academicJournals

Vol. 6(7), pp. 58-63, August, 2014
DOI: 10.5897/JHF2014.0359
Article Number: 55626DF47004
ISSN 2006-9782

http://www.academicjournals.org/JHF

Journal of Horticulture and Forestry

Full Length Research Paper

Propanil - and fenoxaprop-p-methyl resistance *Echinochloa colona* (L.) *link biotype* in upland rice

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Received 23 June, 2014; Accepted 23 July, 2014

The development of resistance of *Echinochloa colona* biotypes is emerging as a major problem in upland rice production, particularly where there is an apparent over use of the propanil - and fenoxaprop-P-methyl herbicides. A series of field studies in a commercial rice production facility were conducted to screen a wide range of recommended herbicides for upland rice weeds and to assess its efficacy and the possible resistance of herbicides. The results indicated that fenoxaprop was not performing as anticipated in upland rice management. However, propanil in combination with oxadiaryl improved yield and weed control. Preliminary evidence suggests that there is *E. colona* biotype present in the population that is exhibiting some level of resistance, but not necessarily to Fenoxaprop-P.

Key words: *Echinochloa colona*, biotypes, propanil, fenoxaprop-p-methyl, oxadiaryl herbicides.

INTRODUCTION

The production of upland-rice is increasing worldwide as most of the potential lowland areas are already cultivated (Gupta and O'Toole, 1986). Approximately 14% of the world's rice growing area is dry seeded in unbounded fields (De Datta, 1981), but the yield is low compared to irrigated and lowland production systems, and is confined to areas with inadequate rainfall and poor soils.

Weed control is a major challenge to upland rice production in addition to crop nutrition (Becker and Johnson, 2001). Excessive herbicide usage is expensive, environmentally harmful, and may contribute to the buildup of herbicide-resistant weed biotypes as is the case of *Echinochloa colona* (Fisher et al., 1993) and *E. crusgalli* (Baldwin et al., 1996). *E. colona* is the most noxious weed in upland rice (Holm et al., 1977, Fisher et al., 1993; Baldwin et al., 1996). It is a very competitive weed capable of suppressing growth and development of the crop. It contributes to the yield decline and a reduction in grain quality of 42 to 90% (Fisher et al., 1993).

E. colona has displayed resistance to propanil, acetyl-coenzyme A carboxylase (ACCase)-inhibitor herbicides, quinclorac and imazapyr (Valverde, 2007). Caseley et al. (1996) found that repeated use of propanil has led to the evolution of propanil-resistant *E. colona* biotypes. The resistant (R) biotypes have elevated levels of aryl acylamidase, which rapidly metabolizes propanil to 3,4-dichloroaniline. Caseley et al. (1997) showed that in the control of *E. colona* in both rainfed and irrigated, Cyhalofop-butyl was selective in rice and effectively controlled *E. colona* which was resistant to propanil, but was ineffective on those that were resistant to

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Fenoxaprop-P. Some *E. colona* populations are resistant to at least three herbicide modes of action quinclorac, bispyribac, imidazolinones and nicosulfuron in ACCase-inhibitor herbicides (Valverde, 2007).

Plaza et al. (2009) reported that in rice crops, different biotypes of *E. colona* have been shown to be resistant to both fenoxaprop and other ACCase-inhibiting herbicides. Pérez et al. (2009) also reported that *E. colona* was not being controlled by herbicides cyhalofop-butyl, clefoxidym, fenoxaprop p-ethyl and bispyribac sodium. The resistance was confirmed when applications of an inhibitor cytochrome P450 enzyme complex was made to resistant populations verification and this complex metabolic pathway enzyme (Caseley et al., 1997). The difference in the metabolization velocity of the herbicide fenoxaprop-p-methyl and cihalofop-buthyl explained the values obtained in the resistance indices (Plaza et al., 2009).

Khaliq and Matloob (2011) and Gealy et al. (2014) observed that critical period of weed competition is central in the development of an effective weed management program. Further, rice yield continued to decline as the duration of *E. colona* weed competition increased, and that weed competition beyond 20 days after sowing (DAS) resulted in drastic reduction in the number of panicles m^{-2} and grains panicle. They found that the period within 20 to 50 DAS appeared to be an important factor in crop weed competition in dry direct-seeded rice. Miquilena and Lazo (2005) found that *E. colona* can grow initially faster than rice variety in both seasons, and the number of seeds per plant was greater in the species of *Echinochloa* genus and they showed less dormancy.

Recently, Werth et al. (2012) and Thai et al. (2012) have reported that *E. colona* (a common weed in the majority of rice fields in Australia) had exhibited resistance to glyphosate. However, increased no-till agriculture and planting of glyphosate-resistant crops are likely to select more glyphosate-resistant weeds. Do-Soon et al. (2000) developed a rapid detection method for discriminating between resistant (R) and susceptible (S) biotypes of *E. colona* to either propanil or propanil resistance in E. *colona*.

The objective of this study is to evaluate the performance of selected herbicides for the control *E. colona* in upland rice production and to assess its possible resistance of propanil - and fenoxaprop-P-methyl.

MATERIALS AND METHODS

Field trials were conducted during the period 2007 to 2012 at the Caroni Research Station, Waterloo on the Waterloo soil series. The soil is a clay loam with a pH of 4.9, with 2% coarse sand, 42% fine sand, 27% silt, and 31% clay; CEC 8.3 meg.100 g^{-1}, and TEB 3.3 meg.100 g^{-1} of oven dry soil. The C/N ratio is 8.9 (Brown and Bally, 1968). The cropping season for upland rice extended from early wet season (June) to late season (December). Three studies were conducted on the assessment of herbicide for the control of *E. colona* and the determination of propanil and fenoxaprop-P-methyl resistance.

Study 1: Chemical weed control in upland rice (2007/2008 season)

Sixteen herbicides were screened for efficacy for pre-emergence and post-emergence weed control in upland rice where the predominant weed is historically *E. colona*. The rates and time of application are presented in Table 1. The herbicides were applied 3 days after sowing (DAS) as pre-emergence, and 15 days after emergence (DAE) as post-emergence. The experimental plot size was 50 m^2, and treatments replicated 3 times in a randomized block design.

Study 2: Chemical weed control in upland (2008/2009 season)

Eight of the herbicides evaluated in the 2007/8 trial were further evaluated to determine their efficacy for pre- or post-emergence control of *E. colona* and similarly resistance in 30 m^2 experimental plots. The trial was laid out in a randomized block design with 4 replicates. The rates and time of application are presented in Table 2.

Study 3: Evaluation of oxadiargyl in upland rice weed control (2009/2010 season)

This trial was designed to evaluate oxadiargyl, a new herbicide, singly and in mixtures as pre- and post-emergence herbicide for the control of *E. colona*. The trial was laid out in a randomized block design with four (4) replicates on 30 m^2 experimental plots. The herbicide was applied either post-emergence to *E. colona* (3 leaf stage) or pre-emergence to *E. colona* (2 leaf stage of crop). After the 3 leaf stage, it was applied in mixtures with propanil (Table 3).

In all trials, the experimental sites were part of commercial cultivation established for upland rice production. The fields were fallow for over six months between crops and were not used previously for herbicide evaluation. The same rice variety (var. *Oryzica* 1) was used in all trials. Field operations involved disc harrowing twice at 10 to 14 days intervals between operations. The seed (14% moisture content, and 99.5% viability) was broadcasted using a Spyker™ seed spreader at the rate of 100 $kg.ha^{-1}$, and immediately incorporated into the soil by rot ovation. The crop received N and K fertilizer applications at 3, 6 and 9 weeks after sowing [WAS]. Nitrogen was applied as urea [90 kg. $N_2.ha^{-1}$] and K as Muriate of Potash [150 kg $K.ha^{-1}$]. Each plot received a standard basal application of P_2O_5 [TSP] equivalent to 50 $kg.ha^{-1}.yr^{-1}$. In all cases, fields had surface drainage and were free of bunds. Spacing between treatments was 1.5 m, and 2m between blocks.

The herbicides were applied using a single nozzle, aluminum carbon dioxide sprayer (model 104B) with a calibrated volume rate of 220 $1.ha^{-1}$ at 207 kPa with an effective boom width of 1.0 m. The nozzle was even, flat spray tip, 8003 brass (50 mesh) with a capacity of 0.066 lpm. The carrier was pipe borne water.

Observations recorded for the crop included plant height (cm) and grain (100% filled spikelets) yield [$t.ha^{-1}$]. *E. colona* density [$pl.m^{-2}$] and shoot dry matter [$g.m^{-2}$] were determined at harvest. A weed control rating system was employed to evaluate the different herbicides as described by Camper (1986). All data were subjected to statistical analysis, using the MINITAB package and generalized linear model, and subjected to the appropriate transformation whereever necessary. Rainfall data were recorded during the experimental period.

Table 1. Effect of various herbicides on weed control (%) and grain yield (t.ha^{-1}) of upland rice (var. *Oryzica 1*), (2007/8).

Treatment	Application rate (kg.a.i.ha^{-1})	Weed control*	Yield (t.ha^{-1})
Accent [Pre-em]	++	3	1.99
Bentazon+Propanil[Pre-em]	2.0	1	2.5
Butachlor [Pre-em]	2.5	6	2.7
Conduct [Pre-em]	0.75	1	0.5
Ioxynil [Post-em]	0.6	3	2.0
Oxidiazon [Pre-em]	1.25	1	2.5
Pendimethalin [Pre-em]	2.0	6	1.9
Quinclorac [Pre-em]	0.3	5	2.2
Bromoxyil [Post-em]	0.75	7	1.9
Clomazone [Post-em]	1.0	1	2.3
Fenoxaprop [Post-em]	0.3	1	1.1
Metsulfuron [Post-em]	0.015	1	2.4
Molinate+propanil [Post-em]	3.0	1	2.2
Pretiachlor [Post-em]	8.0	7	2.6
Propanil [Post-em]	3.0	1	3.2
Sethoxydim [Post-em]	0.186	1	0.6
Weedy check	-	1	1.2
S.E.		0.28	0.24
LSD [0.05]		0.84	0.72

++ = 0.00001 g.a.i.ha^{-1}; *weed score- 0 = no control to 10 = 100% control.

Table 2. Effect of various herbicides on crop, *E. colona* weed density (112 DAT) and grain yield of *Oryzica 1* (Upland Rice).

Treatment	Application rate (kg.a.i.ha^{-1})	Weed density	Weed dry weight	Crop density	Yield (t/ha)
Oxadiazon [pre-em]	1.25	20.5	28.4	9.0	1.1
Butachlor [pre-em]	2.5	15.5	14.4	6.0	2.25
Ioxynil Oxidiazon [pre-em]	+ 0.6+	17.7	21.0	7.3	1.52
Pendimethalin [pre-em]	2.0	25.0	23.2	2.8	1.61
Ioxynil Oxidiazon+ Propanil[post-em]	0.6 + 1.25 + 3.0	21.0	24.8	4.7	2.1
Metsulfuron [post-em]	0.015	17.7	21.8	8.0	1.52
Molinate + Propanil [post-em]	3.0	20.0	30.1	8.8	2.2
Propanil [post-em]	3.0	17.0	34.8	7.7	1.9
Weedy check	-	17.5	39.5	15.8	1.14
SE		3.013	7.984	1.916	0.17
LSD[0.05]		N.S.	N.S.	5.66	0.52

RESULTS AND DISCUSSION

The total rainfall during the experiment period of 2007 to 2010 cropping season varied between 580 and 7780 mm. The grass weeds present in the experimental plots during the study were: *Cynodon dactylon Pers., Eleusine indica Gaerth., Fimbristylis miliacea (L)., Paspalum distichum L., Commelina benghalensis Ll., Digitaria horizontalis Wild., Leptochloa filiforms* and *E. colona* (L.) Link*.* The broadleaved weeds were *Portulaca oleracea Linn.,* and *Emilia sonchiflia (Linn) DC. Cyperus rotundus Linn.* was the sedge encountered in the plots. However *E. colona* was always the predominant weed as observed in the weedy check.

Study 1: Chemical weed control in upland rice (2007/2008)

This study was not only an exploratory screening of currently used and recommended herbicides for weed control in upland rice in general, but also to determine the efficacy of *E. colona* control or its biotypes. The weed control data obtained with the various herbicides as well

Table 3. Effect of oxadiargyl on the *E. colona* weed density and control at 38 and 112 days after treatment.

Treatment	Application ($kg.ai.ha^{-1}$)	38 DAS		112 DAS	
		E. colona	Control	*E. colona*	Control
Oxadiaryl [pre-em]	1.25	27	7.2	5	5.0
Oxadiaryl+ Ioxynil [pre-em]	1.25+6.0	7	8.8	32	7.3
Oxadiaryl+Ioxynil+ Propanil [post-em]	1.25 + 0.6 + 3.0	17	8.5	33	6.8
Oxadiaryl +Propanil [post-em]	1.25 + 3.0	47	5.2	45	5.5
Weedy check	-	85	1.0	90	0.5
SEM		119	1.32	9.51	1.09

as the respective grain yield for upland rice var. *Oryzica1* are presented in Table 1. The results indicated that herbicidal treatments with metsulfuron, clomazone, oxidiazon, molinate + propanil, bentazon + propanil and propanil had a weed control rating of 1. These herbicides gave a poor weed control on both broadleaves and grasses, regardless of pre- or post-emergence application, and the major grass was *E. colona*. The pre-emergence herbicides (butachlor, pendimethalin, quinclorac and bromoxyil) and the post-emergence herbicide (pretilachlor) controlled weeds at rate of 60 to 75% compared with the weedy check where a control of <10% occurred. Two new herbicides, sethoxydim (post-emergence) and Conduct (pre-emergence) had very low levels of control and were not different from the weedy check). These two herbicides caused severe phytotoxicity damage and reduced the crop density significantly thereby creating a resurgence of weed seeds which subsequently resulted in low crop yields (0.5 $t.ha^{-1}$).

The highest yields were obtained from plots treated with propanil (3.2 $t.ha^{-1}$) followed by butachlor (2.7 $t.ha^{-1}$) and pertilachor (2.6 $t.ha^{-1}$). These treatments in addition to metsulfuron (2.4$t.ha^{-1}$) and clomazone (2.3$t.ha^{-1}$) were not significantly different from propanil. At this location *E. colona* continued to be the major weed species escaping chemical control. After this study, the area remained fallow for the following 6 months and regenerate into a pure stand infestation of *E. colona.*

It was observed that both Fenoxaprop [Post-em] and Propanil [Post-em] gave low control of E. *colona.* However, propanil had the highest yield. This is mainly due to propanil having its effect on the other weed during the critical period of competition, thus reducing the pressure on the yield determination. Notably, all treatments with propanil in combination gave weed control (>10%) but also gave high yield (>2.2 $t.ha^{-1}$). The major weed escaping control was always *E. colona.*

Study 2: Chemical weed control in upland (2008/2009 season)

Based on their performances in 2007/2008, eight herbicidal treatments were selected for further evaluation to control *E. colona.* Fenoxaprop [Post-em] was eliminated from any further screening due to its low weed control efficacy and yield.

This weed continued to be the most prolific and dominant in this and nearby fields. It was the major grass weed and densities at 112 days after treatment [DAT] are presented on Table 2. The results showed that there was no significance in the *E. colona* weed density between the weedy check and all the herbicide treatments, but the number and size of the weed had some competitive effect on the emergence and growth of *Oryzica 1* as reflected in the final crop density.

The results indicated that the herbicides had no significant effect on crop density at harvest. The effect of the herbicide on the *E. colona* density was variable as was observed in the weedy check [16pl. per 0.25 m^{-2}] compared to the treatment with pendimenthalin (3pl. 0.25 m^{-2}). There were no significant difference ($P > 0.05$) between weedy check and other herbicides weed dry weight.

However, there were significant variations between treatments with respect to grain yield. The highest yield was obtained from plots treated with butachlor (2.25 $t.ha^{-1}$), but these was not significantly different from the propanil, molinate + propanil and ioxynil + oxidiazon + propanil treatments. All the other treatments produced yields less than 1.6 $t.ha^{-1}$.

This trial emphasized the need for early pre-emergence control as in the case of butachlor. Propanil is the most popular herbicide in use for upland rice compared to the others. When applied in a mixture with molinate or oxidiazon + ioxynil, it gave 0.25 $t.ha^{-1}$ yield increase. Oxadiazon which is used for lowland rice did not perform as efficiently although there was adequate soil moisture. Regardless of herbicide treatment, *E. colona* proved to be the most dominant weed, but not necessarily exhibiting resistance.

Study 3: Evaluation of oxadiargyl for upland rice weed control (2009/2010 season)

When oxadiargyl was applied (as a pre-emergence) emerging weed seedlings were killed upon contact with it.

Table 4. Response of *E. colona* rice [var. *Oryzica1*] density and grain yield (t.ha^{-1}) to oxadiargyl application.

Treatment	Weed density	Crop density	Yield (t.ha^{-1})
Oxadiargyl [pre-em]	1.5	16.1	1.66
Oxadiargyl+ Ioxynil [Post-em]	4	24	1.95
Oxadiargyl+ Propanil [Post-em]	7.3	19.7	1.91
Weedy check	17	22.5	0.7
SEM	1.8	2.001	0.269
LSD [0.05]	8.06	6.310	0.84

The results indicated that oxadiargyl gave between 50 to 70% control *of E. colona* over that of the weedy-check at 38 and 112 DAT. At harvest, efficacy level (50%) of oxidiargyl was increased when mixed with ioxynil and propanil (Table 3).

A similar trend was observed for the effect of oxadiargyl on crop and weed density (Table 4). This effect manifested itself on crop grain yield. All treatments produced more than double yield than that of the weedy check. There were no significant differences ($P > 0.05$) between oxadiargyl (alone) or its mixtures. However, the oxadiargyl + ioxynil + propanil mixture produced 0.45 t.ha^{-1} more grains than oxadiargyl (alone).

Herbicides treatments containing propanil did not improve the weed control efficacy against *E. colona* compared with oxadiargyl. This is the first confirmatory evidence that propanil may be exhibiting some level of resistance against oxadiargyl biotype.

The response of the herbicides evaluated in this study was similar to that reported by (De Datta and Ampong, 1991). Propanil and its mixtures were effective herbicides in controlling *E. colona* for upland rice with no significant reduction in yield. However, it is critical not to depend on propanil especially in developing an appropriate integrated weed management [IWM] Strategy. Fisher et al. (1993) suggested that one way to reduce the level of propanil resistance in *Echinochloa* sp is to use commercial formulation of propanil or molinate as they are more effective than propanil alone.

Riches et al. (1997) recommended that pendimethalin improved post-emergence control in the field compared to the standard propanil treatment and can provide residual pre-emergence control of late-germinating individuals, so reducing the propanil selection pressure. For effective *E. colona* control, growers apply propanil (3·84 kg ha^{-1}) at 10 and 20 days after planting (DAP) followed by one application of fenoxaprop-P-ethyl (0·045 kg ha^{-1}) at 35 DAP, and one application of pendimethalin at 1·5 kg ha^{-1} provided an effective replacement for propanil.

These trials have identified herbicides with different modes of action which may reduce build up of *E. colona* populations resistant to propanil, such as butcachor, oxadiazon oxadiargyl, and pretilachor. When propanil is used, uncontrolled or resistant *E. colona* biotypes (when identified) should be removed.

These herbicides should be included for the control of *E. colona* [and other weeds] for upland rice as components of the improved crop management (ICM) package strategies (Issac et al., 2013). The ICM should have components of minimum tillage and glyphosate application for reducing the weed seed bank. It stresses the importance of timeliness of operations with respect to placement of fertilizer and application of pre- and post-emergence herbicides in the reduction of weed competition. Also, the use of suitably adapted high yielding varieties [HYV's] for upland conditions. Competition by *E. colona* in upland rice has been shown to reduce crop yield between 80 to 90% (Bridgemohan, 1996).

This study has identified the necessity to rotate upland rice with other drought tolerant crops (sorghum) during the dry season [Jan to May] in order to reduce the weed infestation in future crops. Earlier studies by Bridgemohan (1996) have shown that minimum tillage and incorporation of seed together with fertilizer application at sowing, followed by application of pre-emergence herbicides significantly reduces the infestation of other broadleaved and grass weeds. However, it did not control *E. colona* successfully, and there is need to find suitable herbicides to replace propanil or to mix with propanil to reduce development of *E. colona* resistant biotypes.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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