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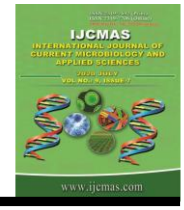

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Phytotoxicity, Flowering Time and Grain Conversion Efficiency of Transplanted Rice (*Oryza sativa* L.) in Response to Application of Selective Herbicides

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A B S T R A C T

A field experiment was conducted in Randomized complete block design to understand the effect of selective pre and post-emergence herbicides on physiology of rice crop in terms of visual toxicity, flowering and grain filling during the *late samba* season (October 2019 – February 2020) at wetland farms of Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. Fourteen herbicide treatments namely Bensulfuron-methyl (0.6%) + Pretilachlor (6%), Metsulfuron-methyl + Chlorimuron-ethyl, Oxadiargyl, Pendimethalin, Butachlor, Pretilachlor as pre-emergence herbicides applied on 3 days after transplantation (DAT); Imazethapyr and Bispyribac-sodium as early post-emergence herbicides applied on 15 DAT; Fenoxaprop-P-ethyl and Cyhalofop-butyl as post-emergence applied on 20 DAT; and Pyrazosulfuron-ethyl as late post-emergence applied on 25 DAT along with herbicide free treatments involving two hand weeding (15 and 25 DAT), weed free check and a control (unweeded) were replicated thrice.The study revealed that pre-emergence application of Butachlor produced the best results with respect to all the three parameters investigated, while the early post-emergence application of Imazethapyr caused maximum damage to the crop, causing the highest phytotoxicity, prolonged 50% flowering and the lowest grain conversion.

Introduction

Among different weed management options, chemical weed management is turning out to be more reliable because of the benefits it offers in terms of time, labour, efficacy and economic weed suppression (Castro-Tendero and García-Torres, 1995). In this context, selective herbicides have attracted much attention in the recent past. Selective herbicides are crop friendly and selectively suppress weeds (Duke *et. al*., 1991).Manual weeding is declining due to labour scarcity and increased labour costs (Duary *et. al*., 2015). Selective herbicides that are recommended for different times of application are available in the form of pre, early post, post and late post-emergence herbicides. These selective herbicides are also known to affect the yield by inducing physiological changes in crop. Herbicide application can cause phytotoxicity to the crops, particularly when they are not used according to the recommended dosages. Some herbicides reduce productivity of crops even without showing any visually detectable effects, while a few show marked injuries but finally enable complete crop recovery (Ferreira *et al.,* 2005). The inability of crop to recover is reflected in stunting, delayed 50% flowering time and inefficient grain filling. The slow grain-filling rate and low grain weight of spikelets are thought to be due to a limitation in carbohydrate supply (Sikder and Gupta, 1976; Murty and Murty, 1982; Zhu *et. al*., 1988) which obviously affects the yield. Simulated drift studies involving Imazethapyr plus Imazapyr resulted in decreased yield and quality along with foliar damage. Such herbicidal drift injuries delayed fruit maturity in sweet cherries (*Prunus avium* L.) (AlKhatib *et al*. 1992b) and straight head symptoms in rice (Richard *et al*., 1981). Selective herbicides can also show such effects in a varying magnitude based on the tolerance of crop. In case of a severe injury the effect will also be evidently seen on the reproductive system and grain filling efficiency of the crop.

In this connection, the present investigation was conducted to understand the impact of a few commonly used selective pre and post-emergence herbicides on phytotoxicity, flowering and grain formation in rice (*Oryza sativa* L.) and utilize the understanding to identify herbicides which are more friendly to this rice variety.

Materials and Methods

Experimental details

A field experiment was conducted at wetland farm of Tamil Nadu Agricultural University, Coimbatore during *late samba* season (October 2019 – February 2020) on medium duration rice variety CO-52 to study the physiological affect of selective herbicides on rice crop. The experimental farm is geographically situated at 11°N latitude and 77°E longitude and at an altitude of 426.7 m above mean sea level (MSL). The soil texture was clay loam with pH 8.2 and electrical conductivity (EC) 0.5 dSm^{-1}.The soil exhibited low nitrogen (246 kg ha^{-1}), high phosphorous (31.8 kg ha^{-1}) and high potassium (1024 kg ha^{-1}) content.

The study was arranged in Randomized complete block design with three replications. The gross plot size and the net plot size were 7 x 3 meter and 4.8 x 2.2 meter respectively. A total of fourteen treatments were taken up in three replications, which are namely, Bensulfuron-methyl 0.6%+ Pretilachlor 6% GR @ 10kg ha^{-1}applied on 3 DAT; Metsulfuron -methyl 10.1% + Chlorimuron-ethyl 10.1% WP applied on 3 DAT @ 20 g ha^{-1}; Oxadiargyl80% WP @ a.i 100 g ha^{-1}applied on 3 DAT; Pendimethalin 30% EC @ 1 kg a.i ha^{-1}applied on 3 DAT; Butachlor 50%EC applied on 3 DAT @ 1kg a.i ha^{-1}; Pretilachlor 50 EC @ ai 1kg ha^{-1} applied on 3 DAT; Imazethapyr 10% SL @ 50g a.i ha^{-1}applied on 15 DAT; Bispyribacsodium 10%SC @ 50g a.i ha^{-1}applied on 15 DAT; Fenoxaprop-P-ethyl 69 EC @ a.i 60gha^{-1}applied on 20 DAT; Cyhalofop-butyl 10% EC a.i @ 70g ha^{-1}applied on 20 DAT; Pyrazosulfuron-ethyl 10% WP @ a.i 10 g ha^{-1}applied on 25 DAT; Hand weeding twice on 15 and 25 DAT; Weed free check and Unweeded Control.

All the other crop production management aspects were followed as per the Tamil Nadu Agricultural University Crop production guide (2019).

Phytotoxic effect

The phytotoxic effect of herbicides on rice crop were assessed on 1,3 and 7 days after pre-emergence, early-post emergence and post-emergence herbicide treatment by using a simple rating scale of 0 to 10 (equal to 0 to 100%)as suggested by Rao (2000), where 0 indicates no injury and 10 indicates complete destruction.

50% flowering time

Days to 50% flowering was counted from the date of sowing to the day when 50% of plants flowered in each plot, which is expressed in number of days.

Grain conversion efficiency

The conversion of grains to filled grains was worked out as grain conversion efficiency from ten randomly selected panicles from the tagged plants (Thavaprakaash, 2019). Total number of grains and number of filled grains in a panicle were counted separately in panicles from five tagged hills of each treatment plot and the mean value was recorded as number of grains/panicle and number of filled grains/panicle, respectively. The grain conversion efficiency was calculated by the following formula.

$$\text{Grain conversion efficiency (\%)} = \frac{\text{Number of filled grains/panicle}}{\text{Total number of grains/panicle}} \times 100$$

Statistical analysis

The 50% flowering time and grain conversion efficiency data corresponding to the fourteen treatments were subjected to analysis of variance (ANOVA) of randomized complete block design by using AGRES software in windows. The critical difference and the mean significance were tested at 5% level (P=0.05) as per the statistical procedure laid by Gomez and Gomez (2010). Wherever the treatment differences were found to be significant (F test), critical differences were worked out at five per cent probability level (P= 0.05).

Results and Discussion

Phytotoxicity and crop injury scoring

The phytotoxicity score of the rice subjected to the fourteen treatments involving various pre and post-emergence herbicides is shown in Table 1. The visual injury symptoms ranged from no injury to severe injury. The treatment involving early post-emergence herbicide Imazethapyr resulted in severe injury, which was assigned a score of 5 on 14 DAHA and 3-4 up to 24 DAHA. Early post-emergence herbicide Imazethapyr showed evident symptoms of persistent injury including severe stunting, discolouration and tip burning which were pronounced on 25 DAHA. Among the pre-emergence treatments, Chlorimuron-ethyl 10% + Metsulfuron-methyl 10%, Oxadiargyl and Pretilachlor show edevident phytotoxic symptoms. The pre-emergence herbicide Chlorimuron-ethyl 10% + Metsulfuron-methyl caused stunting, stand loss, injury and discolouration up to 25 DAHA and the crop showed symptoms of recovery thereafter. Oxadiargyl showed slight stand loss, stunting and pin head spots on few leaves of the plant during the initial days of application while stunting persisted up to two weeks with a good recovery later on. Bispyribac sodium applied plants also showed slight stunting up to 7 DAHA which disappeared later. The post-emergence application of Fenoxaprop-P-ethyl showed moderate injury resulting in stunted growth and slight discolouration up to 20 DAHA. Herbicides namely Pendimethalin, Butachlor, Pyrazosulfuron-ethyl did not cause any visible injury to rice plants.

Angiras and Kumar (2005) also reported that broadcasting Pyrazosulfuron-ethyl at 15 gha^{-1} mixed with sand at 150 kgha^{-1} had an effective weed control in rice without causing phytotoxicity to the crop. Results regarding severe phytotoxicity of Imazethapyr in rice were in agreement with Ottis *et al.,* (2003) who observed 34% injury to rice crop applied with imazethapyr as post-emergence herbicide following a preplant-incorporation. On the other hand, Fenoxaprop-P-ethyl caused stunting of plant, growth reduction, increased tiller and mortality of main stem in rice crop (Oosterhuis *et al.*, 1990; Snipes and Street 1987).

Days to 50% flowering

The longest time for 50% flowering was recorded for the treatment involving early post-emergence herbicide Imazethapyr followed by pre-emergence herbicide application of Chlorimuron-ethyl 10% + Metsulfuron-methyl and post-emergence application of Fenoxaprop-P-ethyl which were on par. while, the treatments involving pre-emergence application of Bensulfuron-methyl + Pretilachlor, Pendimethalin, Butachlor, Pretilachlor and the three herbicide free treatments involving two-hand weeding, weed free check and unweeded control were on par resulting in the lowest time for 50% flowering.

The herbicide free treatments namely two-hand weeding (15 and 25 DAT), weed free check and unweeded control took about 97 to 99 days for 50% flowering after sowing (Table 2). Thus, a significant delay in the time for50% flowering - by about eighteen days- was observed with the early post-emergence application of Imazethapyr followed by the pre-emergence application of Chlorimuron-ethyl 10% + Metsulfuron-methyl and post-emergence Fenoxaprop-P-ethyl, which delayed the time for 50% flowering by about 5-6 days.

The plant reproduction is generally considered more sensitive end point than usual short term physiological measurements of herbicide toxicity (Boutine *et al*., 2014). The pre-emergence herbicide Imazethapyr may have caused severe stress in the rice plants. Greater extent of toxicity symptoms in vegetative phase could have delayed the recovery and thereby the time for flowering. Timely flowering has an important role in grain formation and development. Generally, early-flowering spikelets located on apical primary branches fill rapidly to produce heavier grains, while late-flowering spikelets fill slowly and poorly to produce grains (Mohapatra *et al.*, 1993; Yang *et. al.*, 2000; 2006).Thus delayed flowering becomes one of the deciding factors for the development of grains.

The present results are in accordance with Jason *et al*,. (2006) who observed the inability of rice to recover from late post-emergence application of Imazethapyr plus Imazapyr premix that reflected in 50% heading. The 50% flowering time was delayed by 3-5 days by early post-emergence application and 4 to 6 days by late post-emergence application, while the delay is found to bemuch greater in the present study.

Grain conversion efficiency

The grain conversion efficiency of the panicles of tagged plants is shown in Table 3.The early post-emergence application of Imazethapyr resulted in the lowest grain conversion efficiency (45%) followed by pre-emergence application of Bensulfuron-methyl + Pretilachlor (57.0%), Pendimethalin (60.8%) and Pretilachlor (56.6%) and late post-emergence application of Pyrazosulfuron-ethyl (57.4%), which were on par. In these cases, the number of filled grains were found to be low in the total number of grains, indicating poor grain filling and greater chaff grain production, consequently decreasing the grain conversion efficiency. Remobilization and transfer of the stored assimilates require the initiation of whole-plant senescence.

Delay in plant senescence canresult in poorly filled grains, leading to unused carbohydrates in straws. Slow grain-filling is associated with a delay in entire plant senescence (Zhu *et. al.*, 1997; Mi *et. al.*, 2002; Gong *et. al.*, 2005).

Table.1 Crop injury score for various treatments involving pre-emergence and post emergence herbicides

Treatment	4 DAT 1DAHA PRE	6 DAT 3DAHA PRE	10 DAT 7DAHA PRE	17 DAT 14DAHA PRE	16 DAT 1DAHA EPOE	18 DAT 3DAHA EPOE	22 DAT 7DAHA EPOE	29 DAT 14DAHA EPOE	21 DAT 1DAHA POE	23 DAT 3DAHA POE	27 DAT 7DAHA POE	34 DAT 14DAHA POE	26 DAT 1DAHA LPOE	28 DAT 3DAHA LPOE	32 DAT 7DAHA LPOE	39 DAT 14DAHA LPOE
T_1 - Bensulfuron-methyl 0.6%+ Pretilachlor 6% @ 10kg ha^{-1} on 3 DAT	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
T_2 - Chlorimuron-ethyl 10% + Metsulfuron-methyl 10% @ 20g ha^{-1} on 3 DAT	0	2	4	4	4	4	4	3	4	4	3	1	3	3	1	1
T_3 - Oxadiargyl @ 100 g a.i ha^{-1} on 3 DAT	0	1	3	3	3	3	1	1	1	1	1	0	1	1	0	0
T_4 - Pendimethalin @ 1.0 kg a.i ha^{-1} on 3 DAT	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_5 - Butachlor @ 1.0 kg a.i ha^{-1} on 3 DAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_6 - Pretilachlor @ 1.0 kg a.i ha^{-1} on 3 DAT	0	1	1	1	1	1	1	0	1	1	0	0	0	0	0	0
T_7 - Imazethapyr @ 50g a.i ha^{-1} on 15 DAT	*	*	*	0	0	1	4	5	4	4	4	4	4	4	4	3
T_8 - Bispyribac sodium @ 50g a.i ha^{-1} on 15 DAT	*	*	*	0	0	0	1	1	1	1	1	0	1	0	0	0
T_9 - Fenoxaprop-P-ethyl @ 60g a.i ha^{-1} on 20 DAT	*	*	*	*	*	*	0	2	0	1	2	1	2	2	1	1
T_{10} - Cyhalofop-butyl @ 70g a.i ha^{-1} on 20 DAT	*	*	*	*	*	*	0	0	0	0	0	0	0	0	1	0
T_{11} - Pyrazosulfuron-ethyl @ 10g a.i ha^{-1} on 25 DAT	*	*	*	*	*	*	*	0	*	*	0	0	0	0	0	0
T_{12} - Two hand weeding (15 and 25 DAT)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
T_{13} - Weed free check	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
T_{14} - Control (unweeded)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

DAT: days after transplanting; DAHA: days after herbicide application; PRE: pre-emergence; EPOE: early post-emergence; POE: post-emergence; LPOE: late post-emergence. Rating scale of 0 to 10 (equal to 0 to 100%), where 0 indicates no injury and 10 indicates complete destruction as suggested by Rao (2000).*Not applicable

Table.2 Effect of selective pre-emergence and post-emergence herbicides on time for 50% flowering after sowing

Treatment	Days for 50% flowering After sowing
T_1 - Bensulfuron-methyl 0.6%+ Pretilachlor 6% @ 10kg ha^{-1} on 3 DAT	96
T_2 - Chlorimuron-ethyl 10% + Metsulfuron-methyl 10% @ 20g ha^{-1} on 3 DAT	103
T_3 - Oxadiargyl @ 100 g a.i ha^{-1} on 3 DAT	100
T_4 - Pendimethalin @ 1.0 kg a.i ha^{-1} on 3 DAT	99
T_5 - Butachlor @ 1.0 kg a.i ha^{-1} on 3 DAT	99
T_6 - Pretilachlor @ 1.0 kg a.i ha^{-1} on 3 DAT	98
T_7 - Imazethapyr @ 50g a.i ha^{-1} on 15 DAT	116
T_8 - Bispyribac sodium @ 50g a.i ha^{-1} on 15 DAT	100
T_9 - Fenoxaprop-P-ethyl @ 60g a.i ha^{-1} on 20 DAT	104
T_{10} - Cyhalofop-butyl @ 70g a.i ha^{-1} on 20 DAT	100
T_{11} - Pyrazosulfuron-ethyl @ 10g a.i ha^{-1} on 25 DAT	100
T_{12} - Two hand weeding (15 and 25 DAT)	99
T_{13} - Weed free check	98
T_{14} - Control (unweeded)	97
SEd	1.55
CD (*P*=0.05)	3.19

Data are the means of three replicates on the days for 50% flowering after sowing. The critical difference (CD) was worked out of 5 per cent (*P*=0.05) level to evaluate the significance of differences between the means by one way ANOVA statistics. SEd: standard error of difference.

Table.3 Effect of selective pre-emergence and post-emergence herbicides on grain conversion efficiency (%) on the day of harvest

Treatment	Total number of grains/panicle	Number of filled grains/panicle	Grain conversion efficiency (%)
T_1 - Bensulfuron-methyl 0.6%+ Pretilachlor 6% @ 10kg ha^{-1} on 3 DAT	175.9	97.6	57.02
T_2 - Chlorimuron-ethyl 10% + Metsulfuron-methyl 10% @ 20g ha^{-1} on 3 DAT	186.9	118.6	63.66
T_3 - Oxadiargyl @ 100 g a.i ha^{-1} on 3 DAT	170.0	117.9	68.92
T_4 - Pendimethalin @ 1.0 kg a.i ha^{-1} on 3 DAT	214.8	132.3	60.82
T_5 - Butachlor @ 1.0 kg a.i ha^{-1} on 3 DAT	185.5	125.3	67.52
T_6 - Pretilachlor @ 1.0 kg a.i ha^{-1} on 3 DAT	162.6	88.9	56.45
T_7 - Imazethapyr @ 50g a.i ha^{-1} on 15 DAT	153.3	68.3	45.04
T_8 - Bispyribac sodium @ 50g a.i ha^{-1} on 15 DAT	192.1	142.1	73.19
T_9 - Fenoxaprop-P-ethyl @ 60g a.i ha^{-1} on 20 DAT	134.3	88.0	64.12
T_{10} - Cyhalofop-butyl @ 70g a.i ha^{-1} on 20 DAT	200.8	127.8	63.20
T_{11} - Pyrazosulfuron-ethyl @ 10g a.i ha^{-1} on 25 DAT	192.2	110.0	57.40
T_{12} - Two hand weeding (15 and 25 DAT)	156.4	101.8	63.73
T_{13} - Weed free check	180.4	118.3	65.73
T_{14} - Control (unweeded)	160.7	109.0	66.80
SEd	8.471	7.364	2.912
CD (P=0.05)	17.413	15.137	5.987

Data are the means of three replications 142 days after sowing or 113 DAT (days after transplanting) for all the treatments except for the Imazethapyr treated rice which was harvested 157 days after sowing or 128 DAT. The critical difference (CD) was worked out of 5 per cent (*P*=0.05) level to evaluate the significance of differences between the means by one way ANOVA statistics. SEd: standard error of difference

Slow grain-filling rates are thought to be due to a limitation in carbohydrate supply (Sikder and Gupta, 1976; Murty and Murty, 1982; Zhu *et. al.*, 1988).

On the other hand, pre-emergence application of Oxadiargyl (68.9%) and Butachlor (67.5%), and early post-emergence application of Bispyribac sodium (73.2%) resulted in the highest grain efficiency conversion, which were on par with each other. Thus, in the present study, both higher and lower grain conversions efficiencies were observed for the treatments involving herbicides when compared to that of the weed free check. Further, the two-hand weeded treatment resulted in a lower grain filling efficiency and unweeded control showed more or less the same grain filling efficiency when compared to that of the weed free check. In a related study, Choudary *et al*., (2018) have noticed higher number of filled grains and lower chaffy grains in the herbicide free treatment involving two-hand weeding in comparison to the treatments involving various herbicides. On contrary, Thura (2010) noted lower grain filling in unweeded control than the herbicide applied treatments.

In conclusion from the experiment conducted, it is revealed that, butachlor application enhanced 50% flowering, grain conversion efficiency and reduced phytotoxicity to rice crop. But, application of imazethapyr showed higher visible phytotoxicity, prolonged 50% flowering and lowest grain conversion efficiency. Hence, application of butachlor in rice crop will be the best option for higher physiological efficiency of rice plant.

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