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Interaction between N-fertilizer and water availability on borer-rot complex in sugarcane

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Abstract

This study aimed to evaluate the effects of nitrogen availability in fertigation and rainfed management, as well as their interactions with the incidence of and damage caused by ***D. saccharalis*** and red rot in sugarcane. The experiment consisted of four treatments (0 and 150 kg ha^{-1} of N-fertilizer with irrigation; 0 and 150 kg ha^{-1} of N-fertilizer in rainfed management) in a randomized complete block design with four replications. The evaluated parameters were the number of holes and internodes with red rot per meter of cultivation, stalk yield and sugar content. In the laboratory (T = 25 ± 2 °C; R.H. = 70 ± 10%: 12:12-L:D), we evaluated the attractiveness and consumption of fragments of stalks from the different treatments for fourth instar larvae through choice and no-choice tests in a randomized complete block design with ten replications. Nitrogen fertilization via irrigation has favorable effects on borer-rot complex and leads to higher gains in stalk and sugar yields when compared to rainfed management. The increments of stalk and sugar yields due to nitrogen fertilization compensates for the increase in borer-rot complex infestation. In laboratory tests, ***D. saccharalis*** larvae were similarly attracted to all treatments regardless of the doses of N-fertilizer or the water regimes evaluated. However, fragments of sugarcane stalks produced with nitrogen fertilization were consumed more by ***D. saccharalis*** in both water regimes.

Key words: *Diatraea saccharalis*, irrigation, red rot, *Saccharum* sp.

1. INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is considered to be one of the most important crops in the world, and acreage has been constantly expanding (Silva et al., 2012). Powered by a consolidated sugarcane market, Brazil is the world's largest producer of raw sugarcane (Vale et al., 2011). Nevertheless, due to several factors, such as low fertility (Vale et al., 2011), water deficiency (Oliveira et al., 2011; Wiedenfeld & Enciso, 2008), and attacks by insect pests (Oliveira & Andrade, 2009), expanded cultivation and increased productivity have remained limited (Carvalho et al., 2011).

An adequate water supply is an essential factor for crop production; both a lack and an excess of water can be harmful to the culture. The irregular distribution of rain can limit the growth of the crop and require irrigation. However, crop responses may depend on several factors, such as the relationship between the amount of applied water and nutrient availability (Gava et al., 2011), especially nitrogen (Oliveira et al., 2011).

Research has shown that sugarcane yield is positively correlated with the availability of water and nitrogen (Pannuti et al., 2013; Thorburn et al., 2003). However, to achieve the maximum yields with nonlimiting water and nutrients, other factors must be effectively controlled, such as pests and diseases (Waclawovsky et al., 2010). Furthermore, those practices that promote higher productivity have also resulted in an increased occurrence of pests, mainly *Diatraea saccharalis* (Fabr.,1794) (Dias et al., 2011).

This insect causes galleries inside the stalks, resulting in a severe loss of yield, mainly due to infection with opportunistic microorganisms (genera *Colletotrichum* and *Fusarium*) that cause "red rot". These factors lead to sugar content reduction (Dinardo-Miranda et al., 2011) and reduce the quality and longevity of the crop (Oliveira & Andrade, 2009).

Recently, Pannuti et al. (2013) reported a positive correlation between water and nitrogen availability and the incidence of and damage caused by the borer-rot complex in sugarcane. Although both factors (nitrogen fertilization and water availability) are known to affect the incidence of important pests (Schoonhoven et al., 2005), there are no studies reporting the effects of nitrogen fertilization in different water regimes on the borer-rot complex.

Sugarcane has been expanding in a fast and disorderly manner in non-traditional growing areas, which require fertilization and especially irrigation for cultivation (Vianna & Sentelhas, 2014). Although *D. saccharalis* has been a constant target of studies in the past, baseline information on the management of this important pest is still necessary to effectively prevention sugarcane damage under these new conditions.

Furthermore, considering the great potential of large areas of suitable cropland in Africa with similar weather conditions, including irrigated areas (Watson, 2011), this information may be valuable for the management of pests that cause similar damage to sugarcane in this region, such as *Eldana saccharina* (Berry et al., 2010; Leslie, 2004). Thus, this study evaluated the effects of nitrogen availability in fertigation and rainfed management, as well as their interactions with the incidence of and damage caused by *D. saccharalis* and red rot in sugarcane.

2. MATERIAL AND METHOD

Field experiment

This research was carried out in Jau, Sao Paulo, Brazil (latitude 22°17' S, longitude 48°34' W and an average elevation of 580 m). The soil was classified as red latosol (Santos et al., 2006) with a clay texture, and the sugarcane cultivar was SP80-3280 (4th and 5th cut) during crop years 2009/2010 and 2010/2011.

A randomized complete block design with four replications and four treatments was conducted in a 2 × 2 factorial arrangement. The treatments were composed of: (1) 0 kg ha^{-1} of N-fertilizer with irrigation; (2) 150 kg ha^{-1} of N-fertilizer with irrigation, (3) 0 kg ha^{-1} of N-fertilizer without irrigation and (4) 150 kg ha^{-1} of N-fertilizer without irrigation.

Each plot consisted of five lines (30 m in length) subdivided into three subplots of 10 m in length. Two subplots were used for sequential measures of *D. saccharalis* and the third to determine the productivity of the sugarcane. Planting in double lines was adopted with a spacing of 1.80 m between the double lines and a drip irrigation system underground. The drip pipe was buried 20 cm under the soil surface in the middle of the double line. The drip pipe utilized was the DRIPNET PC 22135 FL (Netafim, Israel) with a flow rate of 1.0 L h^{-1} with drippers every 0.5 m. Potassium fertilization was similar for all treatments (150 kg ha^{-1} of K_2O as potassium chloride) and was applied during the development of the culture through fertigation. The different doses of N-fertilizer, in the form of urea, were also distributed throughout the crop cycle through fertigation.

The amount of applied irrigation was measured by tensiometry and daily crop evapotranspiration, according to the Penman-Monteith equation, aiming to replace 100% of the water that evapotranspirated. Estimates of decennial water balance and water deficit (DEF) were prepared and calculated for the 2009/2010 and 2010/2011 agricultural years. The amount of precipitation that occurred during the 2009/2010 season was 1.435 mm, and the amount of applied irrigation was 390 mm, distributed throughout the growth cycle of the crop (irrigated management, 1.825 mm). The means of the maximum and minimum temperatures observed during the experimental period were 29.1 and 16.4 °C, respectively. During the 2010–2011 season, the precipitation that occurred was 1.462 mm, and the amount of applied irrigation was 265 mm, distributed throughout the growth cycle of the crop (irrigated management, 1.727 mm). The means of maximum and minimum temperature observed during the experimental period were 32.2 and 13.1 °C, respectively.

To evaluate the incidence of borers in the field, one meter of sugarcane per plot was sampled by separating the dried leaves, stalks and the tip (green leaves, stalks and palm). In the sampled stalks, the total number of internodes per meter was counted and the total number of borer holes in each plot was also recorded. Each stalk was longitudinally separated, and the rot incidence was evaluated (Pannuti et al., 2013). The parameters observed were the total number of holes and number of internodes with red rot per meter of cultivation. Four evaluations were carried out: April (208 DAC (days after cut)) 2010 and July (291 DAC) 2010; March (165 DAC) 2011 and July (285 DAC) 2011.

To obtain mass data, the sampled stalks (without straw) from each plot were weighed on a load cell type balance with a 200 g graduation. For all evaluations, 10 stalks were subsampled in each plot. The subsamples were sent to the Laboratory of Technology of the Associcana (Association of the Sugarcane Producers from Jau), in Jau, Sao Paulo, Brazil, to obtain the sugar %, fiber %, reducing sugars and total recoverable sugar (ATR) values, according to the method of CONSECANA (2003). The stalk yield (Mg ha^{-1}) was obtained through a proportional relationship with the area of each plot. The sugar yield (Mg ha^{-1}) was obtained by multiplying the stalk yield and the percentage of sugar (PCC) (Gava et al., 2011).

Bioassays of D. saccharalis

At the same time as the field experiment, *D. saccharalis* was reared (T = 25 ± 2 °C; R.H. = 70 ± 10%: 12:12-L:D) following the methodology of Pannuti et al. (2013) and

Parra (2001). The rearing began with pupae of *D. saccharalis* from the DuPont Company (Paulínia Experimental Station, Sao Paulo). The sugarcane borer pupae were placed in PVC cages. Each cage was 10 cm in diameter and 20 cm in height and was internally covered with bond paper for oviposition. The cages were covered on top with voile fabric, and the bottom was supported with a Petri dish covered with filter paper. After adult emergence, a piece of cotton was soaked in 10% honey solution and put in each cage. The piece of cotton was changed every two days (Parra, 2001).

The eggs were collected daily by cutting out the sulfite paper containing the egg mass. The eggs were sterilized with 5% formaldehyde for five minutes and then washed with distilled water for the same period. After drying, the eggs were put into of vials with an artificial diet. The larvae remained in the vials until the bioassays (Parra, 2001). Attractiveness and consumption were evaluated through choice and no-choice tests using the same treatments described for the field study.

For the choice test, fragments of sugarcane stalk (peeled) from each treatment were equidistantly arranged in a circle in aluminum arenas (50 cm in diameter × 5 cm high). The bottom was lined with moistened filter paper. The fragments were removed from the sixth internode (starting from the ground) of stalks from each treatment (10 g per fragment).

Fourth instar larvae were released in the center of the arenas at a proportion of two larvae per treatment, totaling eight larvae per arena. The trays were sealed with clear plastic film with small holes for air intake. Each arena represented a replication, and there were 10 replications in total in a randomized complete block design. The number of larvae feeding on each of the treatments was counted at 2, 6, 24 and 48 hours after infestation. After a period of 48 hours, the larvae were removed from the treatments. The fragments were dried with circulating air at 60 °C for 72 hours. Consumption was determined by calculating the difference between the dried fragment (portion without infestation) and the infested dried fragment. For each treatment, the weight of the dried fragment without infestation was calculated by taking the mean of 10 fragments (replications).

For the no-choice test, fragments from the same treatments were individually placed inside plastic vials (50 ml). Each vial was lined with moistened filter paper on the bottom and infested with two fourth instar larvae of *D. saccharalis*. The consumption was determined following the same protocol described for the choice test. Each vial represented a replication (10 per treatment) in a completely randomized design.

The results of the field variables, the number of holes and the number of internodes with red rot, were transformed by $(x+0.5)^{1/2}$. The other results were not transformed. For the laboratory assays, the larvae number results were transformed by $(x+0.5)^{1/2}$. The other results were not transformed, according to the method of Banzatto & Kronka (2006).

All of the results were subjected to analyses of variance using the F test at the 5% significance level and compared using Tukey's test. The software utilized was Sisvar version 5.0 (Lavras, MG, Brazil).

3. RESULTS AND DISCUSSION

Field experiment

In general, the mean number of holes caused by larvae was higher in treatments that received nitrogen fertilization. However, significant differences were observed only in the evaluation on July 2010, where the treatment with 150 kg ha^{-1} of N-fertilizer had an average (55.13 holes) that was more than twice as high as the treatment without nitrogen (24.13 holes) (Table 1).

In 2010, when comparing water regimes, there was a significant increase in the number of holes under irrigated cultivation in both of the evaluations. In 2011, there were no significant differences between the water regimes (rainfed and irrigated managements) (Table 1). In July 2010, a significant interaction was observed between the variable doses of N-fertilizer and water availability. The use of nitrogen fertigation with 150 kg ha^{-1} of N-fertilizer significantly increased the number of holes caused by *D. saccharalis* when compared with the same dose of nitrogen utilized in rainfed management. Among the treatments with irrigation, a higher mean number of borer holes was also observed in the treatment that received nitrogen fertilization (Table 1).

The temperature and relative humidity observed most likely affected the insect incidence during the 2011 evaluations because the population was reduced in all treatments. A general review of the data in 2010 (Table 1) reveals an increase in the number of holes caused by *D. saccharalis* with N-fertilizer (150 kg ha^{-1}) when compared to the treatment without nitrogen. The averages in July 2010 also indicated that there was an increase in holes with an application of 150 kg ha^{-1} of N-fertilizer combined with the use of irrigation. In a study that investigated the influence of nitrogen fertilization through drip irrigation on the incidence of *D. saccharalis* in sugarcane, Pannuti et al. (2013) reported a positive correlation between the doses of nitrogen and the number of holes caused by the sugarcane borer. In this study, nitrogen fertilization was found to favor the insect attacks mainly in irrigation management but was not observed in rainfed conditions.

The use of irrigation may have caused higher nitrogen accumulation in the stalks, which could be beneficial in the immature stages of the insect. Nitrogen fertilization favors infestation by several insect species because it increases the levels of soluble nitrogen, mainly as free amino acids, resulting from alterations in the quantity and quality of nitrogen

Table 1. Means (± SE) and interactions between the number of holes per meter caused by *D. saccharalis* in sugarcane without nitrogen and with 150 kg ha^{-1} of N-fertilizer in rainfed and irrigated managements

	April 2010[1]	July 2010[1]	March 2011[1]	July 2011[1]
Doses of N (kg ha^{-1})	Number of holes m^{-1}			
0	19.25 ± 6.99 a	24.13 ± 4.90 b	1.88 ± 0.64 a	17.75 ± 4.45 a
150	41.00 ± 9.00 a	55.13 ± 12.78 a	3.63 ± 1.56 a	22.00 ± 4.05 a
F (Doses)	5.28^{ns}	8.32*	0.79^{ns}	0.46^{ns}
Water availability				
Irrigated	42.38 ± 8,47 a	50.25 ± 14.45 a	1.88 ± 1.01 a	16.50 ± 2.66 a
Rainfed	17.88 ± 6,99 b	29.00 ± 3.82 b	3.63 ± 1.35 a	23.25 ± 5.21 a
F (Water availability)	8.88*	4.51^{ns}	1.62^{ns}	0.99 ^{ns}
F (D × Wa)	0.83^{ns}	10.34*	0.02^{ns}	2.00 ^{ns}
CV%	33.06	19.18	50.30	30.80

Interaction

Water availability	July 2010[1] Doses of N (kg ha^{-1}) 0	150
	Number of holes	
Irrigated	22.25 ± 8.87 aB	78.25 ± 19.35 aA
Rainfed	26.00 ± 5.58 aA	32.00 ± 5.58 bA

[1] Means within columns followed by the same lower-case letter or means within rows followed by the same upper-case letter are not significantly different by Tukey's test (p≤0.05). The data were transformed by $(x+0.5)^{1/2}$; SE = Standard error; * = significant; ^{ns} = not significant.

present in the plant and facilitates nitrogen assimilation by insects (Bortoli et al., 2005).

For the mean number of internodes with red rot, treatment with applied nitrogen (14.50) was observed to be associated with a value that was approximately twice as high as the treatment without N-fertilizer (7.63) in April 2010; however, the difference was not significant. In the same evaluation, the irrigated management had a higher incidence of internodes with red rot (15.13), which differed from the rainfed management (7.00). There was no significant interaction between the doses of N-fertilizer and water availability for this sample (Table 2). In July 2010, the highest mean number of internodes with red rot (26.38) was obtained with 150 kg ha^{-1} of N-fertilizer, which differed from the treatment without N-fertilizer. The analysis of water availability in this evaluation showed no significant differences between the managements. The interaction between doses of N-fertilizer and water regime was significant during this period.

For March and July 2011, significant differences were not detected between the treatments, and interactions between the factors were not significant (Table 2). The low infestation of *D. saccharalis* in these evaluations may have affected the interactions as well as the evaluation of the number of holes (Table 1).

A significant increase in internodes with red rot (9.75 to 36.75) was observed when nitrogen was used in the irrigated management. Regarding the effect of water availability on the treatments, there was a significant difference only for treatments with N-fertilizer. These results indicate that the utilization of fertigation with nitrogen considerably increased infestation with the borer-rot complex in July 2010 (Table 2).

Based on the results presented in tables 1 and 2, the number of internodes with red rot is positively correlated with the infestation and the number of holes caused by *D. saccharalis* in sugarcane. Pannuti et al. (2013) observed a direct relationship between the number of holes and the number of internodes with symptoms of red rot in sugarcane at a ratio of 2.5:1.

Red rot is caused by opportunistic microorganisms, such as *Colletotrichum falcatum* and/or *Fusarium moniliforme*. These microorganisms cause reductions in sugar content in the stalks due to inversion of the sucrose stored in the plant and its transformation into glucose and levulose (Dinardo-Miranda et al., 2011). Additionally, the data (Table 2) suggest that nitrogen fertilizer, especially under irrigated management, favors the incidence of rot. However, additional research is needed for a better understanding of the relationships between the occurrence of rot, nitrogen fertilizer and water availability in sugarcane.

For the sugarcane stalk yield, the results showed significant differences between the different doses of N-fertilizer in all evaluations. For the water availability variable and the interaction between nitrogen doses and water availability, there were also significant differences and interactions between the variables, except in March 2011 (Table 3).

During these periods, the application of 150 kg ha^{-1} of N-fertilizer permitted significantly higher productivity when compared with the treatments without nitrogen. Irrigation also significantly increased productivity when compared with rainfed management. The interaction revealed a significant increase in productivity with the application of 150 kg ha^{-1}

Table 2. Means (± SE) and interactions between the number of internodes with symptoms of red rot in sugarcaneper meter without nitrogen and with 150 kg ha⁻¹ of N-fertilizer in rainfed and irrigated managements

	April 2010[1]	July 2010[1]	March 2011[1]	July 2011[1]
Doses of N (kg ha^{-1})		Number of internodes m^{-1}		
0	7.63 ± 3.08 a	9.63 ± 2.15 b	0.13 ± 0.13 a	6.50 ± 1.45 a
150	14.50 ± 3.41 a	26.38 ± 5.33 a	0.25 ± 0.16 a	9.38 ± 1.86 a
F (Doses)	2.79^{ns}	13.88^{*}	0.30^{ns}	0.91^{ns}
Water availability				
Irrigated	15.13 ± 3.27 a	23.25 ± 6.49 a	0.13 ± 0.13 a	7.63 ± 1.53 a
Rainfed	7.00 ± 3.01 b	12.75 ± 1.73 a	0.25 ± 0.16 a	8.25 ± 1.94 a
F (Water availability)	3.43^{ns}	3.14^{ns}	0.53^{ns}	0.06^{ns}
F (D × Wa)	0.42^{ns}	6.13^{*}	4.77^{ns}	2.62^{ns}
CV%	45.09	23.40	22.12	31.29

Interactions

Water availability	July 2010[1] Doses of N (kg ha^{-1})	
	0	150
	Number of internodes	
Irrigated	9.75 ± 4.59 aB	36.75 ± 7.36 aA
Rainfed	9.50 ± 0.65 aA	16.00 ± 2.55 bA

[1] Means within columns followed by the same lower-case letter or means within rows followed by the same upper-case letter are not significantly different by Tukey's test (p≤0.05). The data were transformed by $(x+0.5)^{1/2}$; SE = Standard error; * = significant; ns = not significant.

Table 3. Means (± SE) and interactions between the stalk yield (Mg ha⁻¹) in sugarcane without nitrogen and with 150 kg ha⁻¹ of N-fertilizer in rainfed and irrigated managements (harvests in 2010 and 2011)

	April 2010[1]	July 2010[1]	March 2011[1]	July 2011[1]
Doses of N (kg ha^{-1})		**Stalk yield (Mg ha^{-1})**		
0	31.67 ± 1.94b	34.31 ± 2.18 b	20.82 ± 1.89 b	40.42 ± 2.07 b
150	53.89 ± 5.68 a	70.91 ± 6.03 a	31.16 ± 2.77 a	72.09 ± 5.59 a
F (Doses)	13.51*	50.46*	6.82*	33.50*
Water availability				
Irrigated	49.59 ± 7.25a	60.63 ± 9.80 a	24.79 ± 1.48 a	63.62 ± 8.51 a
Rainfed	35.98 ± 2.34b	44.59 ± 4.73 b	27.19 ± 4.03 a	48.89 ± 4.37 b
F (Water availability)	28.43*	25.70*	0.62^{ns}	15.98*
F (D × Wa)	33.27*	15.43*	4.52^{ns}	9.10*
CV%	11.93	12.03	23.33	13.10

Interactions

W. A.	April 2010[1]		July 2010[1]		July 2011[1]	
	Doses of N (kg ha^{-1})					
	0	150	0	150	0	150
	Stalk yield (Mg ha^{-1})					
I	31.11±2.36 aB	68.06±3.50 aA	36.11±3.86 aB	85.15±5.71 aA	42.23±3.82 aB	85.01±4.36 aA
R	32.22±3.42 aA	39.73±2.10 bA	32.50±2.24 aB	56.67±1.47 bA	38.61±1.78 aB	59.17±3.96 bA

[1] Means within columns followed by the same lower-case letter or means within rows followed by the same upper-case letter are not significantly different by Tukey's test (p≤0.05); SE = Standard error; W.A.= Water availability; I= Irrigated; R= Rainfed. Original data; * = significant; ns = not significant.

of N-fertilizer in the irrigated areas. However, the increase in productivity also occurred with rainfed management, except in April 2010. In general, the results have shown that the crop responded positively to increases in nitrogen fertilization and water availability during its growth cycle. Additionally, there was a significant increase in the stalk production of sugarcane (Table 3).

All of the results in table 3 indicate that the application of 150 kg ha⁻¹ of N-fertilizer through subsurface drip fertigation increases the yield when compared with the other management methods combined; this justifies the use of subsurface drip irrigation for sugarcane. Gava et al. (2011) obtained a 33% increase (plant and ratoon cane) in stalk yield by utilizing fertigation for the same genotype (SP80-3280) and quantity of N-fertilizer (150 kg ha⁻¹) when compared with rainfed management in plant cane and ratoon. An increase in yield due to water availability was also observed in the present study for the same 4th and 5th cut of sugarcane, indicating that the use of irrigation through a drip system ensures higher yields for up to 5 years (5th cut) of cultivation when compared to rainfed management, which may postpone renewal on sugarcane plantations.

Regarding water availability, Dalri & Cruz (2008) verified that the highest yields were found in irrigated plots in third-cut sugarcane, variety RB72-454. Among the irrigated plots, the authors observed a significant increase in sugarcane yield when using subsurface drip fertigation due to increases in N and K during the crop development cycle. The authors also obtained higher yields with higher doses. Silva et al. (2009) observed a relationship between stalk yield and the doses of N-fertilizer in irrigated sugarcane using a center pivot sprinkler and the SP71-6949 variety. According to these authors, the highest yields were obtained with higher doses of N-fertilizer. These results corroborate the present findings, where the use of N-fertilizer and irrigation favored an increase in sugarcane stalk yield despite using different cultivars, irrigation systems, and cut ages.

Although nitrogen fertilization and irrigation have already been related to increases in sugarcane stalk yields in the literature, there are few studies reporting the interaction of both types of management (water availability and N-fertilizer). Our findings allowed the verification of an additive effect on stalk yield when nitrogen was provided through drip irrigation. According to Thorburn et al. (2003), this effect may occur due to drip irrigation (fertigation), which results in a more efficient use of the fertilizer by the crop when compared to conventional fertilization.

The use of nitrogen fertilization and water availability provided a significant increase in sugar yield in all of the plots, except in March 2011(Table 4). In these evaluations, there was a significant interaction between the quantity of nitrogen applied and water availability management, except in March 2011, when there was no interaction between the factors. Based on these interactions (Table 4), we verified that the use of N-fertilizer (150 kg ha^{-1}) resulted in sugar productivity gains in the plots and differed significantly from the treatment without nitrogen. In addition, the use of irrigation combined with 150 kg ha^{-1} of N-fertilizer outperformed the rainfed treatments with 150 kg ha^{-1} of N-fertilizer in the three samples. The presence of water favored the absorption of this element, and consequently, productivity was increased.

In general, the use of nitrogen and irrigation increased the production of sugar in sugarcane, and the combination of these factors showed an additive effect. Gava et al. (2011) verified that there was an additional TPH (tons of pol per hectare) due to irrigation and fertilization through fertigation during the first and second sugarcane cycle (genotype SP80-3280) when compared with rainfed management using the same dose of N-fertilizer through conventional fertilization in Jau, Sao Paulo. This additional gain in sugar accumulation due to fertigation seems to persist for up to 5 years (5th cut) of cultivation for this cultivar when compared to rainfed management, as observed in the present study. Moura et al. (2005) observed a sugar yield increase of 22.8% in irrigated areas of sugarcane, using the center pivot system, when compared with sugarcane without irrigation. The same authors observed a significant positive response in sugar yield for both irrigation and fertilization with N and K by coverage. Nevertheless, the authors observed no significant interactions between fertilization doses and water availability. Comparing both studies, increases in sugar yield seem to be associated with increases in N-fertilizer and irrigation regardless of the sugarcane cultivar, fertilization and irrigation

Table 4. Means (± SE) and interactions between the sugar yield (Mg ha^{-1}) in sugarcane without nitrogen and with 150 kg ha^{-1} of N-fertilizer in the irrigated and rainfed managements (harvests of 2010 and 2011)

	April 2010[1]	**July 2010[1]**	**March 2011[1]**	**July 2011[1]**
Doses of N (kg ha^{-1})		**Sugar yield (Mg ha^{-1})**		
0	3.76 ± 0.21 b	5.60 ± 0.31 b	1.83 ± 0.17 a	6.34 ± 0.36 b
150	6.21 ± 0.54 a	11.07 ± 0.78 a	2.61 ± 0.22 a	11.35 ± 0.90 a
F (Doses)	17.25*	55.17*	5.25ns	32.39*
Water availability				
Irrigated	5.66 ± 0.72 a	9.39 ± 1.41 a	2.16 ± 0.15 a	10.06 ± 1.33 a
Rainfed	4.31 ± 0.36 b	7.29 ± 0.73 b	2.28 ± 0.31 a	7.63 ± 0.72 b
F (Water availability)	13.05*	24.35*	0.15^{ns}	16.95*
F (D x Wa)	10.84*	16.16*	1.95^{ns}	8.49*
CV%	14.94	10.19	26.59	13.36

Interactions						
W.A.	**April 2010[1]**		**July 2010[1]**		**July 2011[1]**	
	Doses of N (kg ha^{-1})					
	0	**150**	**0**	**150**	**0**	**150**
	Sugar yield (Mg ha^{-1})					
I	3.82±0.21 aB	7.50±0.31 aA	5.80±0.55 aB	12.97±0.65 aA	6.70±0.64 aB	13.43±0.58 aA
R	3.70±0.40 aB	4.93±0.43 bA	5.41±0.35 aB	9.17±0.19 bA	5.99±0.34 aB	9.27±0.73 bA

[1] Means within columns followed by the same lower-case letter or means within rows followed by the same upper-case letter are not significantly different by Tukey's test (p≤0.05); SE = Standard error; W.A.= Water availability; I= Irrigated management; R= Rainfed management. Original data; * = significant; ^{ns} = not significant.

system. However, the present findings showed an additive effect between N-fertilizer and irrigation, which may be related to better use of the nitrogen distributed through drip irrigation along the cultivation.

However, this increase seems to be directly correlated to higher stalk yields, as observed in table 3. Dalri & Cruz (2008) obtained similar results by observing a significant effect on ratoon and second ratoon management in sugarcane (cultivar RB 72454) that was irrigated through a subsurface drip and utilized the same doses of N and K. Otto et al. (2009) concluded that nitrogen fertilization in sugarcane (cultivar SP81-3250), cultivated in eutrophic red-yellow latosol, increased the dry mass growth of the aerial parts of the plant.

Bioassays of D. Saccharalis

There were no significant differences among the treatments in any of the attractiveness evaluations with larvae of *D. saccharalis* (Table 5). These results suggest that there are no attractant and/or repellant factors in the sugarcane stalks, regardless of the doses of nitrogen and water availability used in this study. Another explanation may involve the behavioral characteristics of the insect because adults determine the choice of appropriate locations and respond to volatiles from the hosts. These volatiles are compounds of simple or complex mixtures, which can be stable or unstable, that are transported by wind at certain temperatures. These compounds are produced by plants and attract adults for feeding and in some cases are involved in physiological processes such as reproduction and mating (Tinzaara et al., 2002).

Although there were no significant differences in attractiveness in the choice test, we verified that there was a higher consumption of stalk fragments that were produced with higher doses of N-fertilizer and irrigation. The means were 0.21 g for both conditions (Table 5). The consumption results in sugarcane stalk fragments suggest greater palatability in the treatments with greater water availability and higher doses of N-fertilizer through fertigation. Although the increases in the doses of N-fertilizer and irrigation promoted an increase in the consumption of stalk fragments by larvae, the interaction between these variables was not significant in the choice tests.

In the no-choice test, a higher consumption of stalk fragments produced with higher doses of N-fertilizer was also observed, but it did not differ significantly from the treatment without nitrogen. Regarding water availability, there was higher mean consumption by *D. saccharalis* observed in the treatment with irrigation (0.25 g) than in the rainfed treatment (0.11 g). There was no significant interaction between the variables (Table 6), as observed for the choice test. Awmack & Leather (2002) emphasized that the quality of plant components may interact with the responses of species to host plants. Changes in the availability of nitrogen can vary consumption responses in herbivores. These same authors reported that *Anticarsia gemmatalis* (Lepidoptera: Noctuidae) larvae reared on artificial diets with the addition of water increased food consumption and the conversion efficiency of nitrogen.

Irrigation depths may modify the levels of primary and secondary metabolites of the plants, as occurs in coffee. Under conditions of water stress, the host plant shows varying metabolite levels that alter many biological aspects of the insects (Awmack & Leather, 2002). In addition, secondary metabolites are also important in the insect-plant relationship because they act as toxic allelochemicals to insects (Ashihara & Crozier, 2001).

In general, the results reveal that the use of nitrogen fertilization via drip irrigation favor an increase of the incidence of and damage caused by the borer-rot complex. The results also suggest that the use of both managements together promotes a synergistic/additive effect on the incidence of the sugarcane borer, requiring continuous culture monitoring. However, the significant increases in stalk and sugar yield justify the combined use of these management strategies.

Table 5. Means (± SE) of*D. saccharalis* larvae attracted by stalk fragments and the total dry weight of the fragments consumed by *D. saccharalis* in sugarcane without nitrogen and with 150 kg ha^{-1} of N-fertilizer in the irrigated and rainfed managements, in choice tests

	Choice tests				
	Attractiveness (number of larvae)[1,2]				Consumption (g)[1]
Doses of N (kg ha^{-1})	**2 h**	**6 h**	**24 h**	**48 h**	
0	0.95 ± 0.16 a	1.00 ± 0.17 a	1.00 ± 0.17 a	1.10 ± 0.12 a	0.07 ± 0.02 b
150	1.20 ± 0.17 a	1.40 ± 0.25 a	1.50 ± 0.22 a	1.20 ± 0.19 a	0.21 ± 0.05 a
F (Doses)	0.93^{ns}	1.48^{ns}	3.25^{ns}	0.08^{ns}	10.32*
Water availability					
Irrigated	1.00 ± 0.13 a	1.00 ± 0.13 a	1.05 ± 0.14 a	1.05 ± 0.17 a	0.21 ± 0.05 a
Rainfed	1.15 ± 0.20 a	1.40 ± 0.27 a	1.45 ± 0.25 a	1.25 ± 0.13 a	0.07 ± 0.02 b
F (Water availability)	0.18^{ns}	1.10^{ns}	1.57^{ns}	0.85^{ns}	11.88*
F (D × Wa)	0.39^{ns}	0.30^{ns}	1.90^{ns}	0.85^{ns}	0.98^{ns}
CV%	19.52	21.29	18.24	17.13	68.62

[1] Means within columns followed by the same letter are not significantly different by Tukey's test (p≤0.05). Original data. [2] The data were transformed by $(x+0.5)^{1/2}$; SE = Standard error; * = significant; ^{ns} = not significant.

Table 6. Means (± SE) of the total dry weight of stalk fragments consumed by *D. saccharalis* in sugarcane without nitrogen and with 150 kg ha^{-1} of N-fertilizer in the irrigated and rainfed managements, in no-choice tests

No-choice tests	
Doses of N (kg ha^{-1})	**Consumption (g)**[1]
0	0.15 ± 0.03 a
150	0.21 ± 0.04 a
F (Doses)	1.47^{ns}
Water availability	
Irrigated	0.25 ± 0.03 a
Rainfed	0.11 ± 0.03 b
F (Water availability)	10.12*
F (D × Wa)	0.16^{ns}
CV%	54.79

[1] Means within columns followed by the same letter are not significantly different by Tukey's test (p≤0.05). Original data. SE = Standard error; * = significant; ^{ns} = not significant.

4. CONCLUSION

Although nitrogen fertilization via drip irrigation promotes more favorable conditions for the borer-rot complex, the increment of stalk and sugar yield caused by nitrogen (fertigation) fertilization compensates for the combined use of these management strategies.

In laboratory tests, *D. saccharalis* larvae showed similar attractiveness for all treatments regardless of the doses of N-fertilizer and water regimes evaluated. However, sugarcane stalk fragments produced with nitrogen fertilization are consumed more by *D. saccharalis* regardless of the water regimes.

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