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Evaluation of anti-lodging plant growth regulators on the growth and development of rice (*Oryza sativa*)

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Lodging is characterized by the reduction in plant canopy and the bending or fall over of mature plants with panicles on the soil or water resulting in yield and quality decline. It may be induced by variations in crop nutrition, water management, susceptible tall varieties and windy conditions. In all cases the plant stem base is unusually weak with a reduced diameter. This study evaluated the use of 2 plant growth regulators as Paclobutrazol (PP333) [(2RS, 3RS)-l-(4-chlorophenyl)-4,4-dimethyl-2-(1H-l,2,4-triazol-1-yl)pentan-3-ol], and Trinexapac-ethyl (cyclohexane carboxylate) which are synthetic plant growth regulators that showed reliable stem shortening and a reduction in lodging on two varieties of rice (Oryzica 2 and 3) at varying rates and time of applications. The studies were conducted in commercial fields over several growing seasons. The results indicate that Trinexapac-ethyl reduced plant height and the incidence of lodging in var Oryzica 3, and similarly improved yield over the control by 1.17 t.ha^{-1}.

Key words: Trinexapac-ethyl, paclobutrazol, lodging, cytokinin, gibberellins.

INTRODUCTION

Lodging is a severe problem in rice (*Oryza sativa*) and is influenced by cultivar, production systems, irrigation, nutrition, and weather conditions. It is more prevalent with heavy rains and strong winds at the beginning of the grain-filling period and results in significant yield losses (Pablico et al., 2003). Lodging is the reduction in plant canopy height due to bending of the shoot from vertical. The adverse effects of lodging is on light interception and canopy photosynthesis during grain filling and are largely the result of self-shading by leaves and panicles (Setter et al., 1997). They reported a reduction in grain yield (1%) and reduced canopy photosynthesis (60 to 80%) relative to erect plants. It affects absorption and translocation of nutrients and water, thus causing decreased yield of grain, and reduced milling recovery (Eunggi et al., 2006).

Shimono et al. (2007) found changes in (CO^2) can reduce yield, but lodging was significantly higher under high nitrogen than moderate nitrogen and was alleviated by elevated (CO^2) under high nitrogen. This alleviation was associated with the shortened and thickened lower internodes, but was not associated with a change in the plant's mass around the culm base. Lin et al. (2007) observed that excess soil nitrogen resulted in lodging of rice plants, but a decreased rate of nitrogen fertilizer reduced rice yields. Lodging can reduce production (30 to 35%) and may be related to high nitrogen and phosphorus nutrition in the absence of applied

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potassium. However, potassium application can successfully overcame lodging incidence (Bhiah et al., 2010).

Jianchang et al. (2001) reported that lodging-resistant rice cultivars usually showed slow grain filling when nitrogen is applied in large amounts and water stress increased. The partitioning of fixed $14CO^2$ into grains accelerated the grain filling rate but shortened the grain filling period. Further, hormones such as Cytokinin (zeatin + zeatin riboside) and indole-3-acetic acid contents in the grains transiently increased at early filling stage, and water stress hastened their declines at the late grain filling stage. Gibberellins (GA) in the grains were also high at early grain filling but high nitrogen enhanced. Opposite to GA, abscisic acid (ABA) in the grains was low at early grain filling. Paclobutrazol (PP333) *[(2RS, 3RS)-l-(4-chlorophenyl)-4,4-dimethyl-2-(1H-l,2,4- triazol-1-yl)pentan-3-o*l], and Trinexapac-ethyl (*cyclohexane carboxylate*) are synthetic plant growth regulators that showed reliable stem shortening and a reduction in lodging (Matsuyuki et al.,1990; Pyon and Huh, 1995). Ishimaru et al. (2008) suggested that the rigidity of the upper culm by the higher starch content (as a result of delayed senescence in the upper leaves) may be responsible for the higher lodging resistance during a typhoon in rice.

Lodging-resistant rice (*O. sativa*) cultivars usually show slow grain filling when nitrogen is applied in large amounts, but an altered hormonal balance in rice grains by water stress during grain filling, especially a decrease in GA and an increase in ABA, enhances the remobilization of prestored carbon to the grains and accelerates the grain filling rate (Yang et al., 2001). Through breeding and gene transformation improvement of plants into elite varieties, lodging resistance could be bred through molecular marker-assisted selection (Wang et al., 2007; Hong et al., 2014; Ni et al., 2014). Kashiwagi et al. (2008) observed varietal differences among rice cultivars that showed that stem diameter as a key factor in lodging resistance. They found that increasing stem diameter in rice breeding programs would improve lodging resistance.

Under adequate soil and crop nutrients conditions and water management, and using improved high yielding rice varieties, lodging was very high in both and wet seasons under rainfed and irrigated commercial rice production (Bridgemohan, 1995). The use of plant growth regulators seemed to be a promising intervention to reduce losses. The objective of this study was to evaluate the use of anti-lodging plant growth regulators on the growth, development, yield and quality of rice in a commercial rice production facility.

MATERIALS AND METHODS

This study was conducted during rice growing seasons between 2010 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; cation exchange capacity (CEC) 8.3 meg.100 g^{-1}, and total exchangeable bases (TEB) 3.3 meg.100 g^{-1} of oven dry soil. The C/N ratio is 8.9 (Brown and Bally, 1986). The cropping season for upland rice extended from early wet season (June) to late season (December). Two studies were conducted on the assessment of 2 plant growth regulators (PGR) - Paclobutrizol and Trinexapac-ethyl for the management of lodging.

Study 1

This trial was conducted during the growing season September 2010 to January 2011 in commercial fields using standard agronomic practices with respect to land preparation, direct sowing) 100 $kg.ha^{-1}$), fertilizer and herbicide application, and water management. The variety (Oryzica 2) used in the evaluation of the anti-lodging plant growth regulators Trinexapac-ethyl was applied at 3 rates [R] @ 20, 30 and 40 $g.ai.ha^{-1}$ at application times [3(T1), 2 (T2), and 1(T3)] week before flowering (WBF). Paclobutrizol was applied at 2 rates [50 and 100 $g.ai.ha^{-1}$] at 3 WBF. The trial was laid out in a factorial arrangement with 3 replications. Observations were recorded during the vegetative growth stage for both lodged and unlodged fields and included:

(i) Plant height (cm)
(ii) Tillering ability (%)
(iii) Culm length and diameter (cm)

Lodging assessment was computed in the following manner:

(i) % of area lodged
(ii) Degree of lodging, where
0 = main stem vertical
100 = main stem horizontal

$$\text{Lodging index} = \frac{\%\ \text{area lodged} \quad x \quad \text{degree of Lodging}}{100}$$

Yield component analysis included chalkiness, filled spikelet and grain yield ($t\text{-}ha^{-1}$).

Study 2

This trial was established at the same location and treatments of Trinexapac-ethyl applied to Oryzica 2. The treatment rates were lower than in Trial 1, being 0, 25, 30, 40 and 50 $g.ai.ha^{-1}$. All treatments were applied at 52 days after sowing (DAS) which was prior to flowering. Similar observations were recorded as for Trial 1. The trial was laid out in a randomized block design with 3 replicates.

In all trials, the experimental sites were part of a commercial rice production system. The fields were fallow for over six months between crops and were not used previously for pesticide or fertilizer evaluation. The same rice variety (var. Oryzica 2 or 3) 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 rotovation. 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

Table 1. Comparative morphological measurements of lodged and erect rice (variety Oryzica 2) without treatment.

Plant characteristic	Lodge	Erect	Mean	S.E [±]
Tillers (Nos.m^2)	137	103	120	7.74
Panicle (Nos. m^2	139	100	19	9.13
Plant height (cm)	117	118	119	1.31
Stem diameter	0.15	0.55	0.35	0.20
Base diameter	0.48	0.53	0.50	0.025

Table 2. The effect of 2 anti-lodging PGR on the Rice (Var. Oryzica 2 and Oryzica 3) plant height (cm).

Plant growth regulator	Rate [g.ai.ha^{-1}].	Plant height [cm]	
		Oryzica 2	Oryzica 3
		3 - 1 WBF	3 -1 WBF
Trinexapac-ethyl	20	Y = 97.4 - 0.025R R^2 = 98.8%	Y = 99.6 - 0.108 R R^2 =74.0%
Trinexapac-ethyl	30	Y = 97.0 - 0.05R R^2 = 90.8%	Y = 81.3 - 0.005R R^2 = 75.0%
Trinexapac-ethyl	40	Y = 97.9 - 0.05R R^2 = 90.9%	Y = 97.3 - 0.06R R^2 = 90.1%
Paclobutrizol	50	101	85.7
Paclobutrizol	100	105	86.0
Control		103.3	90.3
Mean		93.6	84.7
S.E [±]		4.17	

between treatments was 1.5 m, and between blocks 2.0 m. The PGRs 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 *l*.m^{-1}. The carrier was pipe borne water without any adjuvants. All data was subjected to statistical analysis, using the MINITAB package and generalized linear model, and subjected to the appropriate transformation where ever necessary. Rainfall data were recorded during the experimental period.

RESULTS AND DISCUSSION

Prior to conducting the two field studies, a field survey on some selected morphological traits was undertaken for one rice variety only (var. Oryzica 2) as it was available, and similar to that of the other test variety that were lodged or erect (Table 1). It was found that the lodged plants had more tillers and panicles than the erect plants. There were no variations in plants height. The stem diameter and plant base diameter for the erect plants were greater than that of the lodged plants.

Study 1

The effect of the two anti-lodging plant growth regulators – Trinexapac-ethyl and Paclobutrizol on plant height are present in Table 2. The results indicated that increasing the rates of Trinexapac-ethyl treatments caused a linear decline plant height, regardless of the time of application compared to the control and Paclobutrizol. There was no significant varietal response between varieties. Generally, both PGR's did not influence the reproductive capacity of the two varieties and had no significant effect on productive tillers (Table 3). This may be related to the time of application of the PGR, as the plant was not in its optimum vegetative phase (and photosynthetic capacity), and after this only translocation and partitioning of assimilates occurred, and therefore would not correlate with yield. Trinexapac-ethyl at all rates applied 3WBF increased grain filling and yield in Oryzica 2. However, its effect on Oryzica 3 was variable, and only had a significant response when applied at 30 g.ai.ha^{-1} at 2 and 3WBF (Table 4). Both Trinexapac-ethyl and Paclobutrizol had no effect on final grain yield for Oryzica 2. However, for Oryzica 3, Trinexapac-ethyl at 20 g.ai.ha^{-1} had the highest yield (Table 4).

Study 2

This study confirmed and validated that increasing the rates of Trinexapac-ethyl reduced the plant height linearly of var Oryzica 3 (Table 5). Generally, the % filled

Table 3. The effect of 2 anti-lodging PGR's on the Rice (Var. Oryzica 2, and Oryzica 3) % productive tillers.

Plant growth regulator	Rate [g.ai.ha^{-1}]	% productive tillers					
		Oryzica 2			Oryzica 3		
		3WBF	2WBF	1WBF	3WBF	2WBF	1WBF
Trinexapac-ethyl	20	67	66	69	66	74	74
Trinexapac-ethyl	30	73	59	68	75	68	68
Trinexapac-ethyl	40	67	67	67	73	75	72
Paclobutrizol	50		72			69	
Paclobutrizol	100		67			75	
Control			70			74	
Mean			88.03			72.47	
S.E [±]					3.27		

Table 4. The effect of 2 anti-lodging PGR's on the rice (varieties Oryzica 2, and Oryzica 3).

Plant growth regulator	Rate [g.ai.ha^{-1}]	Yield t.ha^{-1}					
		Oryiza 2			Oryzica 3		
		3WBF	2WBF	1WBF	3WBF	2WBF	1WBF
Trinexapac-ethyl	20	2.2	2.3	1.5	2.8	1.9	2.6
Trinexapac-ethyl	30	2.3	1.9	1.7	3.0	3.4	2.1
Trinexapac-ethyl	40	2.1	1.2	1.2	2.1	2.3	2.2
Paclobutrizol	50		2.3			2.8	
Paclobutrizol	100		1.7			2.2	
control			2.2			2.8	
mean			1.5			2.5	
SE					0.4		

Table 5. The effect of Trinexapac-ethyl on the growth development and yield of rice variety Oryzica 3

Treatment rate (g.ai.ha^{-1})	Plant height(cm)	Filled spikelet (%)	Yield (t.ha^{-1})	Chalkiness (mature grains %)
0	125	86	2.01	1.5
25	108	88	3.5	1.1
30	106	89	3.03	0.8
45	106	90	3.28	0.9
50	99	89	3.28	1.8
x	108.7	88.2 [0.59	3.03	1.2 [0.16]
	$Y_{pl.ht}$ =123 - 0.46 rate: R^2 = 89.2%	**NS**	**Y_{yld} =2.32+ 0.02 rate: R^2 = 60%**	**NS**

spikelets were higher in Study 2 compared to Study 1. Increasing the rates of Trinexapac-ethyl, similary increased yield linearly (Table 5), and at 50 g.ai.ha^{-1}of the PGR, the plant was the shortest and yield highest. In all treatments, the quality in terms of chalkiness was below the acceptable level of 2.0%.There were no significant effects of the treatment on the plant tissue and soil analysis (Table 6). There was 2 to 4% increase in the percentage of filled spikelets compared to the control. This manifested itself more significantly in grain yield. The result show that all the treatments gave significantly increased yield by 1.0 to1.5 t.ha^{-1} over the control (Table 5). The level of chalkiness among treatments was not critical, and all had less than 2% chalkiness. There was

Table 6. Leaf tissue and soil analysis of rice variety Oryzica 3 treated with Trinexapac-ethyl at 9 WAS.

Treatment rate (g.ai.ha^{-1})	NPK content (%)					
	Leaf Tissue			Soil Analysis		
	N	P	K	P	K	pH
0	3.27	0.30	2.31	10.00	129.33	5.20
20	3.02	0.31	2.31	10.67	140.00	5.18
30	3.17	0.28	2.19	9.67	134.67	5.25
40	2.93	0.31	2.15	8.67	143.33	5.32
50	3.15	0.31	2.25	10.0	129.33	5.14

no evidence of lodging during the experimental period.

The 2 PGR's under study are not commonly used in small farm production where manual harvesting is practiced. However, in commercial production systems, and where the use of combined harvesters are common, lodging is intolerable. Not only this reduced yield, losses from submerged or partial wet plants leads to further deterioration of grain quality. Both Paclobutrazol and Trinexapac-ethyl are antagonist of the plant hormone gibberellin, and inhibiting gibberellin biosynthesis, thereby reducing inter-nodal growth to give stouter stems, increasing root growth, causing increasing grain filling.

Similarly, they are both synthetic plant growth regulator applied as a foliar spray post-emergence, and are translocated to the growing shoot. They act as inhibitors of the action of a key enzyme in the formation of gibberellic acid (GA1), preventing the formation of the plant growth regulator gibberellins which promotes cell elongation. In the absence of gibberellins, the internodes of the plants fail to grow and prevent the plant from growing taller. As a result they reduce or prevent lodging, and increase the yield in crops by redirecting energy into the production of reproductive parts. This study confirmed that Trinexapac-ethyl as a PGR reduced plant height and the incidence of lodging in var Oryzica 3, and similarly improved yield over the control by 1.17 t.ha^{-1}. This is a significant improvement given the cost of the treatment and application, although it may appear low compared to international standards.

Conflict of Interest

The authors have not declared any conflict of interest.

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