Other weeds in lower densities were *A. arvensis, M. alba, E. colona* and *C. iria***.**

Crop yield

Rice: In general, hand weeding twice at 20 and 35 DAS proved to be significantly superior over control but was at par with most of the other treatments. However, herbicide combinations or integration with one hand weeding applied either in continuation for six years or rotation between fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron- methyl 4 g/ ha and pyrazosulfuron 25 g/ha *fb* one hand weeding at 35 DAS every two years, the grain yield was significantly higher under the continuous application of oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac-Na 25 g/ ha 25 DAS but this was statistically at par with other herbicide combinations (**Table 7**). The effectiveness of bispyribac-Na as a PoE herbicide for DSR is also reported by Mahajan *et al.* (2009), Khaliq *et al.* (2011) and Choudhary and Dixit (2018). The initial broad- spectrum weed control by oxadiargyl and later on by bispyribac-Na provided a weed free environment continuously for a period of nearly 60-70 days and even more resulted in rice yield similar to that of two hand weeding. The yield of rice was at par to two hand weedings and other herbicide combination treatment applied in rotation of two years. This indicates that the continuous or rotational use of same herbicide combinations did not affect the rice yields adversely as compared to manual weeding. Higher seed yield under above treatments was due to the proper utilization of moisture, nutrients light and space by the rice crop in the absence of weed competition**.**

Chickpea: The effect of previously applied weed management treatments to direct-seeded rice during *Kharif* season had no significant effect on seed yield of chickpea in *Rabi* (**Table 8**). However, marginally higher chickpea yield obtained under the treatment of oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac- Na 25 g/ha at 25 DAS as oxadiargyl has the potential to check some of the *Rabi* season weeds especially *M. denticulata* and *C. album* upto some extent. Therefore, weed population was low in this treatment. However, tillage had no significant impact on chickpea seed yield and there was no significant yield difference between conventional and zero tillage. Seed yield was marginally higher under conventional than zero tillage. More mobilization of photosynthates to grain under conventional tillage as a result of higher harvest index might have also led to slight increase of yield over zero tillage (Singh *et al.* 2011). Among different weed management treatments, significantly higher seed yield was obtained under pendimethalin 1.0 kg/ha than unweeded check and this was closely followed by farmers' practice. On an average of five years, increase of 11.85% seed yield under pendimethalin 1.0 kg/ha was estimated over farmers' practice. Higher seed yield under above treatments might be due to the proper utilization of moisture, nutrients light and space by the chickpea crop in the absence of weed competition. Similar findings have been reported by Singh and Mukherjee (2009).

Table 7. Grain yield and B:C ratio of rice as influenced by long-term weed management practices under rice-chickpea cropping system

Treatment	Grain yield(t/ha)							B:C ratio					
	2010	2011	2012	2013	2014	2015	Mean	2011	2012	2013	2014	2015	Mean
Oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha	3.53	4.21	4.64	4.82	4.53	5.08	4.47	2.21	2.54	2.52	2.37	2.65	2.46
Fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha	3.90	4.11	4.19	4.07	4.23	4.83	4.22	2.33	2.46	2.28	2.37	2.65	2.42
Pyrazosulfuron 25 g/ha *fb* hand weeding at 35 DAS	4.22	3.87	4.22	4.45	4.25	4.83	4.31	1.97	2.23	2.24	2.14	2.37	2.19
Hand weeding twice at 20 and 35 DAS	4.15	4.56	4.34	5.02	4.59	4.92	4.60	2.06	1.97	2.28	2.09	2.08	2.10
Unweeded control	0.52	0.41	1.44	0.46	0.10	0.38	0.55	-0.24	-0.90	-0.29	-0.06	-0.35	-0.37
LSD (p=0.05)	0.42	0.60	0.40	0.22	0.37	1.18	-						

Table 8. Seed yield and B:C ratio of chickpea as influenced by long-term weed management practices under rice-chickpea cropping system

Treatment	Seed yield (t/ha)						B:C ratio					
	2010-11	2011-12	2012-13	2013-14	2014-15	Mean	2010-11	2011-12	2012-13	2013-14	2014-15	Mean
Weed management (Kharif)												
Oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha	1.09	1.22	1.24	0.84	0.99	1.08	1.60	2.33	2.03	1.38	1.78	1.82
Fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron methyl 4 g/ha	1.16	1.15	1.16	0.83	0.95	1.05	1.70	2.20	1.90	1.36	1.72	1.78
Pyrazosulfuron 25 g/ha *fb* hand weeding at 35 DAS	1.13	1.14	1.12	0.83	0.96	1.04	1.66	2.18	1.83	1.36	1.73	1.75
Hand weeding twice at 20 and 35 DAS	1.19	1.20	1.18	0.87	0.98	1.08	1.75	2.30	1.93	1.43	1.76	1.83
Unweeded control	1.08	1.02	1.04	0.76	0.89	0.96	1.60	1.95	1.70	1.25	1.60	1.62
LSD (p=0.05)	0.08	NS	NS	NS	NS	-						
Tillage												
Conventional	1.17	1.20	1.22	0.84	0.94	1.07	1.72	2.30	2.00	1.38	1.69	1.82
Zero	1.08	1.10	1.11	0.81	0.97	1.01	2.13	2.80	2.27	1.65	2.16	2.20
LSD (p=0.05)	NS	NS	NS	NS	0.02	-						
Weed management (Rabi)												
Farmers practice	1.28	1.22	1.39	0.91	1.17	1.19	1.60	1.97	1.88	1.24	1.77	1.69
Pendimethalin 1.0 kg/ha	1.38	1.47	1.48	1.14	1.30	1.35	1.84	2.55	2.31	1.78	2.24	2.14
Unweeded control	0.70	0.61	0.62	0.34	0.38	0.53	1.03	1.14	1.01	-0.65	-0.63	0.38
LSD (p=0.05)	0.08	0.13	0.12	0.11	0.08	-						

Table 9. Rice equivalent yield of chickpea as influenced by long term-weed management practices under rice-chickpea cropping system

Treatment	Rice equivalent yield of chickpea (t/ha)					
	2010-11	2011-12	2012-13	2013-14	2014-15	Mean
Weed management (Kharif)						
Oxadiargyl 80 g/ha *fb* bispyribac-Na 25 g/ha	2.12	3.02	2.86	1.85	2.15	2.40
Fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron methyl 4 g/ha	2.25	2.85	2.68	1.82	2.06	2.33
Pyrazosulfuron 25 g/ha *fb* hand weeding at 35 DAS	2.20	2.82	2.58	1.82	2.09	2.30
Hand weeding twice at 20 and 35 DAS	2.31	2.97	2.72	1.91	2.13	2.41
Unweeded control	2.10	2.53	2.40	1.67	1.93	2.13
Tillage						
Conventional	2.27	2.97	2.81	1.85	2.04	2.39
Zero	2.11	2.72	2.56	1.78	2.11	2.26
Weed management (Rabi)						
Farmers practice	2.49	3.02	3.21	2.00	2.54	2.65
Pendimethalin 1.0 kg/ha	2.68	3.64	3.41	2.51	2.83	3.01
Unweeded control	1.36	1.49	1.43	0.75	0.83	0.12

Rice yield equivalence

The highest rice yield equivalence was recorded under the continuous application of two hand weeding at 20 and 35 DAS in direct-seeded rice during *Kharif* which was closely followed by the treatments of oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS. This was due to higher chickpea yields in these plots. The average of five years of rice yield equivalence was marginally high under conventional tillage than zero tillage dut to higher chickpea yields. The pre-emergence application of pendimethalin 1.0 kg/ha produced higher rice yield equivalence over farmers' practice and unweeded control, respectively due to better weed control by pendimethalin in chickpea during *Rabi* season (**Table 9**).

Economics

Rice: Treatment having oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS and fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha were more profitable than hand weeding and other treatments due to higher yield with low cost of cultivation. Maximum B: C ratio was obtained for above treatments contuously for six years, which proved the efficacy and economics of the above herbicide combinations for weed management in direct-seeded rice (**Table 7**). Use of herbicides is an efficient and cost-effective method for weed control in DSR while manual weeding could be adopted where cheap labour is available (Mahajan *et al*. 2009).

Chickpea: Economics in terms of B: C was higher under the treatments of hand weeding twice at 20 and 35 DAS and oxadiargyl 80 g/ha at 3 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS applied to direct seeded rice during *Kharif* seasons, respectively (**Table 8**). However, B: C ratio calculted for other treatments was also very close to each other. The

zero tillage proved to be more economical than conventioanl tillage with an obvious reason of low cost involved in tillage operations in zero tillage system. Among the weed management practices, the highest B: C ratio was obtained under the treatment of pre-emergence application of pendimethalin 1.0 kg/ha and was followed by farmers' practice. The average B: C ratio was higher by 21% over the B: C ratio of farmers practice.

Conclusion

It was concluded that the continuous or rotational use of herbicides, manual weeding or their integration as well as cropping system has no effect on weed shift and crop performance. However, there exists a direct relationship between weed shift and submergence especially during *Kharif*. Different herbicides although have depressive impact on weeds in long run but under natural condition as in unweeded control there is a possibility of replacing one or more species by another dominant one in intra-weed competition.

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