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Impacts of plant spacing and nitrogen fertiliser on incidences and density of spotted and African pink stem borers in Tanzania

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ABSTRACT
Nitrogen fertilisation and plant spacing hold potential for the integrated management of rice insect pests. Field experiments were conducted in Kilombero, Tanzania to evaluate the effects of plant spacing and nitrogenous fertiliser on incidences and density of spotted and African pink stem borers. A $3 \times 4 \times 4$ factorial experiment was used in a randomized complete block design with three replications. Treatments included application of urea fertiliser at four levels (0, 40, 80, and 160 kg N ha^{-1}) and spacing at four levels (10 cm × 10 cm, 15 cm × 15 cm, 20 cm × 20 cm, and 25 cm × 25 cm). Nitrogen significantly increased dead hearts by 4.8%, white heads by 2.8% and stem borer larvae density from 0 to 5.6 larvae/m^2. Decreasing the planting density significantly increased dead hearts by 4.7%, white heads by 2.7% and stem borer larvae density from 0 to 5.4 larvae/m^2. The interaction of nitrogen fertiliser rates and plant spacing did not affect stem borer incidences nor larvae density, but did influence the rice yield.

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Chilo partellus; *Sesamia calamistis*; incidences; stem borer larvae density; nitrogen fertiliser; spacing; rice yield

1. Introduction

Rice (*Oryza sativa* L.) is attacked by numerous insect pests, both in the field and in storage. The most important insect pests of rice in the field reported in Africa include the lepidopterous stem borers, spotted stem borer, *Chillo partellus* Swinhoe, and African pink stem borer, *Sesamia calamistis* Hampson, which belong to the Crambidae and Noctuidae families (Leonard and Rwegasira 2015), and the dipterous stem borer, Stalk eyed fly, *Diopsis thoracica* Westwood, which belongs to the Diopsidae family (Banwo 2002). Of all rice stem borer species, *Chilo* spp has been reported as the most injurious insect pest in Tanzania (Leonard 2015; January et al. 2018a). Stem borers infest rice crops from the nursery through to harvesting by attacking the tillers and panicles, particularly at panicle initiation stage (Ranasinghe 1992; Sarwar 2011). The larvae (the destructive stage) bore into rice stems and hollow out the stem completely, resulting in damage to the plant.

The damage intensity depends on the growth stage of the plant that is attacked by stem borers (Indike 2002). When stem borers infest a plant during the vegetative stage, it causes a symptom of damage called 'dead heart' (Pathak and Khan 1994). This occurs as a result of the larvae feeding on the terminal shoot, and causes the stem to turn brown, wilt, and die. If the infestation occurs during the flowering stage, it results in a symptom of damage known as 'white head'. This causes the panicles to bear empty spikelets (Pathak and Khan 1994). Stem borer damage incidences of approximately 30-50% of plant tillers have been reported in many rice-producing countries in Africa (Ogah 2013). It is estimated that for every 1% incidence of white heads, the expected yield loss will be 1-3% (Touhidur et al. 2004). In Tanzania, dead heart incidences ranged from 0.56% to 7.57% and white head incidences ranged from 0.34% to 2.89%; substantial yield losses of 3–9% due to stem borers have been reported (Leonard 2015).

Chemical insecticides have been suggested for use in controlling the stem borers *Scirpophaga incertulas* Walker (Prasad and Gupta 2012), *Chilo* spp. and *S. calamistis* (United Republic of Tanzania 2014), but most are reportedly ineffective owing to the cryptic nature of the pest attack (January et al. 2018b). Chemical insecticides also need to be minimized owing to their harmful side effects for humans, animals, and birds, as well as their negative effects on the environment and beneficial organisms (Singh et al. 2015). Attempts to avoid the excessive use of

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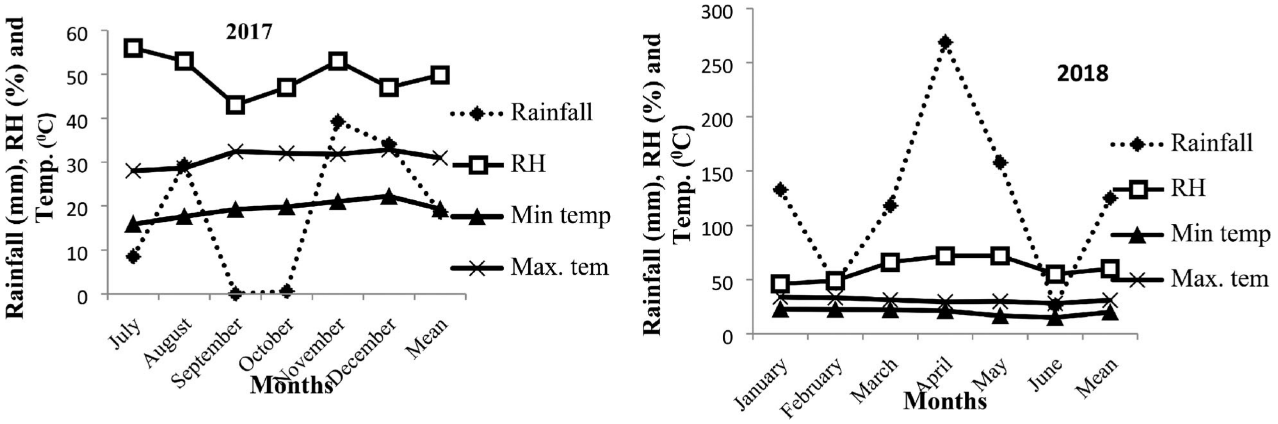

Figure 1. Weather data (Rain fall, relative humidity (RH) and temperature (temp.) of Kilombero valley during 2017 and 218 crop seasons.

insecticides have prompted interest in cultural, physical, and biological control options in most rice cultivating countries of Asia (Zhu et al. 2017) and Africa (Rami et al. 2002; Nwilene et al. 2013). Although physical and biological control options are challenging to implement, cultural control options are often practical and manageable by farmers. The control of plant spacing and the amount of fertiliser applied as either basal or top dressing on crops has been reported to reduce infestation and subsequent damage caused by *C. partellus* in maize (Ali 2006; Arshad et al. 2013). This study aims to determine whether a similar outcome can be achieved with rice. Moreover, the study aims to help in striking an ecological balance between stem borer control and yield increases to ensure sustainable food production with minimal environmental effect, while sustaining resources for future generations (Nwilene et al. 2013).

Manipulation of nitrogenous fertiliser rates and plant spacing can impact insect pests, and can be used as cultural practices within integrated management programs (Ogah et al. 2005). Chabi-Olaye et al. (2006) reported that high infestation rates of the African stem borer, *Busseola fusca* Fuller, were linked to high nitrogen fertiliser rates. Dense spacing in rice can change crop growth, development, and microclimate, which can affect insect pests and their natural enemies (Litsinger 1994). Wide plant spacing treatments encourage the growth of other plants, including weeds. This leads to an increase in plant biodiversity, which can also lead to an increase in the diversity of arthropods some of which can act as natural enemies to major pests. Litsinger (1994) reported that wide spacing in rice encourages weeds and can have an indirect effect on insect abundance. Nevertheless, the presence of weeds in rice fields can either be beneficial or not in terms of impact on insect pests. In some cases, the vegetation diversity inherent to the presence of weeds supports a higher number of arthropod prey, and that in turn supports natural enemies of the pest species (Showler 2004). However, in some cases, such increases in biodiversity might exert a competitive effect on the crop, weakening crop vigour and promoting susceptibility to insect pests and diseases.

The potential of cultural control practices in the management of rice stem borers have not been exploited by many African farmers (Rami et al. 2002). Available data are limited to support the role of nitrogenous fertilisers and plant spacing in promoting or deterring damage by rice stem borers (Baidoo 2004; Ogah et al. 2005; Ali et al. 2006; Wale et al. 2006). The interaction effects of stem borers and nitrogen fertiliser on rice have received little interest in the literature (Sarwar 2012). In sub-humid areas with heavy rainfall, such as Tanzania, substantial losses of nitrogen are encountered through leaching. In these regions, understanding the interaction effects of fertiliser and plant spacing could assist with increasing the productivity of rice through fertiliser usage and stem borer management. This study, therefore, reports on the combined effects of fertilisers and plant spacing on stem borer damage in rice.

Materials and methods

Description of the study site

A study was conducted over two consecutive years on a lowland rice crop grown under irrigation in the Kilombero District, Tanzania. Three wards, Sanje (7° 45′ 33.1981″ S, 36° 55′ 15.0247″ E; 307.788 m a.s.l.), Mkula (7° 46′ 4.2672″ S, 36° 56′ 43.4076″ E; 261.27 m a.s.l), and Signali (8° 0′ 1.4234″ S, 36° 50′ 13.5179″ E; 264 m a.s.l) were included in the study. The sites are major producers of rice and *Chilo* spp and *S. calamistis* are the major stem borer species (January et al. 2018b). The growing seasons covered the period from July to November in 2017 and from February to June in 2018. The three wards experience bimodal rainfall pattern characterized by two rainfall peaks in a year, with a definite dry season separating the short and long rains. The short rain season is from July to December while the long rain season starts from March and ends in May (Msanya et al. 2003). The meteorological data for 2017 and 2018 are shown in Figure 1. The experimental sites were flat, with a mean rainfall of 124.88 mm, a minimum temperature of 19 °C, a maximum temperature of 30 °C, and a relative humidity of 50% during the 2017 season, and a mean rainfall of 49.83 mm, a minimum temperature of 20 °C, a maximum temperature of 31 °C, and a relative humidity of 60% during the 2018 season. Meteorological data only considered the period during which experiments were conducted.

Soil sampling

Soil samples were taken from each experimental field at least three months prior to planting and sent for analysis to the Department of Soil Science Commercial Testing Laboratory, Sokoine University of Agriculture, Morogoro, Tanzania, to determine the physical and chemical properties of the soil.

Experimental design and planting

A $3 \times 4 \times 4$ factorial experiment was used in a randomized complete block design (RCBD) with three replications. Treatments included three locations (Sanje, Mkula, and Signali wards), urea fertiliser applied at four levels (0, 40, 80, and 160 kg N ha^{-1}) and plant spacing at four levels (10 cm × 10 cm, 15 cm × 15 cm, 20 cm × 20 cm, and 25 cm × 25 cm). Using these plant spacing treatments, the estimated planting densities were 1,000,000., 444,444., 250,000, and 160,000 plants ha^{-1}, respectively. The nitrogen rates and spacing used were selected based on recommendations suggested by Mbaga et al. (2017) for nitrogen rates of $50 - 200$ kg N ha^{-1} and Reuben et al. (2016) for spacing of 15 cm × 15 cm, 20 cm × 20 cm, 25 cm × 25 cm, 30 cm × 30 cm and 35 cm × 35 cm for optimum yielding of rice in most Tanzanian soils. The tested N levels were nested within plant spacing such that levels N levels were included as subplots within main plots that differed in plant spacing. The rice cultivar 'TXD 306', which is commonly grown by many farmers and is known to be susceptible to stem borers, was used. The total experimental area at each site (ward) was 1404 m^2 (39 m × 36 m) with treatment plots measuring 20 m^2 (5 m × 4 m). Each treatment plot was partitioned using 0.5 m × 0.5 m bunds. The separating distance between blocks (468 m^2 block size) and experimental plots was 1 m and 0.5 m, respectively. Transplanting was undertaken at 14 days after nursery establishment, with one seedling planted per hole. Urea fertiliser was added in two doses, 50% at 3 days after transplanting (DAT) and 50% at panicle initiation in respective treatment plots. A blanket application of 40 kg P ha^{-1} of Triple Super phosphate and 40 kg K ha^{-1} muriate of potash was added to all the plots as basal treatments once at 3 DAT. Other agronomic practices such as weeding and irrigation were conducted regularly (Mghase et al. 2010). No pesticide was used in the experimental fields.

Data collection

Collected data included incidences of stem borer (dead heart and white head damage), stem borer larvae density, agronomic parameters including stem diameter, Chlorophyll content, water content, and grain yield. The damage, larvae density and agronomic parameters were assessed from plants in a 1 m^2 sampling area in each treatment plot. Damage data were collected twice, at 42 DAT for dead hearts and 72 DAT for white heads whereas that of larvae density were collected once at 72DAT. The incidences of stem borers were calculated using the formula described by Suresh et al. (2009):

$$\text{Stem borer incidence } \% = \frac{\text{Number of dead heart}}{\text{Total no. of tillers}} \times 100$$

Stem diameter and chlorophyll content were measured once by randomly selecting one tiller from every plant hill in 1 m^2 sampling area at 72 DAT. The total number of sampled plant hills per sampling area was 100 plants from 10 cm × 10 cm, 45 plants from 15 cm × 15 cm, 25 plants from 20 cm × 20 cm and 16 plants from 25 cm × 25 cm plant spacing. Stem borer larvae density was obtained by counting the number of larvae after dissection and removal of larvae from the rice stems in a sampled 1 m^2 area. Identification of stem borer species was according to the method of Pathak and Khan (1994). The diameter of stem segments was measured at the fifth, sixth, and seventh phytomer positions of selected tillers' stems using digital callipers, and the average of the three measurements recorded (Kato et al. 2007). The chlorophyll content was measured using a soil plant analysis development chlorophyll meter (*SPAD*-502). Measurements were taken once on the longest leaf (flag leaf) of a selected tiller from plant hill in a sampling area, and the average SPAD readings recorded (Yuan et al. 2016). Water content was determined at harvesting by measuring samples of five plants from each 1 m^2 sampling area from each plot after threshing (removal of grains) while fresh and oven drying for

Table 1. Chemical and physical properties of the soil samples from the trial sites.

Year	Site (wards)	PH	Total N (%)	Available P (mg/kg)	Exchangeable K (cmol (+)/kg)	Organic Carbon (%)	Clay (%)	Silt (%)	Sand (%)	Texture class
2017	Signali	5.5	0.12	8.85	0.21	2	24.7	13.1	62.1	Sand clay loam
	Msufini	5.19	0.16	0.48	0.16	1.95	33.4	10.3	56.3	Clay loam
	Sanje	5.64	0.12	1.25	0.13	2.1	29.4	14.3	48.4	Clay loam
2018	Signali	5.61	0.14	7.76	0.11	1.8	36.4	37.7	26.9	Sand clay loam
	Msufini	5.54	0.18	3.04	0.17	2.02	30.7	12.2	56.1	Clay loam
	Sanje	5.68	0.14	7.63	0.28	2.32	27.3	24.3	48.4	Clay loam

24 hours at a constant temperature of 75 °C. Grain yield (t ha^{-1}), standardised to 14% moisture content, was computed from shelled and winnowed grains in a 12 m^2 quadrat area that had been marked earlier in every plot. The 1 m^2 sampled area for agronomic parameters were also included within the 12 m^2, the sampling area for grain yield computation. The stem borer incidence, larvae density, agronomic parameters and yield data were tested for normality using R statistical software (2016) and found to conform to normal distributions and therefore there was no need for transformation.

Data analysis

Data were subjected to analysis of variance (ANOVA) using GNU R statistical software (2016). Analysis was performed for all collected data, separately for each year. Significant differences among means were separated using the Student Newman Keuls test (SNK) test at the $p \leq 0.05$ level of significance. The analysis model was according to Gomez and Gomez (1984) for factorial experiments, i.e., Yijkl = μ+Ti + βj + yk+(Tβ)ij+(Ty)ik+(βy)jk+ (Tβy)ijk + eijkl; Where Yijk = response; μ = mean; (Ti, βj and yk) are the effects of i^{th} site, j^{th} nitrogen level and k^{th} plant spacing; (Tβ)ij,(Ty)ik and (βy)jk are the two factor interactions for site vs. nitrogen level, site vs. plant spacing and nitrogen level vs. plant spacing; (Tβy) ijk are the interaction effects for the i^{th} site, j^{th} nitrogen level and k^{th} plant spacing; eijkl is the random error of the k^{th} observation from i^{th} site, j^{th} nitrogen and k^{th} plant spacing.

Results

Chemical and physical properties of the soil

Some physicochemical properties of the soils are as shown in Table 1. The total soil nitrogen ranges from 0.16% to 0.18%, which is considered to be low according to Dobermann and Fairhurst (2000). The soil pH ranged between 5.19 and 5.58, and Potassium between 0.11 and 0.28 $cmol_{(+)}$ kg^{-1} which falls in the low to medium ranges, whereas Phosphorous concentration in soil ranged between 4.8 and 8.85 mg/kg which is below the critical level of 15 mg/kg according to Landon (1991).

Effect of location, plant spacing, and nitrogen on stem borer damage, density and rice yield

Nitrogen fertilisation and plant spacing significantly ($p < 0.001$) affected dead heart incidences, white head incidences, stem borer larvae density, stem diameter, chlorophyll content, water content, and grain yield. In contrast, the interaction of locations with either nitrogen or plant spacing, and the interaction of all the three factors (locations, nitrogen fertiliser and plant spacing), were not significant ($p > 0.05$) (Table 2).

Effects of nitrogen and spacing on stem borer damage

Significant differences were observed for the 2017 cropping season on incidences of dead hearts between nitrogen levels and plant spacing, but not for their interactions. Likewise, nitrogen levels and plant spacing had a significant ($p < 0.001$) influence on incidences of white heads, with no interaction effect between these two factors (Figure 2(a,c); Table 2). Similar trends were also recorded during the 2018 cropping season for the influence of nitrogen and plant spacing on damage by stem borers ($p < 0.001$), again apart from their interactions ($p > 0.05$) (Figure 2(b,d); Table 2).

Stem borer damage increased with increasing levels of nitrogen fertilisation, as well as with wider spacing (lower plant populations). A fertiliser rate of 160 kg N ha^{-1} was recorded to have the highest incidences of stem borers in 2018 but in 2017 the incidences of dead hearts or white heads were increased only up to 80 kg N ha^{-1}. Moreover, the incidences of dead hearts or white heads increased as the plant population decreased from 1,000,000 plants to 160,000 plants ha^{-1} (i.e., as plant spacing increased) in both the 2017 and 2018 cropping seasons (Figure 2(c,d)).

Effects of nitrogen and plant spacing on stem borer density

Significant effects were observed for the 2017 cropping season on stem borer larval density for nitrogen levels and plant spacing ($p < 0.001$), but their interactions were non significant (Figure 3(a,c); Table 2). Similarly, significant difference was

Table 2. Summary of mean squares and significance levels of the effects of location, spacing and N fertiliser on rice agronomic parameters, incidences of stem borers, stem borer larvae density and yield in 2017 and 2018.

Year	Factor	df	DHI	WHI	*C. partellus*	*S. calamistis*	SD	C.C	WC	GY
	Location (L)	2	6.10**	5.42**	125.08**	15.19**	0.63**	27.08**	687.89**	10.15**
2017	Nitrogen rate (N)	3	10.75**	5.07***	107.93**	24.94**	8.98**	574.83**	3424.72**	61.41**
	Spacing (S)	3	31.78**	12.82**	54.72**	14.27**	7.99**	91.39**	3791.46**	8.44**
	L X N	6	0.30ns	0.14ns	11.23ns	1.66ns	0.05ns	2.22ns	146.29ns	0.17ns
	L X S	6	0.50ns	0.06ns	1.00ns	0.94ns	0.04ns	1.86ns	167.26ns	0.58ns
	N X S	9	0.83ns	0.4ns	3.27ns	1.9ns	0.36**	7.76**	67.22**	1.07**
	L X N X S	18	0.20ns	0.17ns	0.84ns	0.57ns	0.02ns	1.32ns	20.91ns	0.26ns
	Error	94	0.51	0.4	0.96	0.36	0.07	2.01	25.2	0.24
2018	Location (L)	2	8.09**	6.058**	123.382**	7.55**	0.69*	24.17**	787.11**	2.02**
	Nitrogen rate (N)	3	13.63**	5.26**	95.39**	9.6181**	16.05**	573.71**	3832.43**	45.54**
	Spacing (S)	3	34.46**	15.58**	52.50**	7.91**	4.89**	91.20**	7070.38**	21.69**
	L X N	6	0.38ns	0.12ns	12.58ns	1.3264ns	0.10ns	2.57ns	155.3ns	0.27ns
	L X S	6	0.64ns	0.06ns	0.826ns	0.826ns	0.10ns	1.904ls	197.21ns	0.12ns
	N X S	9	0.32ns	0.37ns	3.85ns	2.2292ns	0.34*	7.72**	41.75**	1.11**
	L X N X S	18	0.203ns	0.140ns	1.132ns	0.51ns	0.092ns	1.37ns	29.82ns	0.11ns
	Error	94	0.51	0.51	1.22	0.1568	0.028	1.99	19.2	0.28

df = degrees of freedom; DHI = dead heart incidences; WHI = white head incidences; SD = Stem diameter; WC = water content; C.C = Chlorophyll content; GY = Grain yield; L = location; N = Nitrogen level and S = Spacing.
*Significant ($p \leq 0.05$) probability level and ns = none significant ($p > 0.05$).
**Highly Significant ($p \leq 0.001$).

observed for the 2018 cropping season for the influence of nitrogen and plant spacing on stem borer larval density ($p < 0.001$), again apart from their interactions ($p > 0.05$) (Figure 3(b,d); Table 2).

Stem borer density increased with increasing levels of nitrogen fertilisation, as well as with wider spacing (lower plant populations). A fertiliser rate of 160 kg N ha^{-1} was recorded to have the highest stem borer larvae density in both the 2017 and 2018 cropping seasons. Moreover, the stem borer larvae density increased as the plant population decreased from 1,000,000 plants to 160,000 plants ha^{-1} (i.e., as plant spacing increased) in both the 2017 and 2018 cropping seasons (Figure 3(c,d)).

Effects of nitrogen and spacing on rice agronomic parameters

Rice agronomic parameters including stem diameter, chlorophyll content, and water content were significantly affected by nitrogen fertiliser and planting density ($p \leq 0.001$) (Tables 2 and 3). These parameters increased as the amount of nitrogen fertiliser increased with the exception of stem diameter. Likewise, the agronomic parameters increased as plant density decreased with the exception of diameter and chlorophyll content.

Effect of nitrogen and plant spacing on grain yield

Rice grain yield varied among nitrogen levels and spacing in 2017 and 2018, with significant interactions. Optimum grain yield was recorded in plots that received 80 kg N ha^{-1} and a planting density of 250,000 plants ha^{-1} in both years (Figure 4(a,b,d and E)). The effect of nitrogen on grain yield varied with plant spacing in 2017 and 2018 (Figure 4(c,f)). The optimum yield was recorded at 250,000 plants/ha for all nitrogen levels in both the 2017 and 2018 cropping seasons. Highest yield (5.63t ha^{-1} in 2017 and 6.06t ha^{-1} in 2018) was recorded from 80 kg N ha^{-1}, followed by 160 kg N ha^{-1} (4.03t ha^{-1} in 2017 and 4.7 t ha^{-1} in 2018). Likewise, the combination of 40 kg N ha^{-1} with 250,000 plants/ha had grain yields of 3.291 t ha^{-1} in 2017 and 3.72 t ha^{-1} in 2018, whereas the combination of 0 kg N ha^{-1} with 250,000 plants/ha had grain yields of 1.742 t ha^{-1} in 2017 and 2.17 t ha^{-1} in 2018.

Effects of locations (wards) on incidences and density of stem borers

The incidences and density of stem borers were significantly different ($p < 0.001$) among the wards in 2017 and 2018 cropping seasons (Table 4). Among the three wards studied, Signali and Mkula had higher incidences and density of stem borers than Sanje.

Discussion

The findings of this study indicate that the addition of nitrogen fertiliser at different rates affects stem borers, and *C. partellus* and *S. calamistis* injury in rice. Plants grown at high nitrogen levels were more prone to attack by these stem borer species, and hence experienced more damage than plants grown at low nitrogen levels. The addition of nitrogen fertiliser is a useful method for the improvement of plant growth but can predispose them to severe damage by herbivores. The current findings are supported by Ogah et al. (2005) on rice gall midge (*Orseolia oryzivora* Harris and Gagne in Nigeria), and Zhong-Xian et al. (2005) on brown plant hopper (*Nilaparvata lugens* Stal of rice in Philippines), who found that the addition of nitrogen fertiliser

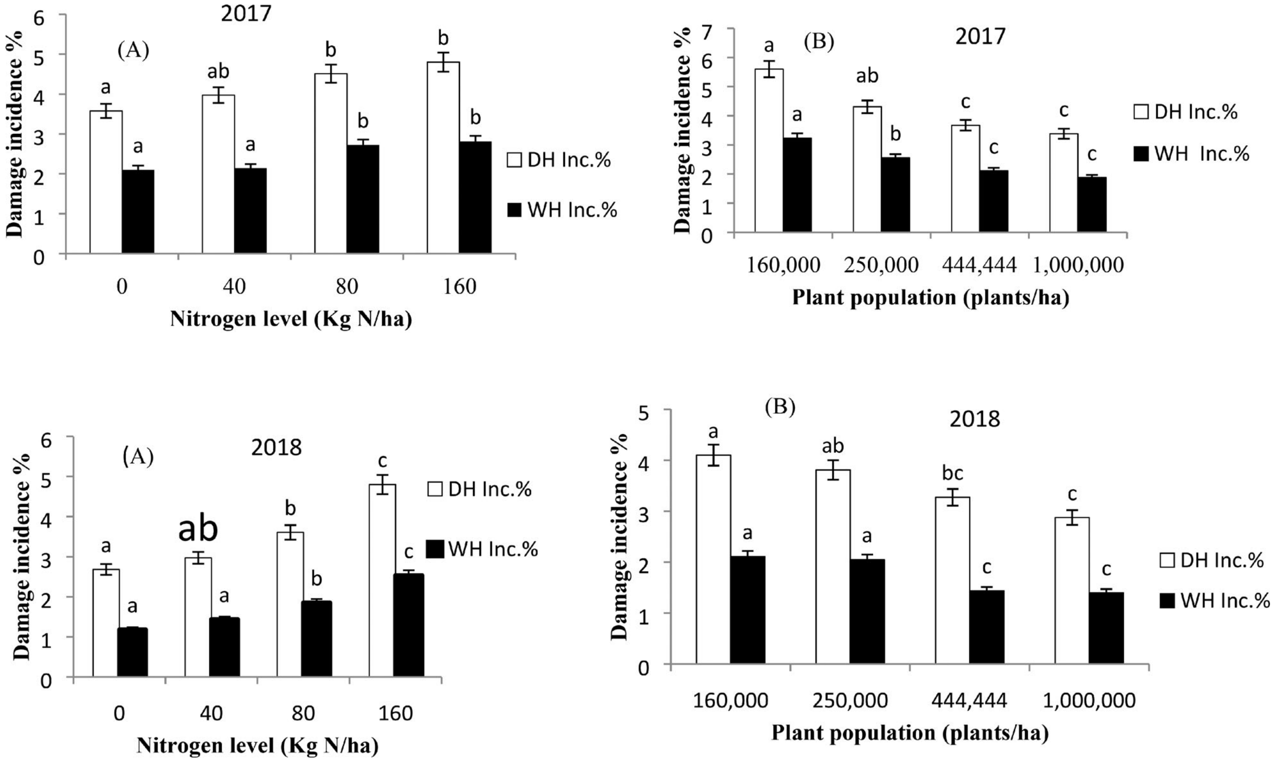

Figure 2. The effects of nitrogen levels (A, C) and plant spacing (B, D) on rice stem borer and dead heart or white head incidences in 2017 and 2018 cropping season. DH Inc. = dead heart incidence; WH Inc. = white head incidence. Bars followed by the same letters are not significantly different ($p > 0.05$). Error bars were established based on computed standard errors of each of the parameters.

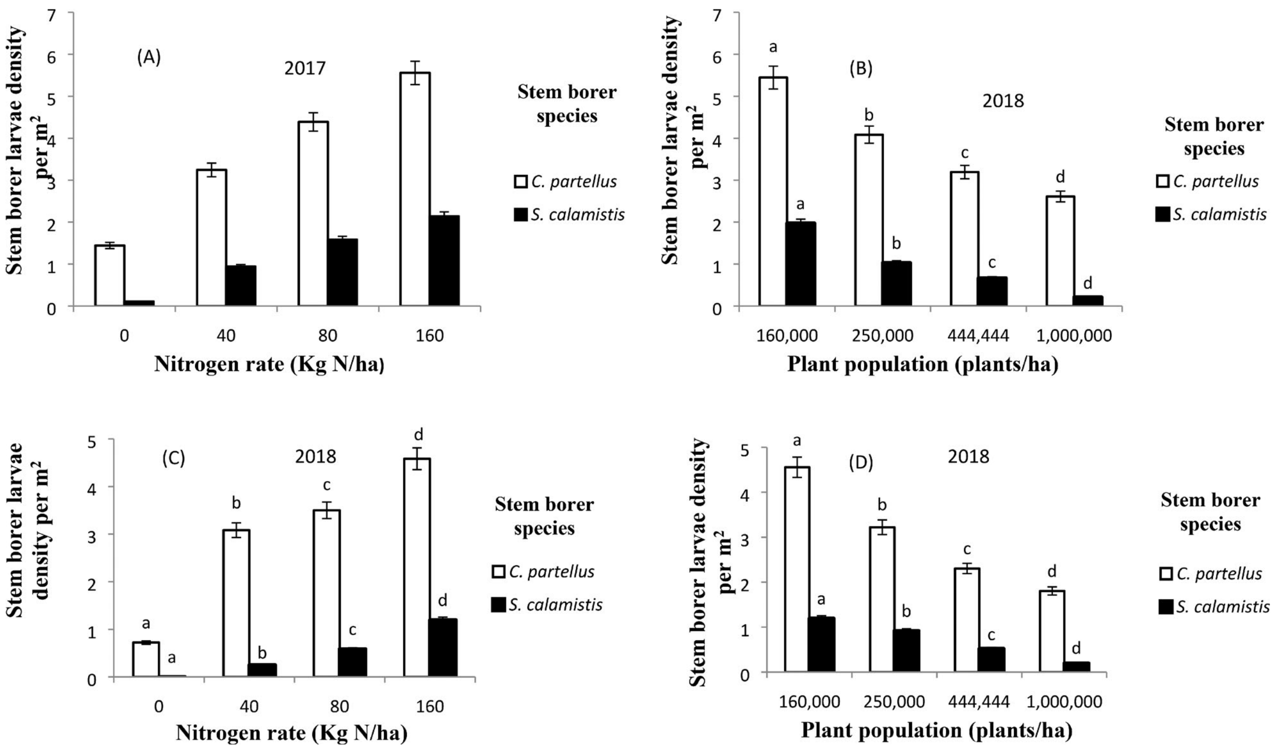

Figure 3. The effects of nitrogen levels (A, C) and plant spacing (B, D) on *C. partellus* or *S. calamistis* larvae density in 2017 and 2018 cropping season. Bars followed by the same letters are not significantly different ($p > 0.05$). Error bars were established based on computed standard errors of each of the parameters.

resulted in a significant increase in damage by these insect pests in rice. These are further supported by Zhong-Xian et al. (2007) and Veromann et al. (2013), who found that nitrogen fertilisation affects herbivore host selection, where plants grown with moderate or low nitrogen treatments were less attractive to herbivores than plants treated with high nitrogen levels.

Table 3. Effects of nitrogen fertiliser and spacing on growth variables of rice in the 2017 and 2018 cropping seasons (mean ± SE).

		2017			2018		
Treatment	Treatment levels	SD (mm)	C.C	WC (%)	SD (mm)	C.C	WC (%)
Nitrogen rates (Kg N/ha)	0	2.89 ± 0.15a	34.63 ± 0.95a	49.60 ± 3.68a	2.68 ± 0.15a	32.56 ± 0.98a	47.78 ± 3.41a
	40	3.80 ± 0.12b	37.48 ± 0.75b	53.19 ± 3.83ab	3.57 ± 0.12b	35.90 ± 0.74b	62.26 ± 2.82b
	80	3.83 ± 0.13b	41.47 ± 0.72c	57.36 ± 4.13b	3.60 ± 0.13b	39.89 ± 0.71c	68.83 ± 3.05c
	160	3.966 ± 0.14b	43.19 ± 0.77d	66.16 ± 4.61c	3.72 ± 0.14b	41.46 ± 0.75d	73.57 ± 3.36d
$F_{3,94}$		22.95	286.17	135.9	125.04	288.35	115.6
P value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Plant population	1,000,000	3.136 ± 0.15a	37.34 ± 0.47a	39.04 ± 4.74a	2.91 ± 0.14a	35.73 ± 0.46a	50.98 ± 3.18a
	444,444	3.406 ± 0.12b	38.89 ± 0.29b	51.53 ± 3.51b	3.19 ± 0.12b	37.24 ± 0.29b	61.10 ± 2.2b
	250,000	3.847 ± 0.06c	40.02 ± 0.12c	64.78 ± 1.5c	3.62 ± 0.06c	38.39 ± 0.11c	66.82 ± 1.58c
	160,000	4.102 ± 0.01c	40.51 ± 0.25d	70.96 ± 5.48d	3.872 ± 0.19d	38.86 ± 0.14c	73.54 ± 5.7d
$F_{3,94}$		109.41	45.5	150.45	112.53	45.84	140.75
P value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SD = Stem diameter; C.C = Chlorophyll content; WC = Water content. Means followed by the same letters are not statistically different ($P > 0.05$)

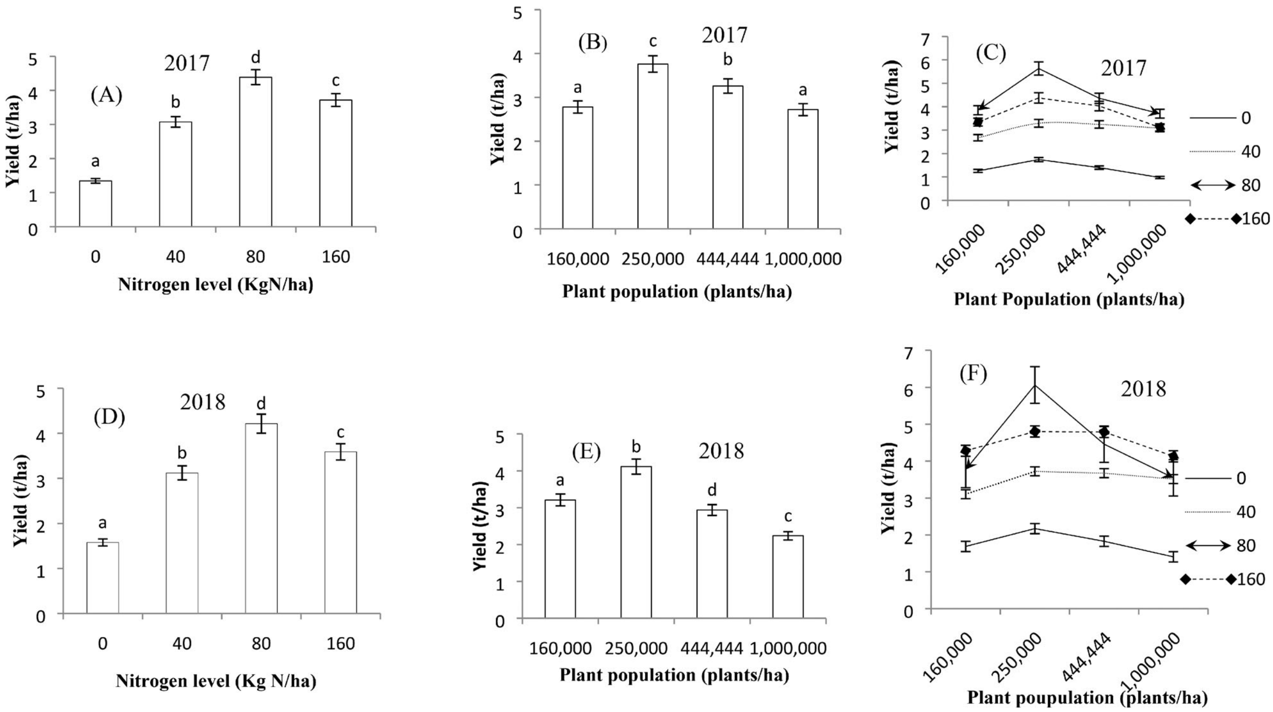

Figure 4. The effects of nitrogen levels (A), plant spacing (B) and the interaction (C) of these two factors on rice grain yield in t/ha in the 2017 and 2018 cropping seasons. Bars followed by the same letters are not significantly different ($p > 0.05$). Error bars were established based on computed standard errors of each of the parameters.

Table 4. Incidences and density of stem borers in the different wards (Mean ± SE).

	2017				2018			
	Stem borer incidence (%)		Stem borer larvae density/m²		Stem borer incidence (%)		Stem borer larvae density/m²	
Ward site	DH	WH	*C. partellus*	*S. calamistis*	DH	WH	*C. partellus*	*S. calamistis*
Sanje	3.82 ± 0.21a	2.07 ± 0.19a	2.333 ± 0.28a	0.5 ± 0.10a	3.12 ± 0.21a	1.39 ± 0.19a	1.479 ± 0.26a	0.125 ± 0.07a
Mkula	4.3 ± 0.21b	2.53 ± 0.19b	3.625 ± 0.23b	1.083 ± 0.07b	3.6 ± 0.09b	1.83 ± 0.07b	2.771 ± 0.19b	0.4792 ± 0.06b
Signali	4.52 ± 0.14b	2.72 ± 0.12b	5.542 ± 0.13c	1.625 ± 0.05c	3.82 ± 0.13b	2.03 ± 0.11b	4.667 ± 0.08c	0.9167 ± 0.04c
$F_{2,94}$	11.93	13.41	130.46	41.82	11.92	12.9	100.86	48.15
p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

DH = dead heart; WH = white head; SE = standard error.
Means followed by the same letters are not significantly different ($p > 0.05$) (SNK)

Nitrogen affects plant compensation for herbivores by causing the plant to produce more tillers that may counter the effect of stem borer damage. Tillers are associated with the production of panicles that contribute directly to the grain yield (Wu et al. 1998). A study by Reay-Jones et al. (2008) reported that increasing nitrogen rates before panicle initiation can lead to increased tiller numbers, which may counter the effects of the rice water weevil, *Lissorhoptrus oryzophilus* Kushel, on rice yield. Moreover, nitrogen influences the production of insect pest offspring. Chu and Horng (1994) reported, high rates of nitrogen fertilizer to significantly increase the number of egg masses deposited by Asian corn borer, *Ostrinia furnacalis*, on maize leaves, while Cisneros and Godfrey (2001) showed nitrogen modified plant nutrition while reducing resistance against aphids in cotton.

Nitrogen affects suitability of host plant for insect herbivores by altering semio-chemicals and the nutrition value of the plant (Zhong-Xian et al. 2007). According to Baidoo (2004), higher nitrogen leads to decline in the carbon/nitrogen ratio in favour of nitrogen. High nitrogen supply may increase protein production and decrease carbohydrate content, resulting in the formation of thin cells and softer or more succulent tissues which make the plant prone to insect attack. Furthermore, nitrogen containing fertiliser creates a healthier plant with increased leaf area which favours high stem borer populations and oviposition.

Incidences of stem borers were higher in the dry season (2017) than in the wet season (2018). This could be because only a limited number of farmers cultivated rice during the dry season, and therefore insect pests had to compete for limited resources. A similar observation was reported by Mengistu and Selvaraj (2013) in Ethiopia, who found that the incidence and severity of sugarcane borer, *Diatraea saccharalis* Fabricius, infestations in sugarcane increased in the dry season, compared to the wet season. The lower incidences of damage observed during the wet season may not be due to a lower number of stem borers, but instead to the increased abundance of the rice crop, the preferred host plants upon which the pests may forage.

The findings of this study indicated higher incidences of stem borers in plots with lower planting densities, or wider plant spacing, compared to plots with high planting densities, or narrow plant spacing. The high incidence observed at lower planting densities could be explained by reduced plant competition for nutrients and other growth resources. This will result in high nitrogen uptake by the plants, which will lead to increases in stem diameter, tenderness, succulent content, and soluble amino acids of the plant, the preferred characteristics for stem borer attack (Elanchezhyan and Arumugiachamy 2015). Wide plant spacing also increases the number of tillers and the canopy size, which create a favourable microclimate for pest and disease infestation (Ali 2006). Similar observations were reported by Mohamed (2012) for cucumbers, who found that cucumber plants grown in the widest plant spacing treatments were infested with *Bemisia tabaci* Gennadius nymphs at a higher rate than plants planted at closer plant spacing.

Different plant agronomic parameters such as stem diameter, chlorophyll content, and water content were found to be affected by nitrogen or plant spacing, and positively correlated with stem borer incidences. The amount of nitrogen fertiliser and plant spacing used had an influence on chlorophyll content. Tajul et al. (2013) reported that chlorophyll content in maize was highest at the lowest planting density with the highest amount of nitrogen. In contrast, Moro et al. (2016) reported high chlorophyll content in two wider plant spacing treatments (25 cm × 20 cm and 20 cm × 20 cm) than narrower plant spacing treatments of 25 cm × 15 cm, 15 cm × 15 cm, and 30 cm × 10 cm in lowland cultivated rice, which is also in line with the findings of the present study. Incidences of stem borers were found to increase as chlorophyll content increased. This is likely due to the increased nitrogen content, which allows the plant to grow more vigorously, and therefore to become more susceptible to stem borer attack, as plant tissue becomes more tender and succulent. Arshad et al. (2013) found that increased nitrogen levels in maize led to softer tissues, which eased attack by *C. partellus.*

In this study, stem diameter increased as plant spacing increased, or as planting density was reduced. This could be due to a reduction in competition for nutrients, light, and other photo-assimilates with wider plant spacing than with closer plant spacing, which favours the uptake of more nutrients. This corresponds with Snider et al. (2012), who observed that stem diameter of sorghum declined as seeding rates and stem density (i.e., planting density) increased. Larger stem diameters offer more food and habitat for insect herbivores compared to narrow ones, and are often preferred by stem borers. This corresponds with the results of studies by John and Warren (1967), Padhi and Sen (2002), and Amin (2011), who reported a correlation between stem diameter and stem borer survival, noting that wild rice with a narrow stem diameter was more resistant to stem borers than cultivated varieties with large stem diameters.

A significant increase in the water content of rice with an increase in applied nitrogen rates was also observed. The plants with high water content showed the highest incidences of stem borer damage, compared to plants with low water content. This may be because nitrogen has a tendency to reduce the sap flow within the plant tissues, as described by Hu et al. (1986), which leads to an increase in the soluble amino acid content of rice sap. The presence of soluble amino acids increases the nutritional values of the sap, which makes the plant more susceptible to insect pest attack. Similar observations were reported by Zhong-Xian et al.

(2004), who found that the water content of rice plants increased and the amount of sap flow decreased as nitrogen levels increased. Our study also indicates that there is a significant increase in water content with increased plant spacing or reduced planting densities. This could be due to an increased nitrogen uptake in lower planting densities, and is in line with the findings of Lin et al. (2011), who found that increasing planting density in an intensive rice growing system in China caused a significant decrease in nitrogen uptake.

The findings of this study show that nitrogen has a significant influence on grain yield, where the highest yield was obtained at the optimum nitrogen rate of 80 kg N ha^{-1}. This is in agreement with Lacerda and Nascente (2016), who reported that increasing rates of nitrogen up to 50 kg N ha^{-1} in the topdressing improved grain yields of upland rice grown in no-tillage fields, whereas applications of nitrogen beyond or above that rate did not improve the yield. Likewise, in the current study, increasing the nitrogen rate to 160 kg N ha^{-1} did not cause any significant change in yield after the optimum yield had been attained at 80 kg N ha^{-1}. The findings of the current study also indicate the grain yield decreased as planting density increased. This is likely due to competition for limited resources at higher planting densities, which led to a decreased number of tillers and panicles compared with lower planting densities. Moro et al. (2016) reported the same observations regarding the influence of plant spacing on rice grain yield, with a higher grain yield at a plant spacing of 20 cm × 25 cm and 20 cm × 20 cm compared with the wider plant spacing of 30 cm × 10 cm.

The findings of this study revealed differences in incidences and density of stem borers between wards, with a higher record in Signali and Mkula than Sanje in both 2017 and 2018 cropping seasons. This could be due to differences in altitude and/or the existence of natural or exotic alternative host species for stem borers. Ong'amo et al. (2006) reported that *B. fusca* was dominant at high altitude gradients and *C. partellus* at low altitudes. Furthermore, rice is cultivated as a monoculture at Sanje, unlike Mkula and Signali where other crops such as maize and sugarcane are also cultivated. Maize and sugarcane are known to be hosts of stem borer species such as *Chilo* spp and *S. calamistis* (Nsami et al. 2001; Ong'amo et al. 2013), the species which have also been reported by January et al (2018b) to be presented in the study area. Moreover, Mkula and Sanje are located near the Udizungwa mountain forests, where natural alternative host species for stem borers may be present. Mailafiya (2011) reported that Poaceae, Cyperaceae, and Typhaceae are important plant families that promote parasitoid diversity and therefore should be grown adjacent to cultivated habitats within the cereal crop ecosystem. These important plant families are also present in the Udizungwa forest, which is close to the rice cultivation fields of Mkula and Sanje.

Conclusions

This study demonstrated that incremental doses of nitrogen fertiliser increased damage and infestation of rice by stem borers, *C. partellus* and *S. calamistis*. The application of nitrogen fertiliser beyond 80 kg N ha^{-1} did not result in any added advantage in terms of rice yield. Similarly, reducing rice planting density to 160,000 plants ha^{-1} significantly increased borers' infestation, density and decreased grain yield. Generally, the interactions of nitrogen and planting density did not produce any significant effect on the incidences and densities of stem borers. The results of this study therefore suggest that variety 'TXD 306' should be cultivated with a plant spacing of 20 cm × 20 cm and 80 kg N ha^{-1} topdressing to obtain optimum yields and to reduce losses that may be incurred due to stem borer infestation. Further studies should examine the effect of plant spacing and nitrogen on stem borer damages in commonly grown and preferred rice varieties.

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