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Carryover effect and plant injury from oxyfluorfen herbicide applied in transplanted rice

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Abstract
A field investigation were carried out at the Agricultural Research Station, Bhavanisagar of Tamil Nadu Agricultural University, Coimbatore, India during *rabi* season of 2010 and 2011 to evaluate the new formulation of oxyfluorfen (23.5% EC) on weed control in transplanted rice and their residual effect on succeeding crops. Oxyfluorfen is a diphenyl-ether herbicide as a pre or post-emergence herbicide used for control of annual and perennial broad-leaved weeds in a variety of field crops. Many of the field experiments revealed that the bio-efficacy of oxyfluorfen herbicide; however, no information is available on the field persistence of oxyfluorfen, phytotoxicity symptoms in plant and carryover effect in succeeding crops under Indian tropical conditions. Therefore, the field experiments were undertaken to investigate the plant injury and persistence of oxyfluorfen in soil and rice crop in red sandy clay loam soil. Bioassay remains a major tool for qualitative and quantitative determination of herbicides residue in soil. Detection of the oxyfluorfen herbicide in soil can be done by bioassay which measures the biological response of a living plant to that particular herbicide. Based on two years field experimentation, the results clearly indicated, Pre-emergence (PE) application of oxyfluorfen (23.5% EC) at 250 g a.i. ha^{-1} can keep the weed density and dry weight below the economic threshold level and increased the rice grain yield. Plant injury symptoms of oxyfluorfen was complete recovery of affected rice plants could be observed only after 30 days after herbicide application (DAHA) and the phytotoxicity was not evident thereafter in rice crop. Carryover effect results showed that the oxyfluorfen herbicide to be safe on the succeeding crops and this might be due to detoxification of herbicides in soil and do not adversely affect the growth attributes of the succeeding crops in terms of germination percentage and dry matter production of the succeeding sunflower and blackgram.

Keywords: Rice, oxyfluorfen, grain yield, plant injury, carryover effect, succeeding crop safet

Introduction
To meet the global rice demand, it is estimated that about 114 million tonnes of additional milled rice need to be produced by 2035 which is equivalent to an overall increase of 26% in the next 25 years (Kumar and Ladha, 2011) [5]. There is a need to sustain the present food self-sufficiency and to meet future food requirements. India has to increase its rice productivity by 3% per annum but the possibility of expanding the area under rice in the near future is limited. Weeds constitute one of the biggest problems in agriculture that also reduce the yield and also utilize essential nutrients. Most of the improved crop management practices in rice cultivation failed due to poor and improper practices for containing weeds. Weeds compete with rice for moisture, nutrients, light, temperature and space. Pillai and Rao (1974) [9] estimated the extent of yield reduction due to weeds to be over 50% in direct seeded upland rice, 30-35% in direct seeded rice under puddled condition and around 15-20% in transplanted rice. Uncontrolled weeds have caused yield reduction of 28-45% in transplanted rice (Singh and Singh, 2007; Manhas *et al*., 2012) [14, 6]. Furthermore, any delay in weeding will lead to increased weed biomass which has a negative correlation with yield. Hand weeding is the traditional weed control measure in rice cultivation practices. However, due to high labour cost, non-availability of labour and time taken for manual removal, farmers are forced to decide for cheaper alternative of chemical weed control. Most of the presently available herbicides provide only a narrow spectrum weed control. Many of them have activity only on annual species, while a few are only effective against perennial weeds. Plenty of the new formulation of herbicides is recommended for each crop and in a cropping system, sequential application of herbicides for every crop leads to residue accumulation in soil and crop, thus causing adverse effect of succeeding crops.

Knowledge on the plant injury and residual effect of herbicides in soil is essential to use them safely, effectively and for non-hazardous chemical weed control schedules. Bioassay remains a major tool for qualitative and quantitative determination of herbicides residue in soil. Detection of the presence of an herbicide can be done by bioassay which measures the biological response of a living plant to the herbicide was given by Jayakumar (1987) [4]. Considering above facts, an attempt has been made to study the plant injury due to herbicides applied in *rabi* rice and carryover effect on succeeding *rabi* sunflower and blackgram crops.

2. Materials and Methods

Field experiments were laid out during *rabi* seasons of 2010 and 2011 in North Block Farm of Agricultural Research Station (ARS) Bhavanisagar, located at Western Zone of Tamil Nadu, India. The geographical location of the experimental site is 11º29"N latitude and 77º08"E longitude with an altitude of 256 m above MSL and the farm receives the normal total annual rainfall of 696 mm in 44 rainy days. The soil was red sandy loam in texture with low in available nitrogen (246 kg ha^{-1}), medium in available phosphorus (20 kg ha^{-1}) and high in available potassium (262 kg ha^{-1}) with pH of 6.7. The experiment was laid out in randomized block design with nine treatments and replicated thrice. Treatments consisted of pre-emergence application of already registered oxyfluorfen (goal) at 200 g ha^{-1}, new formulation of oxyfluorfen (23.5% EC) at 150, 200, 250, 300 and 400 g ha^{-1}, butachlor 50% EC at 0.75 kg ha^{-1} + HW on 45 DAT, hand weeding twice on 25 and 45 DAT and unweeded control. The herbicides as per the treatment schedule were applied as pre-emergence at third day after sowing followed by a hand weeding on 45 DAT. Hand operated knapsack sprayer fitted with a flat fan type nozzle (WFN 40) was used for spraying the herbicides adopting a spray volume of 500 litres ha^{-1}. After transplanting, immediately a light irrigation was given to the crop for uniform germination. Weed species present in the experimental plot were identified from unweeded control plot and grouped as grasses, sedges and broad leaved weeds. Crops response is also rated in the scale 0-10 to record herbicide toxicity on plant stand and growth. Visual assessment of crop response is based on such effects as plant kill, crop growth and also injury to plants *etc*., by a particular herbicide treatment. This was done by using the scale of 0-10, where 0 represents no effect (crop no injury and normal) and 10 correspond to complete effect (complete destruction of crop). After harvesting of the rice crop to know the residual effect of oxyfluorfen (23.5% EC) herbicide, without disturbing the layout of each plot was manually prepared for sowing of succeeding crops. Seven rows of each succeeding sunflower (Co-4) and blackgram (Vamban-4) were sown in each plot in *rabi* season. The germination percentage, plant height, dry weight of plants and yield of *viz*., sunflower and blackgram crops were recorded for the test crops to evaluate bioassay of herbicide residues. During the course of experiment, the data were recorded on predominant weed flora, weed density, weed dry weight and grain yield of rice. The data pertaining to weeds was transformed to square root scale of $\sqrt{(X+2)}$ and analysed as suggested by Snedecor and Cochran (1967) [15]. Whenever significant difference existed, critical difference was constructed at five per cent probability level.

3. Results and Discussion

3.1. Weed flora of the experimental field

The observation made on the common weeds of the experimental field. The experimental field consisted of grasses, sedges and broad leaved weeds (BLW) from unweeded check plot at flowering stage of the crop. The major grass weed was *Echinochloa colona* (*L*.), *Echinochloa crus galli* (L.), *Panicum repens* (L.) and the major sedge weed was *Cyperus rotundus* (L.). Among the broad leaved weeds *Eclipta alba* (L.), *Ammannia baccifera* (L.) and *Ludwigia parviflora* (L.) were the dominant species.

3.2. Weed dry weight and weed control efficiency

Considerable reduction in weed dry weight was recorded with the application of oxyfluorfen at 300 and 400 g ha^{-1} at all the stages of observation and it was followed by PE application of oxyfluorfen at 250 g ha^{-1} and butachlor at 0.75 kg ha^{-1} + HW on 45 DAT**.** This herbicide kills weed seedlings through contact action and membrane disruption, since light is required for herbicidal activity, diphenyl ether phytotoxicity is related to the process of photosynthesis and inhibition of both electron transport and ATP synthesis (Janaki *et al*, 2013) [13]. Minimum dry weed biomass was recorded in plots sprayed with oxyfluorfen at 200 g ha^{-1} while, maximum dry weed biomass was noticed in weedy check, where weeds were not controlled. Throughout the experimental period, weed control efficiency was higher with PE application of oxyfluorfen at 400 g ha^{-1} followed by oxyfluorfen spray at 300 and 250 g ha^{-1} owing to the fact that it registered lesser weed density and weed dry weight (Table 1).

3.3. Effect on transplanted rice

During both the years of study, among the weed control treatments, PE application of oxyfluorfen at 250 g ha^{-1} recorded higher grain yield of 6645 and 7102 kg ha^{-1} due to better control of weeds at critical stages thus providing favourable environment for better growth and development leading to enhanced yield and yield attributes in transplanted rice (Table 2). This treatment was comparable with oxyfluorfen at 200 g ha^{-1} with a grain yield of 6421 and 6854 kg ha^{-1} during *rabi* 2010 and 2011, respectively. Azad *et al*., (1990) [2] reported that in transplanted rice, oxyfluorfen granules applied at 0.2 kg ha^{-1} controlled all types of weeds from germination stage, gave the lower dry weight of weeds, higher number of panicles per square meter and the higher grain yield. Rice productivity is mainly decided by the weed control efficiency of weed management methods as earlier observed by Abraham *et al*. (2010) [1]. Hand weeding twice on 25 and 45 DAT and application of butachlor at 0.75 kg ha^{-1} + HW on 45 DAT was the next best treatment compared to application of oxyfluorfen at 200 and 250 g ha^{-1} during both the years. PE application of oxyfluorfen at lower doses of 150 g ha^{-1} and oxyfluorfen (goal) at 200 g ha^{-1} registered lower grain yield when compared to other herbicidal treatments due to poor control of problematic weeds like *Echinochloa colona*, *Echinochloa crus galli* and *Panicum repens* which showed higher weed density, dry weight and lower weed control efficiency. Under such conditions the crop may not be able to put forth optimum growth due to lack of resources resulting in reduced leaf area, dry matter production and to end with recorded lower grain yield of transplanted rice.

3.4. Phytotoxic symptom scoring and rating on crop

Phytotoxicity symptom of PE application of oxyfluorfen was observed at higher doses of 300 and 400 g ha^{-1}. Visual scoring

for phytotoxic symptoms (crop discolouration/chlorosis/ stunting / wilting/ deformation / vein clearing) in rice was done on 7, 15 and 30 days after pre-emergence oxyfluorfen application (Table 3 & 4). Moorthy and Menna (1988) [7] reported that oxyfluorfen at 0.1 kg ha^{-1} caused phytotoxicity to rice. Sathya Priya (2013) [12] also found that onion crop recovered from the phytotoxicity symptom of oxyfluorfen within 15 days of application in higher doses of 300 and 400 g ha^{-1}. Pillai *et al*. (1983) [10] also reported slight toxicity to rice when oxyfluorfen was applied at 0.2 kg ha^{-1} six days after transplanting. Singh *et al*. (1990) [13] reported that oxyfluorfen at above 0.5 kg ha^{-1} resulted in slight phytotoxicity to the crop during the initial growth period but afterwards the crop recovered. Even though some phytotoxicity effect was noticed in rice seedlings immediately after application of oxyfluorfen, the seedlings recovered and resulted in higher grain yields.

3.5. Carryover effect of oxyfluorfen on the succeeding crops

Persistence of herbicide in the soil is an important consideration for recommending it to the farmers as it is related to length of the time that the herbicide remains active. It also causes residual phytotoxocity which may injure the succeeding crops. In the present study, the possible residual toxicity of the herbicides used was studied by sowing the commonly grown garden land crops *viz*., sunflower (Co-4) and black gram (Vamban-4). The effect of herbicides was worked out by studying the growth characters such as germination at 10 DAS and plant height, DMP at 7, 15 and 30 DAS, respectively and yield attributes. Germination percentage of the sunflower and black gram indicated that there was no significant difference among treatments. It is evident that there is no residual toxicity due to the application of herbicide oxyfluorfen and butachlor at all the doses of the succeeding crops. In black gram number of pods plant^{-1}, seeds pod^{-1} and 100 seed weight at showed no distinct variation in the test crops due to different dose of herbicide oxyfluorfen. So the various dose of oxyfluorfen tested in rice had no adverse residual effect on the growth of the succeeding crop. In sunflower head diameter and seed yield showed no distinct variation in succeeding crop due to different dose of herbicide oxyfluorfen. The dry matter production of sunflower and black gram did not show any variation among the weed control treatments (Table 5). This result is in line with the results of Sathya Priya (2012) [11] who reported that, the PE application of oxyfluorfen in onion at higher doses of 300 and 400 g ha^{-1} did not leave any residue in the soil and there was no toxic effect beyond 30 DAHA. It might be shown that new formulation of oxyfluorfen with different doses could be very effective against most of the broad leaved and grassy weeds in onion. So, there was no residual toxicity due to herbicide oxyfluorfen on the succeeding crop. Therefore, the various dose of oxyfluorfen tested in rice had no adverse residual effect on the growth of the succeeding crop.

4. Conclusion

In light of the results obtained from this investigation, it is indicated that application of oxyfluorfen (23.5% EC) at 250 g ha^{-1} as PE herbicide can keep the weed density and dry weight below the economic threshold level and increase the grain yield in transplanted rice. Even though some phytotoxicity effect was noticed in rice seedling immediately after application of oxyfluorfen, the seedlings recovered within days and resulted in higher grain yield. Bioassay study results showed that the new formulation of oxyfluorfen at 150, 200, 250, 300 and 400 g ha^{-1} and oxyfluorfen (goal) at 200 g ha^{-1} applied in transplanted rice was found to be safe on the succeeding crops and this might be due to detoxification of herbicides in soil and do not adversely affect the growth and yield of the succeeding crops in terms of plant height, dry matter production and grain yield of the succeeding sunflower and pearl millet crops.

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Table 1: Total weed dry weight and weed control efficiency as influenced by different weed management practices in transplanted rice

Treatments	*Rabi*, 2010				*Rabi*, 2011			
	Total weed dry weight (kg ha^{-1})		WCE (%)		Total weed dry weight (kg ha^{-1})		WCE (%)	
	15 DAHS	30 DAHS	15 DAHS	30 DAHS	15 DAHS	30 DAHS	15 DAHS	30 DAHS
T_1 - PE oxyfluorfen (Goal) at 200 g a.i ha^{-1}	3.66 (9.43)	6.89 (38.52)	82.63	76.75	2.86 (5.0)	7.04 (40.37)	91.76	77.05
T_2 - PE oxyfluorfen at 150 g a.i ha^{-1}	3.99 (11.58)	8.04 (53.20)	78.68	67.87	4.37 (14.32)	8.41 (58.46)	76.36	66.77
T_3 - PE oxyfluorfen at 200 g a.i ha^{-1}	3.66 (9.46)	8.01 (52.80)	82.55	68.12	3.70 (9.7)	7.83 (50.33)	84.07	71.32
T_4 - PE oxyfluorfen at 250 g a.i ha^{-1}	3.01 (5.73)	7.25 (42.91)	89.48	74.09	3.28 (7.2)	6.72 (36.57)	88.18	79.285
T_5 - PE oxyfluorfen at 300 g a.i ha^{-1}	2.88 (5.07)	6.84 (37.97)	90.63	77.11	2.84 (4.9)	6.35 (32.57)	91.99	81.53
T_6 - PE oxyfluorfen at 400 g a.i ha^{-1}	2.59 (3.74)	6.35 (32.43)	93.10	80.43	2.63 (3.9)	5.97 (28.55)	93.62	83.87
T_7 - Butachlor at 0.75 kg ha^{-1} + HW on 45 DAT	3.40 (7.86)	7.46 (45.52)	85.82	72.52	3.78 (10.2)	7.77 (49.53)	83.15	71.73
T_8 - HW twice on 25 and 45 DAT	7.98 (52.43)	6.02 (11.85)	48.66	92.87	8.68 (62.4)	3.58 (8.96)	42.44	94.98
T_9 - Unweeded control	8.11 (54.18)	14.01 (165.60)	-	-	8.56 (60.5)	14.41 (175.24)	-	-
SEd	0.15	0.21	-	-	0.16	0.22	-	-
CD (P=0.05)	0.31	0.45	-	-	0.34	0.47	-	-

Figures in parenthesis are original values; PE - Pre emergence; HW - Hand weeding

Table 2: Effect of weed management methods on grain and straw yield of transplanted rice

Treatments	*Rabi*, 2010			*Rabi*, 2011		
	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1 - PE oxyfluorfen (Goal) at 200 g a.i ha^{-1}	18.7	4836	6578	18.2	5552	7336
T_2 - PE oxyfluorfen at 150 g a.i ha^{-1}	18.8	4341	6158	18.2	5967	6867
T_3 - PE oxyfluorfen at 200 g a.i ha^{-1}	19.2	5495	6854	19.1	6421	7148
T_4 - PE oxyfluorfen at 250 g a.i ha^{-1}	19.4	5709	7102	19.3	6645	7327
T_5 - PE oxyfluorfen at 300 g a.i ha^{-1}	19.1	5007	6349	19.0	5435	6707
T_6 - PE oxyfluorfen at 400 g a.i ha^{-1}	18.9	4477	5850	18.9	5276	4892
T_7 - Butachlor at 0.75 kg ha^{-1} + HW on 45 DAT	19.0	4737	6019	19.0	5744	6591
T_8 - HW twice on 25 and 45 DAT	19.1	4944	6368	19.4	5813	6984
T_9 - Unweeded control	18.5	3382	4780	18.4	4356	4736
SEd	0.04	220	407	0.05	206	386
CD (P=0.05)	NS	463	855	NS	433	787

Table 3: Visual scoring for phytotoxic symptoms in transplanted rice during both the years

Treatments	7 DAHA	15 DAHA	30 DAHA	45 DAHA
T_1 - Oxyfluorfen (goal) at 200g ha^{-1}	0	0	0	0
T_2 - Oxyfluorfen at 150g ha^{-1}	0	0	0	0
T_3 - Oxyfluorfen at 200g ha^{-1}	0	0	0	0
T_4 - Oxyfluorfen at 250g ha^{-1}	2	0	0	0
T_5 - Oxyfluorfen at 300g ha^{-1}	3	2	0	0
T_6 - Oxyfluorfen at 400g ha^{-1}	4	4	3	0

DAHA - Days After Herbicide Application

Table 4: Phytotoxic symptom scoring and rating on weeds and crop

Weed control rating	Crop injury symptom	Rating	Effect
No control	No injury, Normal	0	None
Very poor control	Slight stunting, injury or discoloration	1	Slight
Poor control	Some stand loss, stunting / discoloration	2	Slight
Poor to deficient control	Injury more pronounced but not persistent	3	Slight
Deficient control	Moderate injury, recovery possible	4	Moderate

Table 5: Residual effect of herbicides on yield parameters and yield of succeeding crops (Mean of two years)

Treatments to proceeding rice	Sunflower		Blackgram		
	Plant height at 15 DAS	Seed yield (kg ha^{-1})	No. of branches plant^{-1}	No. of pods plant^{-1}	Seed yield (kg ha^{-1})
T_1 - PE oxyfluorfen (Goal) at 200 g a.i ha^{-1}	25.4	948	10.5	36.5	807
T_2 - PE oxyfluorfen at 150 g a.i ha^{-1}	25.2	868	11.4	34.7	824
T_3 - PE oxyfluorfen at 200 g a.i ha^{-1}	25.8	952	13.4	41.2	834
T_4 - PE oxyfluorfen at 250 g a.i ha^{-1}	25.2	974	13.2	43.5	828
T_5 - PE oxyfluorfen at 300 g a.i ha^{-1}	24.9	958	12.8	40.6	842
T_6 - PE oxyfluorfen at 400 g a.i ha^{-1}	25.7	892	13.6	42.4	837
T_7 - Butachlor at 0.75 kg ha^{-1} + HW on 45 DAT	24.9	932	12.8	43.5	828
T_8 - HW twice on 25 and 45 DAT	25.7	890	12.5	42.4	839
T_9 - Unweeded control	25.6	889	13.7	41.6	842
SEd	2.8	62	3.7	4.1	65
CD (P=0.05)	NS	NS	NS	NS	NS

DAS - Days after sowing

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