MAIZE YIELD LOSSES ATTRIBUTED TO THE STEMBORER; *CHILO PARTELLUS* (SWINHOE) (LEPIDOPTERA: CRAMBIDAE), IN THE EASTERN AGRO-ECOLOGICAL ZONE OF TANZANIA

BY

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ABSTRACT

Lepidopteran stem borers are generally considered the major biotic constraint to increased maize production in Tanzania and elsewhere in Africa. The exotic stem borer, *C. partellus*, is by far the most important species causing serious damage to maize and sorghum in the eastern zone of Tanzania. The effect of four nitrogen rates (0, 50, 75 and 100 kg Nha^{-1}) on stem borer damage, growth and yield loss of maize was assessed in two seasons in two locations Kibaha and Morogoro. The results show that nitrogen had a positive effect on growth variables, mainly stem diameter, plant height and yield, and negative effect on stem borer damage and stem tunneling. At Kibaha the percentage yield loss due to natural stem borer infestation decreased with increasing nitrogen application from 52.75 % to 19.38 % in the 0 kg $Nha^{-1}$and 100 kg Nha^{-1}rates, respectively. There was no stem borer infestation at Morogoro during the first season. During the second season, yield loss decreased from 27.09 % in the 0 kg Nha^{-1} to 14.84 % in the 100 kg Nha^{-1} rates at Kibaha, and from 13.19 % to 0.40 % in 0, and 100 kg Nha^{-1} rates, respectively, at Morogoro. During the second season of 2003, maize fields were surveyed at the vegetative growth phase to asses stem borers abundance and distribution and at harvest for stem borer damage and yield loss. At vegetative stage, *C. partellus* was the dominant stem borer accounting for 98.58 %, while *S. calamistis* accounted for 1.42 % of the population. During harvesting time, there were more *S. calamistis* (64 %) than *C. partellus* (36 %). Results from on-farm surveys showed that stem borer tunneling reduced grain yield of infested plants by 10.14 %. A 16.63 % yield loss was found in plants with more than 15 cm tunnels. Stem diameter, plant height, and stem tunneling were found to be the key variables affecting maize grain yield.

DECLARATION

I, VICTOR H. MGOO, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor concurrently being submitted for a degree in any other University.

Signed.......................

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To my sons Allen, Anonvictor and Brain, my parents Shabani Mgoo and Tatu S. Mgoo, and my brother Juma S. Mgoo for their constant love, encouragement and all kinds of support during my studies.

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%	percent
µs	micro semen
°C	degree Celsius
a. i.	active ingredient
a. s. l.	above sea level
E	East
FAO	Food and Agricultural Organization of the United Nations
g	gram
ha	hectare
kg	kilogram
log	logarithm
m	metre
N	total number of samples
Nha^{-1}	nitrogen per hectare
pH	hydrogen ion concentration
Proc	Procedure
$P \leq 0.05$	significant at less or equal to 5 % level
r	Pearson's correlation coefficient
S	South
SAS	Systems Analytical Software
S. E	standard error
SNK	Students Neumans Keuls
SUA	Sokoine University of Agriculture

CHAPTER ONE

INTRODUCTION

1.1 Background information

Maize (*Zea mays* L.) is the principal food and cash crop for millions of people in eastern Africa. In Tanzania maize is produced on approximately 1.7 million ha, this is about 60 % of the total area planted with cereals (CIMMYT, 19[illegible]2). Smallholder farmers, particularly women farmers, account for the largest share of maize production in the country. Maize is produced mainly under rainfed agriculture and yields under farmers' conditions are generally low, averaging around one ton per ha, compared to a world average of 4.23 tons per ha. (FAO, 2000). Low maize productivity is attributed to several factors including land degradation, unreliable rainfall, pest infestations, pre- and post harvest losses, poor infrastructure, policy and marketing systems. Lepidopteran stem borers are generally considered the major biotic constraint to increased maize production (Nye, 1960; Van Hamburg, 1979; Youdeowi, 1989)

Surveys conducted between 1980 and 2000 in some of the maize and sorghum growing regions revealed that *C. partellus, Busseola fusca, Sesamia calamistis, Eldana saccharina, and Chilo orichalcociliellus* were the pest species of stem borers found in Tanzania (Nyambo & Kabissa, 1988; Omwega *et al.*, 1997) There is evidence that *C. partellus* may be displacing indigenous stem borer species (Overholt *et al.*, 1994). The stem borer: *C. partellus* was first reported in Tanzania in the early 1950s (Duerden, 1953). Surveys carried out in the country in the late 1980s and early

1990s indicated the presence of *C. partellus* in the lake zone (i.e. Mara, Mwanza, and Shinyanga), and Morogoro regions in the eastern zone (Nyambo and Kabissa, 1988; Omwega *et al.*, 1997). In a survey conducted in eastern zone of Tanzania in 2000, *C. partellus* accounted for 80 % of all stem borers collected while indigenous stem borers: *S. calamistis, C. orichalcociliellus and B. fusca* accounted for 4, 0.85, and 15 % respectively (Nsami *et al.*, 2001). Recent surveys also revealed that the difference in the abundance of *C. partellus* and *B. fusca* was relatively small in the Central zone (40.94 % *C. partellus* and 53 % *B. fusca*) and Lake zone (40.12 % *C. partellus* and 58.26 % *B. fusca*) (Pallangyo and Omwega, 2002 unpubl.)

The degree of stem borer attack may be assessed by determining the percentage of plants attacked, extent of plant damage, percentage of stem tunneled, percentage of node bored, extent of ear damage, and number of larvae or pupae per plant (Walker, 1981). It is possible to measure the relationship between infestation rate and crop loss by using natural or artificial infestations and by preventing attack, using insecticides or other methods of control (Walker, 1981)

1.2 Justifications

Maize, apart from being a staple food, is also grown as a cash crop..The production of this crop has consequently increased largely due to expansion of cultivated area and availability of high yielding varieties (Moshi *et al.*, 1997). Maize is produced in varying area under production in all agro–ecological zones of Tanzania including: Southern highlands zone (44.8 %), lake zone (19.7 %), Eastern zone (8.4 %), Northern zone (11.0 %), Western zone (9.7 %), Central zone (3.8 %), and Southern zone (2.6 %) (Moshi. *et al.*, 1997). Small-scale farmers (on 1-3 hectare holdings), particularly women, account for about 85 percent of the total production of maize in Tanzania. Medium sized farms (10-100 hectares) account for 10 %, while large-scale farms (over 100 hectares) contribute the remaining 5 percent. The average yield of maize is very low (1.2 tones per hectare). Among the factors responsible for low yields are insect pests, of which lepidopteran stem borers are the most important (Nye, 1960; Van Hamburg, 1979; Youdeowi, 1989).

The exotic stem borer, *C. partellus*, is by far the most important species causing serious damage to maize and sorghum in the eastern zone of Tanzania (Nsami, *et al.*, 2001). In the eastern Africa region, reports on objective assessment of grain yield losses in maize and sorghum are very few (Seshu Reddy, 1998). Studies on the relationship between maize yield losses and plant nutrients are also very few. In Benin, Laboratory studies showed that survival, growth rates and fecundity of *S. calamistis* have a positive relationship with nitrogen application (Sétamou *et al.* 1993). Sétamou and Schulthess (1995) also found a positive relationship between soil nitrogen and stem borer densities. However, Sétamou *et al* (1995) showed that, the percent yield loss attributed to *S. calamistis* due to artificial infestation decreased with increasing nitrogen dose from 20 % to 11 % in the 0 $kgha^{-1}$ and 120 $kgha^{-1}$ treatments, respectively. In Tanzania, despite the importance of cereal stem borers, yield losses caused by these pests have not been quantified. Yield losses due to stem borers of up to 80 % have been reported in neighboring Kenya (Ampofo, 1986; Seshu Reddy, and Sum, 1992), where maize grows in agro ecological conditions similar to those found in Tanzania. The present study aimed at determining the potential maize yield losses due to the exotic stem borer, *C. partellus* in relation to different nitrogen rates and the economic significance of the pest in Tanzania.

1.3 Overall objective

The overall objective of the study was to determine maize yield losses caused by the stem borer, *C. partellus* in the eastern agro-ecological zone of Tanzania

1.4 Specific objectives

(i) To estimate the grain and biomass yield losses caused by the stem borer; *C. partellus* under controlled experimental and farmers' field conditions

(ii) To assess the effect of nitrogen levels on stem borer infestation, damage, and yield of maize at two on station locations in the eastern agro-ecological zone of Tanzania

(iii) To investigate the effect of nitrogen levels on borer abundance, and the ability of maize plants to compensate for borer damage

(iv) To determine the effect of different nitrogen levels *on C. partellus* larval development

(v) To investigate the effect of nitrogen levels on parasitism of *C. partellus* by its larval parasitoids.

CHAPTER TWO

LITERATURE REVIEW

2.1 Quantitative yield losses caused by stem borers on maize and other cereals

Reported yield losses due to lepidopteran borers in Africa vary greatly among agro-ecological zones, regions and cropping seasons (short/first rains and long/second rain seasons) (Bosque–Pérez and Schulthess, 1998). In Kenya, 18 % yield losses were attributed to *C. partellus* and *C. orichalcociliellus* in maize (Warui and Kuria, 1983) and 88 % in sorghum owing to *C. partellus* (Seshu Reddy, 1988). de Groote (2002) estimated that, in Kenya, yield losses due to stem borers was 12.9 %, amounting to 0.39 million tons of maize, with an estimated value of US$ 76 million. High-potential maize growing areas have relatively low crop loss levels (10 – 12%), while the low potential areas have higher losses (15–21 %). Yield losses of 18 % in maize due to *C. partellus* and *C. orichalcociliellus* were recorded. In Zanzibar grain yield losses due to stem borers attack range from 30 – 40 % (van Kuelen, 1990).

In Mozambique yield losses due to stem borer attack ranged from 20 to 40 % at research stations and were more than 50 % in small-scale farmers' fields (Segeren *et al.*, 1991). Yield losses of more than 50 % are common in southern Mozambique (Sithole, 1990). In Ethiopia, an on-station field experiment recorded grain losses of 20–50 % were caused by stem borers in maize and sorghum (Emana and Tsedeke, 1999). In a field survey conducted in eastern Kenya to assess maize stem borer damage, *C. partellus* was the most dominant stem borer and accounted for 89.5 % of all stem borers collected. Stem borer damage greatly reduced maize yield, with tunnel lengths greater than 20 cm causing a 40 % reduction of potential yield. A 33 % yield loss was recorded in plants with more than one stem borer exit holes (Songa *et al.*, 2001).

Yield-loss assessment trials on sorghum had different outcomes in West Africa due to different methods and the circumstance of the estimation (Ajayi, 1998). A significant positive correlation was recorded between the number of stems bored and yield due to *B. fusca* infestation (Harris, 1992). Yield loss was found to be 49 % in the northern Guinea savannah of Nigeria, where *B. fusca* predominates (Ajayi, 1987). In Ghana a positive relationship between the number of *Sesamia* sp. and the extent of maize stem tunneled and a significant negative relationship between percent stem tunneling and maize yield was reported using data from surveys conducted in late 1990 (Gounou *et al.*, 1993).

2.2 Effect of nitrogen on stem borer damage and plant growth variables

Susceptibility of plants to various insect pests and diseases can vary depending on heterogeneity of soil nutrients, and as early as 1946, Haseman suggested soil improvement as a new approach that can complement various pest control measures. The US National Academy of Sciences (Anonymous, 1969) concluded that each species or variety of host plant and each soil type on which they were grown seems to constitute a separate problem. Studies that relate plant nutrients and cereal stem borers are few, and include the following:

Sétamou *et al.* (1993), in his laboratory study found that survival, growth rates, and fecundity of *S. calamistis* were increased by nitrogen application. Sétamou and Schulthess (1995) also in their on farm survey, showed a positive relationship between stem borer densities and soil nitrogen. Sétamou *et al.* (1995) found that percent yield loss due to artificial infestation of *S. calamistis* decreased with increasing nitrogen application rate from 20 % to 11 % in the 0 kg Nha^{-1} and 120 kg Nha^{-} treatments, respectively. Plant height, stem diameter, and stem tunneling were found to be the most important variables explaining the variability in maize yield. Saroja *et al.* (1987) conducted a field trial in 1985–86 to determine the effect of nitrogen fertilizer level on the incidence of the yellow stem borer (*Scirpophaga incertulas*) and rice leaf folder (*Cnaphalocrosis medinalis*) on grain yield in TM8089 variety. They found that every increase in nitrogen level resulted in an increase in incidence of both pests as well as an increase in yield. Infestation of *Chilo auricilius* in sugarcane varieties was found to increase with rising nitrogen rates from 0 to 150 kg Nha^{-1} (Singh and Singh, 1983). Stem-boring dipterans larvae in perennial ryegrass (*Lolium perene*) were found to be more abundant in plots treated with high nitrogen levels regardless of the form applied. *Geomyza tripunctata* occurred almost exclusively in plots that received high nitrogen rates, while *Oscinella vastator* was more frequent in plots that received low level of nitrogen (Moore and Clements, 1984).

2.3 Comparison of yields of insecticide – protected and infested plots

A study on the effect of *Eldana saccharina* infestation on the yield components of maize through comparison of infested and insecticide – protected plants, showed that natural infestations decreased yields by 16, 15, and 28 % in the dry season, first, and second rainy season, respectively. Infested plots had significantly 'ower 100-grain weight and the percentage stem tunneled (r = -0.79) suggesting that *E. saccharina* damage to the stem affects grain filling. The regression coefficient obtained from covariance analysis showed 100-grain weight to decrease by 0.125 ± 0.0477 g for each unit increase in the percentage of the stem tunneled (Bosque–Pérez and Mareck, 1991)

Maize yield reduction of 12–15% as a result of *E. saccharina* attacks was recorded in Burundi by using insecticides and exclusion cages (Muyango, 1987). Yields of unsprayed sorghum in 22 farmers' fields in 1990 were compared and a mean yield loss of 21 % was obtained in local cultivars (Kaura 32.5 %, Farafara 31 %, and Gaya Early 12 %). However, the effects due to *B. fusca* and *S. calamistis* could not be separated (Ajayi, 1991). In Zimbabwe, stem borer infestations ranged from 30 to 70 % in fields of resource-poor farmers, and less than 30 % in commercial farms, where insecticides are used for control (Sithole, 1987). In Burkina Faso and Niger, highest grain yield was obtained when sorghum was protected from *C. partellus* and in millet by *C. ignefusalis* attack at the age of between 15 and 30 days after emergence. The infestation in unsprayed sorghum plots was 60–62 %. (Taneja and Nwanze, 1989).

2.4 Infestation Levels and maize crop stage influence on stem borer damage

The severity and nature of stem borer damage depend upon: the borer species, the plant growth stage, the number of larvae feeding on the plant, the plant's reaction to borer feeding (Bosque-Pérez and Schulthess, 1998), crop cultivars (Barrow, 1987), as well as the prevailing environment conditions and agronomic practices (Seshu Reddy, 1983). Maximum grain-yield reduction and stalk damage was reported in maize (cv. Katumani) due to *C. partellus* on 20-days-old crop, while there was insignificant larval effect on yields for a crop of 60-days-old. The economic injury levels (EIL) of *C. partellus* was defined as 3.2 and 3.9 larvae/plant in maize, 20 and 40 days after emergence, respectively (Seshu Reddy and Sum, 1991).

In Uganda, 56 % loss of grain yield resulted when sorghum was infested with *C. partellus*, 20 days after emergence (Starks, 1969), whereas, in Kenya, losses ranged from 2 to 88 % (Sheshu Reddy, 1988). Larvae of the third generation were reported to infest 87 % of cobs of maize planted late and to severely damage 70 % of the grain (Berger, 1981). Sorghum (cv IC2) infested with eight *C. partellus* larvae/plant at 21 days after emergence resulted in 80 % grain yield loss, whereas the same density gave statistically insignificant losses when plants were infested at 60 days after emergence (Seshu Reddy *et al.*, 1989). In Zanzibar (Unguja), the highest increase in attacked plants occurred between 3 and 6 weeks after sowing in the long rains of 1989. In the same field, a second peak occurred at about 9 weeks after sowing (van Kuelen, 1990).

the time of infestation; sorghum infested by *B. fusca* before the booting stage suffered greater yield losses (McFarlane, 1990). It was also recorded that the percentage of internodes bored in the lower half of the stalk had a more consistent negative correlation with grain yield than did the percentage of stems tunneled (McFarlane 1990).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study sites

3.1.1 On-station experimental sites

During the first and second rainy seasons of 2003/04, on-station experiments were conducted in Morogoro and Coast Regions. In Coast Region the trial was at the Sugarcane Research Institute, Kibaha (S 6^0 41.708' E 38^0 42.613', 152.5 m a.s.l.). In Morogoro, the trial was conducted at Sokoine University of Agriculture (SUA) (6^o 51.061′ S, 37^o 39.336′ E, 549 m a.s.l.). Maize was planted on a sandy loam soil and on clay loam soil at Kibaha and SUA, respectively.

3.1.1.1 Experimental setup

A split plot randomized complete block design experiment was set-up to evaluate the impact of *C. partellus* on 110-day lowland, TMV1 maize variety, which is high yielding, drought tolerant, and maize streak virus resistant. Two treatments were administered including four nitrogen levels (whole plot) (0, 50, 75 and 100 kg Nha^{-1}) and two levels of stem borers infestations (sub-plot) (natural infestation and treated with an insecticide). An insecticide, furadan 5G, was applied to each plant of protected subplots at 14 and 35 DAE by applying 0. 068 g a.i./plant or 81g per plot, (corresponding to 1.5 kg a.i./ha) of granules in the funnel of the plant). Four replications were set-up per treatment, thus the experiment contained 32 subplots of 4.5 m x 6 m. A 1.0 m path within each block separated the plots, and blocks were separated by 2.0 m path. Three maize seeds were sown per hill at a spacing of 30 cm within rows and 75 cm between rows and thinned to one at 14 days after planting (DAP); thus each subplot contained 120 plants.

3.1.2 On-farm sample survey

Two surveys were conducted in Morogoro region (Kilosa district) during the first and second seasons of 2003/04. The first survey was carried out in maize at pre-tasseling stage (6 weeks after planting). The second survey was carried out when the maize was at maturity stage. A total of 30 fields were selected at random at approximately 5-km intervals including fields well away from major roads. Forty maize plants per field were randomly sampled from each of the fields. Selection of fields was done independent of maize variety, but TMV-1 and Staha were the most common maize varieties grown in Kilosa District.

3.2 Data collection

3.2.1 On-station experiments

3.2.1.1 Soil analyses

Soil sampling was done prior to planting of maize in the short rainy season. Fifteen samples were taken at 0-25 cm depth along the diagonals and transects in each main plot. Soil samples were air-dried and ground to pass a 2 mm mesh. Phosphorus was extracted by the Mehlich-3 procedure (Mehlich, 1984). Soil pH was determined in water at a 1:2.5 soil solution ratio. Organic carbon was determined by chromic acid digestion and spectrophotometric procedure (Heanes, 1984). Total nitrogen was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner and Tabatabai, 1972; Nelson and Sommers, 1972). At Kibaha the trials were planted on a friable sand loam soil. The soil had a pH of 5.62 (in 1:2.5 soil water ratio), total nitrogen content of 0.0112 %, phosphorus content of 8.66 mg P/kg soil,), cation exchangeable capacity of 16.6cmol(+)/kg soil, electrical conductivity of 194.7µs/cm and organic matter content of 1.269 %. At SUA, Morogoro, the trials were planted on a clay loam soil with pH of 6.02 (in 1:2.5 soil water ratio), total nitrogen content of 0.0291 %, phosphorus content of 9.18 mg P/kg soil, cation exchangeable capacity of 20.7 cmol (+)/kg soil, electrical conductivity of 104.2 µs/cm and organic matter content of 2.759 %.

3.2.1.2 Plant analyses

Ten plants were randomly taken from each treated plot of each treatment in replicates. The mid stem portions were oven-dried at 65 °C until they reached constant weight. The dried samples were ground to pass a mesh of 0.5 mm and their nitrogen concentration determined. Total nitrogen was determined according to Kjeldahl using block digestion and steam distillation. The nitrogen contents of stems were measured at pre-tasseling stage (42 DAP).

3.2.1.3 Pest numbers, plant damage, growth variables and yield

At six weeks after planting (6 WAP), ten plants were randomly selected per subplot and the following information was recorded. Plant morphological parameters (plant height, stem diameter), damage variables (number of bored holes, tunnel length, internodes bored) and stem borer density (number of stem borer larvae and pupae). Weight of individual larvae and their fresh and dry frass were recorded in order to determine the effect of nitrogen on larval development and parasitism, respectively. Fresh frass weight was recorded during sampling and oven dried in the laboratory. Samples were oven dried at 60 ^{0}C for three days, and the dry weight was recorded. The extent of cob damage, cob, and grain weights were determined at harvest. Cobs were shelled and moisture content of each sample was determined immediately after recording the weight. Moisture content was adjusted to storage moisture as recommended by Hellevang (1995).

$$Y = \left[\frac{(100-k)}{(100-13.0)}\right] * J \qquad \text{(i)}$$

Where;

Y = Grain weight at storage

K = Moisture content of the sample as determined by moisture meter in percentage at harvest

J =Initial weight of the sample/Grain weight at harvest

3.2.2 On-farm survey

3.2.2.1 Pest numbers and weights; plant damage, growth variables and yield

Abundance and extent of maize plant damage by stem borers (*C. partellus* and *S. calamistis*), as well as growth variables were noted for each plant at pre-tasseling stage. During maturity stage (9, senescence) of the maize crop, the same number of fields was sampled in the same sites. In each field, forty maize plants were sampled at random and plant height and stem diameter were measured. The plants were then dissected and the number of larvae and pupae of each species, number of bored holes, length of stem tunnel below and above the cob, number of internodes bored (tunneled), as well as percentage of cob damage were recorded from each plant. Cobs were dehusked and the weight was recorded. The cobs were shelled and grain weight of each cob was noted. The grain moisture content was recorded from five randomly selected samples from each field. Moisture content was adjusted to storage moisture as recommended by Hellevang (1995).

3.3 Data analyses

3.3.1 On-station experiments

Analysis of variance (ANOVA) using the Proc GLM (SAS 1997) was used to compare growth variables, damage variables, pest counts, cob and grain weights at different nitrogen rates. The analyses were done separately for each cropping season and location. Single and Multiple regression analyses were used to measure the effect of nitrogen, growth variables (plant height and stem diameter), and stem damage (stem tunnel) on grain yield. Insect counts and damage variables were log (x+1) transformed and percentage data transformed using arcsine square root before analysis. Data from the SUA experiment had small values and therefore no transformation was carried out.

3.3.2 On-farm survey

The General Linear Model (SAS 1997) was used to analyze differences in borer numbers, plant damage, and growth variables by categories of centimeter stem tunneling. Healthy plants (plants with no damage, i. e. 0 cm stem tunnel) were used as control plants. Stem borer densities, plant damage and growth variables of healthy plants were therefore compared to those of infested plants in three categories of centimeter tunnels (i. e. > 1 cm tunnel, 1–15 cm tunnel, and > 15 cm tunnel). Counts of borers and damage variable were log x +1, and percentage data were arcsine square root transformed before analyses, but in the tables and figures, back transformed mean values are presented. Multiple regressions were used to estimate the contribution of centimeter stem tunnel, plant height, stem diameter, and percentage cob damage on cob and grain yields (SAS 1997).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Abundance of borers

Two stem borers, namely *C. partellus* and *S. calamistis*, were found at Kibaha and only *C. partellus* was recorded at SUA during the short rainy season. *Chilo partellus* was the dominant species in both locations. and at Kibaha in the short rainy season, constituted 98.15 % (424 *C. partellus* out of 432 borers), while *S. calamistis* constituted 1.85 % only (8 *S. calamistis* out of 432 borers). During the long rainy season, two species were found at Kibaha: *C. partellus* (96.97 %) and *C. orichalcociliollus* (3.03 %) while at SUA, only C. *partellus* was found during the short and long rainy seasons. No other species were collected from the experimental sites. In both locations and seasons, *C. partellus* was the dominant species (98.36 %), and during both seasons pest density was higher at Kibaha than at SUA (Table 1). Nsami *et al.* (2001) also reported predominance of *C. partellus* in the eastern zone of Tanzania where it constituted 80 % out of four collected species. *Sesamia. calamistis* constituted 4 %.

4.2 Nitrogen effect on stem borers density

The number of *C. partellus* increased with increasing nitrogen rates at Kibaha in the first season experiment (Table 1). There were no significant differences in borer densities in both seasons and locations. Stem borer pressure tended to be highest at Kibaha during the short rainy season. The highest number of *C. partellus* was recorded in plots, which received 100 kg Nha^{-1} while the lowest number was recorded in plots that had low rate of nitrogen application. *Sesamia calamistis* densities were very low and not significant at both locations. Likewise, the number of *C. orichalcociliollus* found at Kibaha during the second season was also very low, and did not vary significantly among nitrogen levels (Table 1).

Chilo partellus lays eggs on the upper and underside of leaves, mainly near the midribs. Some eggs are also laid on the stem. After hatching, young larva start feeding on the young leaves before they penetrate into the stem or ascend the plant to enter the leaf whorls where they feed for the first two or three instars on young succulent tissue. 'Pinhole' and 'windowpanes' characterize their type of feeding. Older larvae tunnel into stem tissue. It appears that the higher foliar nitrogen contents of plants in the higher nitrogen rates led to a higher survival of young larvae. This corroborates results by Sétamou *et al.* (1993) from a fertilizer trial, which yielded a positive relationship between survival of *S. calamistis* and nitrogen application.

Increased nitrogen content of plants in fertilized plants can increase infestation and survival of stem borers (Van den Berg *et al.*, 1998). Sétamou and Schulthess (1995) found that, stem borer densities and soil nitrogen were positively correlated in their on farm survey in Benin. Saroja *et al.* (1987), found that increase in nitrogen level in TM8089 maize variety, resulted in an increase in the incidence of the yellow stem borer (*Scirpophaga incertulas*) and rice leaf folder (*Cnaphalocrosis medinalis*). Infestation of *Chilo auricilius* in sugarcane varieties was found to increase with rising nitrogen rates from 0 to 150 kg Nha^{-1} (Singh and Singh, 1983). Stem-boring Dipteran larvae (*Geomyza tripunctata*) occurred almost exclusively in plots that received high nitrogen rates in perennial ryegrass (*Lolium perene*) regardless of the form applied (Moore and Clements, 1984).

Letourneau (1994) assessed the effects of different management practices on a key pest, bean fly (Agromyzidae) by comparing densities among 19 farmers' fields in central Malawi. He revealed that, total soil nitrogen was positively correlated with the most common species of bean fly (*Ophiomyia spencerella*). Complementary experiments with potted plants showed a direct relationship between synthetic NPK fertilizer treatment and *Ophiomyia spencerella* density. The abundance of the delphacid plant hopper, *Prokelisia marginata*, which feeds on salt marsh cord grass, *Spartina alterniflora*, was found to increase with the addition of nitrogen fertilizer. Plant foliar nitrogen was significantly increased after the addition of the fertilizer (Bowdish and Stirling, 1998).

Table 1: Stem borer densities (mean± SE) at different nitrogen levels at pre-tasseling stage

	Season					
	Short rains			Long rains		
Nitrogen level (kg Nha^{-1})	*C. partellus*	*S. calamistis*	*C. orichalcociliollus*	*C. partellus*	*S. calamistis*	*C. orichalcociliollus*
KIBAHA						
0	2.15 ± 0.43	0.10 ± 0.08	0.00 ± 0.00	0.75 ± 0.27	0.00 ± 0.00	0.00 ± 0.00
50	2.08 ± 0.40	0.03 ± 0.03	0.00 ± 0.00	1.10 ± 0.35	0.00 ± 0.00	0.05 ± 0.05
75	3.15 ± 0.50	0.05 ± 0.04	0.00 ± 0.00	0.83 ± 0.20	0.00 ± 0.00	0.00 ± 0.00
100	3.23 ± 0.74	0.00 ± 0.00	0.00 ± 0.00	1.33 ± 0.40	0.00 ± 0.00	0.08 ± 0.06
F	1.50	0.90		0.70		1.10
P	0.21	0.47		0.58		0.36
N	40	40	40	40	40	40
SUA						
0	0.05 ± 0.35	0.00 ± 0.00	0.00 ± 0.00	0.30 ± 0.14	0.00 ± 0.00	0.00 ± 0.00
50	0.08 ± 0.08	0.00 ± 0.00	0.00 ± 0.00	0.15 ± 0.08	0.00 ± 0.00	0.00 ± 0.00
75	0.03 ± 0.03	0.00 ± 0.00	0.00 ± 0.00	0.83 ± 0.34	0.00 ± 0.00	0.00 ± 0.00
100	0.10 ± 0.08	0.00 ± 0.00	0.00 ± 0.00	0.50 ± 0.19	0.00 ± 0.00	0.00 ± 0.00
F	0.20			2.00		
P	0.88			0.12		
N	40	40	40	40	40	40

4.3 Nitrogen effect on plant damage variables

4.3.1 Effect of nitrogen on damage variables at pre-tasseling stage

Table 2 presents the stem borer damage variables at pre-tasseling stage in both locations. The results show that at Kibaha, stem borer damage was higher compared to that of SUA in both seasons. Considerable differences in damage levels are common between locations. It can be noted that Kibaha had a high pest pressure than SUA. These variations in damage levels between locations and seasons were attributed to differences in stem borer densities. Delayed onset of rainfall at SUA (Morogoro Region) may have had a negative effect on stem borer (*C. partellus*) density. In the first season, it may delay breaking of diapause resulting in low population growth. Many cereal stem borers have a diapausing period toward the end of the rain season, which they complete as fully-grown larvae in dry crop residues in the fields. In Kenya, *C. partellus*, *S. calamistis*, and *C. orichalcociliellus* enter diapause for several months in the dry season (Ofomata *et al.*, 1999; Sheshu Reddy, 1983). In areas with long dry season in winter or in summer, *C. partellus* enter into a resting period. It was reported to diapause in the dry season in India (Tams *et al.*, 1953) and on several islands off the coast of Africa (Breniere *et al.*, 1985; Delobel, 1975).

Extent of plant damage increased with increasing nitrogen levels and was significantly different between nitrogen levels at Kibaha during the short rainy season. Stem tunnel length varied significantly between nitrogen levels at Kibaha and was highest in 100 kg Nha^{-1} (P = 0.0002). The number of bored holes was significantly higher in plots that received higher rates of Nitrogen (P =0.003). The least number of bored holes was recorded in 0 kg N/ha plots. There were no significant differences in percent internodes bored between different nitrogen rates in both seasons and locations (Table 2).

Nitrogen enhances growth rate, and during the vegetative stage of growth, the proportion of young to mature tissue shifts in favor of young tissue, which is more susceptible. When plants are supplied with high amounts of nitrogen, the activity of some key enzymes of phenol metabolism (Matsuyama and Dimond, 1973) and the content of some phenolics and lignin may also be lower (Kiraly, 1964). The lower content of phenols, which are precursors in the biosynthesis of lignin, together with the higher proportion of young tissue in plants grown at high nitrogen levels increases damage by stem borers.

Table 2: Damage variables (mean± SE) at different nitrogen levels at pre-tasselling stage

	Season					
	Short rains			Long rains		
Nitrogen level (kg Nha^{-1})	% Internodes bored	Boring holes	Tunnel length (cm)	% Internodes bored	Boring holes	Tunnel length (cm)
KIBAHA						
0	30.45 ± 3.87	6.80 ± 1.12^{c}	8.87 ± 1.24^{c}	11.52 ± 3.44	1.60 ± 0.67	2.06 ± 0.81
50	28.76 ± 3.92	7.40 ± 1.12^{abc}	9.33 ± 1.43^{bc}	11.49 ± 3.06	1.93 ± 0.55	2.20 ± 0.56
75	31.59 ± 3.23	10.85 ± 1.43^{a}	11.38 ± 1.25^{ab}	9.60 ± 2.57	2.78 ± 0.89	2.24 ± 0.69
100	25.96 ± 2.61	9.13 ± 1.25^{ab}	13.15 ± 1.65^{a}	13.07 ± 2.60	3.10 ± 2.60	3.27 ± 0.71
SUA						
0	1.11 ± 0.78	0.13 ± 0.10	0.15 ± 0.15	1.43 ± 0.63	0.15 ± 0.67	0.13± 0.08
50	0.25 ± 0.25	0.15 ± 0.15	0.16 ± 0.16	1.05 ± 0.60	0.10 ± 0.06	0.11 ± 0.06
75	0.28 ± 0.28	0.15 ± 0.15	0.13 ± 0.13	2.20 ± 1.35	0.65 ± 0.46	0.93 ± 0.64
100	1.23 ± 1.02.	0.23 ± 0.17	0.74 ± 0.63	3.78 ± 1.30	0.68 ± 0.28	1.00 ± 0.36

Means within columns followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK test)

In the correlation matrices, nitrogen levels were positively and significantly correlated with growth variables (plant height r = 0.365, P<0.0001, stem diameter r = 0.268, P= 0.0006), and damage variable (tunnel length r = 0.204, P = 0.0096). Bored holes, damaged internodes, and *C. partellus* density were positively but not significantly correlated with nitrogen application. Growth variables (plant height and stem diameter) showed strong correlation (r = 0.475, P<0.0001), as well as damage variables (tunnel length and damaged internodes, r = 0.696, P<0.0001, boring holes r = 0.699, P<0.0001). *Chilo partellus* density was positively correlated with nitrogen application (r = 0.133, P = 0.093), and negatively correlated with plant height (r = -0.056, P = 0.486). *Chilo partellus* density was positively correlated with all damage variables (Table 3). In contrast, in Benin in on-farm surveys, density of stem borers was found to be positively correlated to soil nitrogen (Sétamou and Schulthess 1995). Saroja *et al.* (1987) found that increase in nitrogen level in TM8089 maize variety resulted in an increase in the incidence of the yellow stem borer (*Scirpophaga incertulas*) and rice leaf folder (*Cnaphalocrosis medinalis*). Nitrogen application increased plant height and stem diameter whereas stem borer had negative effect on them (Sétamou *et al.*, 1995).

Table 3: Correlation matrixes of nitrogen level, *C. partellus* density, and growth and damage variables at pre-tasseling stage of maize during short rainy season at Kibaha (computed across treatments).

	1	2	3	4	5	6
1. N-level (kg Nha^{-1})	-					
2 Plant height (cm)	0.365***	-				
3. Stem diameter (cm)	0.278***	0.475***	-			
4. Bored internodes (%)	0.020	-0.260***	-0.068	-		
5. Bored holes (no./plant)	0.150	-0.084	0.156*	0.699***	-	
6. Tunnel length (cm)	0.204**	-0.025	0.187*	0.696***	0.766***	-
7. *C. partellus* (no./plant)	0.133	-0.056	0.220**	0.499***	0.531***	0.609***

*** = Significant at $P \leq 0.001$, ** = Significant at $P \leq 0.01$, * = Significant at $P \leq 0.05$

4.3.2 Effect of nitrogen on damage variables at harvest

The second assessment of plant damage was again done at harvesting time. During this sampling, the damage on stems was recorded below and above the cobs. Plant damage below the cob has been found to be more important than total damage and therefore, it is recommended to use the relationship between plant damage below the cob to calculate yield losses (Gounou *et al.*, 1994; Sétamou *et al.*, 1995; Cardwell 1997; Ndemah, *et al.*, 2001). Percentage internodes bored increased with increasing nitrogen application rates, but relationship was not significant (P = 0.6431, Table 4). In the short rainy season, total bored holes and bored holes before and after the cob were all significantly different between nitrogen application rates (P = 0.002, P = 0.012, P = 0.003, respectively) at Kibaha, while at SUA, significant differences were not seen. Similarly, there were no significant differences in holes bored between different nitrogen levels at SUA during the long rainy season. Total holes bored and holes bored before the cob were found to vary significantly between nitrogen levels at Kibaha during the long rainy season. More holes were found in plots that received high rates of nitrogen (Table 5).

Table 4: Percentage damaged internodes (mean ± SE) at different nitrogen levels at harvest

	Season					
	Short rains			Long rains		
Nitrogen level (kg Nha^{-1})	%Total internodes bored	% Internodes bored before cob	% Internodes bored after cob	%Total internodes bored	% Internodes bored before cob	% Internodes bored after cob
KIBAHA						
0	34.62 ± 4.30	33.88 ± 4.61	36.07 ± 5.20	14.88 ± 2.29	22.17 ± 3.73	9.26 ± 3.31
50	37.29 ± 4.33	42.09 ± 4.89	31.74 ± 4.82	15.67 ± 2.90	22.14 ± 3.89	8.56 ± 2.44
75	42.09 ± 3.11	43.67± 4.25	38.73 ± 4.22	19.31 ± 2.71	28.48 ± 3.82	9.14 ± 2.49
100	46.45 ± 3.12	46.53 ± 3.50	46.92 ± 4.60	19.97 ± 2.68	25.77 ± 4.13	15.50 ± 3.89
SUA						
0	1.72 ± 0.93	2.20 ± 1.50	1.36 ± 1.05	2.34 ± 0.79	4.58 ± 1.54	0.00 ± 0.00
50	1.33 ± 0.66	2.14 ± 1.21	0.42 ± 0.42	2.76 ± 0.95	3.72 ± 1.38	1.77 ± 0.86
75	2.70 ± 1.46	3.48 ± 1.72	1.79 ± 1.79	2.45 ± 0.97	1.43 ± 0.86	3.60 ± 1.74
100	4.18 ± 1.85	4.72 ± 1.83	2.78 ± 2.10	3.94 ± 1.14	7.67 ± 2.36	0.36 ± 0.36

Table 5: Number of holes bored (mean ± SE) at different nitrogen levels at harvest

	Season					
	Short rains			Long rains		
Nitrogen level ($kg\ Nha^{-1}$)	Total holes bored	Holes bored before cob	Holes bored after cob	Total holes bored	Holes bored before cob	Holes bored after cob
KIBAHA						
0	9.68 ± 1.31^{c}	6.33 ± 0.98^{c}	3.35 ± 0.59^{c}	3.90 ± 0.91^{b}	2.85 ± 0.59^{b}	1.05 ± 0.43
50	14.53 ± 1.52^{b}	9.45 ± 1.11^{b}	5.13 ± 0.89^{b}	5.15 ± 1.06^{ab}	3.73 ± 0.80^{ab}	1.43 ± 0.43
75	20.53 ± 2.13^{a}	13.40 ± 1.45^{a}	7.13 ± 1.10^{a}	5.90 ± 0.83^{a}	4.05 ± 0.83^{a}	1.10 ± 0.31
100	19.95 ± 2.22^{a}	12.48 ± 1.63^{a}	7.48 ± 1.04^{a}	6.83 ± 1.16^{a}	5.00 ± 0.93^{a}	1.83 ± 0.46
SUA						
0	0.55 ± 0.29	0.45 ± 0.28	0.10 ± 0.10	1.45 ± 0.42^{b}	1.30 ± 0.39^{a}	0.15 ± 0.09
50	0.68 ± 0.39	0.55 ± 0.37	0.13 ± 0.13	1.25 ± 0.39^{b}	0.98 ± 0.29^{b}	0.28 ± 0.21
75	0.98 ± 0.53	0.70 ± 0.38	0.28 ± 0.28	2.00 ± 0.65^{a}	1.28 ± 0.46^{a}	0.73 ± 0.44
100	1.80 ± 0.74	1.15 ± 0.56	0.65 ± 0.47	2.20 ± 0.55^{a}	2.03 ± 0.51^{a}	0.18 ± 0.10

Means within columns followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

The results presented in Table 6, show the damage due to stem borer larval feeding on maize stems assessed in terms of stem tunneling. Damage at SUA was generally low, although it was a bit higher during the second season. At Kibaha, stem tunneling was considerably higher in both seasons, and was more serious during the short rain season. It was observed that stem tunneling increased with an increasing nitrogen application during both seasons at Kibaha, and only in the long rain season at SUA (Table 6).

Analysis of variance (Proc GLM, SAS 1997) undertaken showed an increase in stem tunneling between different nitrogen rates in both short and long rain seasons at Kibaha and only in the long rainy season at SUA. In the short rainy season at Kibaha, the increase in stem tunneling was significantly different between treatments (P = 0.0218) due to higher pest pressure. *Maliarpha separatella* damage increased with increasing fertilizer rate in Nigeria (Ukwungwu, 1985). Sétamou *et al.* (1995) also observed a negative effect of nitrogen application on stem borers damage and positive effect on plant growth and yield. Nitrogen alters plant composition much more than any other mineral nutrient (Marschner, 2002). Marschner (2002) found that, the dry matter production of ryegrass is increased by nitrogen in a typical yield response curve. Simultaneously, the total nitrogen content increases, but the contents of the two main storage carbohydrates in grasses, polytructosans and starch, decrease drastically. In contrast to the carbohydrate content, lignin content in grasses may increase rather than decrease with higher nitrogen supply (Kaltofen, 1988), as the amino acid phenylalanine and tyrosine are precursors of lignin synthesis. However, part of this enhancement effect on lignin content in mature tissues may be counteracted by enhanced formation of new leaves with their typical lower lignin content. In general, the proportion of soluble nitrogen increases with elevated levels of nitrogen supply and is higher in leaves and storage organs with higher water content, low in grains and seeds. Due to lower lignin content and higher water content in higher nitrogen rate, the maize plant becomes more succulent and therefore easier for tunneling by stem borer larvae.

During sampling at harvest, stem tunneling below and above the cob (ear) was recorded. Plant damage below the cob has been found to be more important than total damage and therefore, it was recommended to use the relationship between plant damage (stem tunnel) below the cob to calculate yield losses (Gounou *et al.*, 1994; Sétamou *et al.*, 1995; Cardwell, 1997; Ndemah, *et al.*, 2001). The plant growth stage is also among key factors, which determine the severity and nature of stem borer damage (Bosque-Pérez and Schulthess, 1998). The normal pre-tasseling stage of the variety that was used for the experiment (TMV-1), is before 6 weeks (42 days) after planting. This implies that any stem borer damage after reproductive stage could not cause reduction in cob and grain yields.

Table 6: Stem tunnels (mean ± SE) at different nitrogen levels at harvest

	Season					
	Short rains			Long rains		
Nitrogen level ($kg\ Nha^{-1}$)	Total tunnel length (cm)	Tunnel length below cob (cm)	Tunnel length after cob (cm)	Total tunnel length (cm)	Tunnel length below cob (cm)	Tunnel length after cob (cm)
KIBAHA						
0	17.56 ± 2.37^{c}	10.82 ± 1.60^{c}	6.74 ± 1.36^{b}	9.32 ± 1.60^{b}	7.17 ± 1.35^{c}	2.15 ± 0.88^{c}
50	24.40 ± 2.71^{b}	15.47 ± 1.82^{b}	8.93 ± 1.36^{b}	11.93 ± 2.51^{b}	9.43 ± 2.04^{b}	2.50 ± 0.72^{c}
75	36.65 ± 3.26^{a}	20.85 ± 2.01^{a}	15.80 ± 1.88^{a}	15.52 ± 2.44^{a}	12.61 ± 1.88^{a}	2.91 ± 0.83^{b}
100	36.23 ± 3.31^{a}	23.03 ± 2.51^{a}	13.21 ± 1.46^{a}	16.61 ± 2.60^{a}	13.05 ± 2.27^{a}	3.56 ± 0.84^{a}
SUA						
0	1.04 ± 0.61	0.74 ± 0.53	0.33 ± 0.23	2.11 ± 0.61^{b}	1.96 ± 0.58^{c}	0.15 ± 0.09
50	0.74 ± 0.53	0.56 ± 0.52	0.19 ± 0.14	2.17 ± 0.68^{b}	1.82 ± 0.54^{c}	0.27 ± 0.23
75	1.43 ± 0.74	1.00 ± 0.51	0.43 ± 0.43	3.63 ± 1.20^{a}	2.51 ± 0.90^{b}	1.12 ± 0.70
100	3.10 ± 1.28	1.60 ± 0.93	1.50 ± 0.87	4.29 ± 1.07^{a}	4.03 ± 1.02^{a}	0.26 ± 0.15

Means within columns followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

4.4 Nitrogen effect on plant growth variables

Two important growth variables (plant height and stem diameter) were assessed. At pre-tasseling stage, both variables were significantly affected by nitrogen application i.e. plant height and stem diameter increased (except in the short rainy season at SUA) as the level of nitrogen was increased (Figures 1, and 2). There were significant increases in plant height and stem diameter with increasing nitrogen rates in the short rain season at Kibaha. Results from SUA showed different trends compared to Kibaha. Significant differences in both growth variables were found in the long rain season. The differences in growth variables at different nitrogen levels during the short rain season at SUA were very small and might have been affected by water stress, due to insufficient rainfall. Natural infestation by stem borers was very low and therefore damage was also low. Shorter plant height in the 100 kg Nha^{-1}treatment was probably due to stem tunneling (29.5 cm). Tunneling lengths at other nitrogen levels were 10.5, 6.5, and 4.0cm, in 0, 50, 75 kg. Nha^{-1}respectively.

Seasons

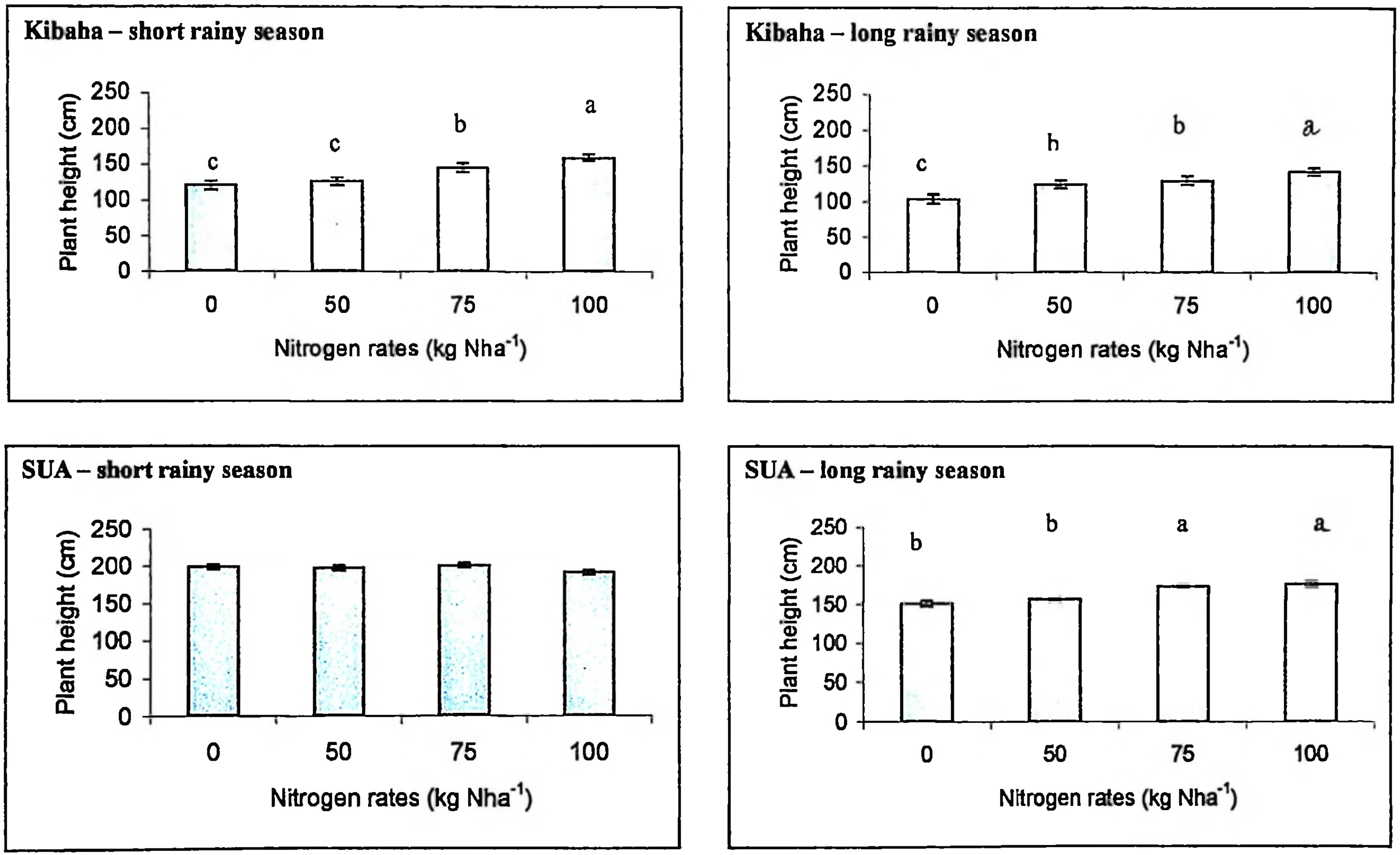

Figure 1: Effect of nitrogen on maize plant height under stem borer infestation at pre-tasseling stage

Bars followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

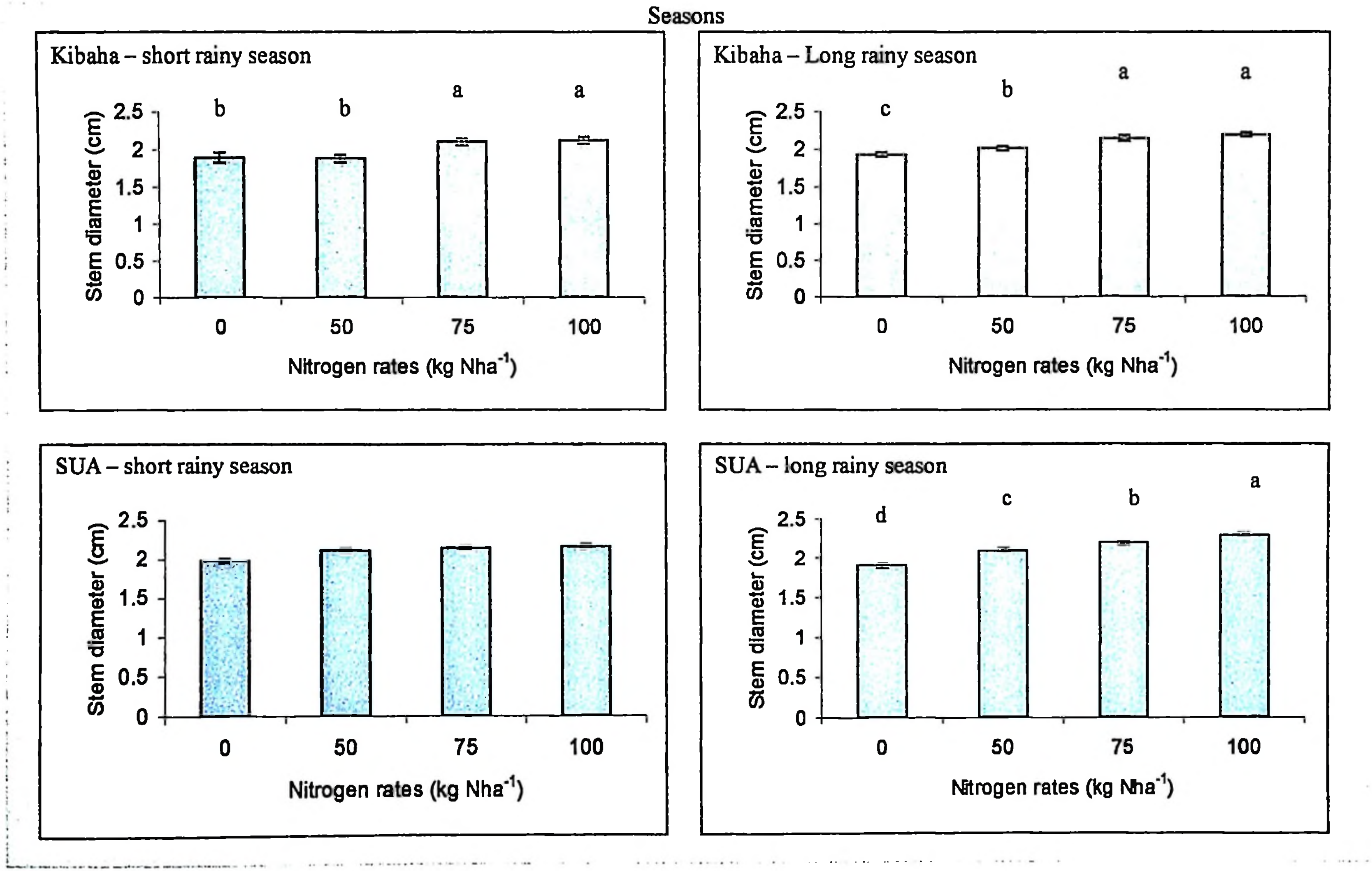

Figure 2: Effect of nitrogen on stem diameter under stem borer infestation at pre-tasseling stage

Bars followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

At harvest plant, height and stem diameter varied significantly with different nitrogen application rates in both sites and seasons. At Kibaha, the average plant height increased by 19.2 % and 14.6 % from 0 to 100 kg Nha^{-1} in the short, and long rainy seasons, respectively. Stem diameter increased by 29.3 % in the short rain season and by 23.5 % in the long rainy season from 0 to 100 kg Nha^{-1}.

There was a small increase in growth variables at SUA as compared to Kibaha (Table 6). Apart from the effect of different nitrogen doses, it is also possible that low pest pressure at SUA might have contributed to a small increase in growth variables in 100 kg Nha^{-1} plots. Increases of 3.7 % and 7.6 % in plant height were recorded in the short and long rainy seasons from 0 to 100 kg Nha^{-1}, respectively. Stem diameter increased by 12.8 % during the short rainy and by 16.6 % in the long rainy season from 0 to 100 kg Nha^{-1}. An increase in nitrogen supplies not only delays senescence and stimulates growth but also changes plant morphology, particularly if the nitrogen availability is high in the rooting medium in the early growth (Marschner, 2002). Sétamou *et al.* (1995) in Benin assessed the effect of stem and cob borers on maize subjected to different nitrogen treatments, and found a positive effect of nitrogen on maize growth variables.

Table 7: Growth variables (mean ± SE) at different levels of nitrogen at harvest

	Season			
	Short rains		Long rains	
Nitrogen levels ($kg\ Nha^{-1}$)	Plant height (cm)	Stem diameter (cm)	Plant height (cm)	Stem diameter (cm)
KIBAHA				
0	168.18 ± 5.92^{b}	1.74 ± 0.06^{b}	183.60 ± 3.55^{d}	1.66 ± 0.04^{b}
50	167.20 ± 5.42^{b}	1.87 ± 0.06^{b}	191.14 ± 3.06^{c}	1.77 ± 0.04^{b}
75	194.13 ± 5.68^{a}	2.12 ± 0.06^{a}	201.08 ± 3.76^{b}	1.95 ± 0.03^{a}
100	201.35 ± 3.87^{a}	2.25 ± 0.06^{a}	210.35 ± 2.85^{a}	2.05 ± 0.03^{a}
SUA				
0	237.75 ± 2.78^{b}	1.95 ± 0.04^{b}	235.80 ± 3.36^{b}	1.75 ± 0.03^{b}
50	243.55 ± 3.44^{a}	2.05 ± 0.04^{b}	225.03 ± 4.25^{b}	1.85 ± 0.03^{b}
75	244.80 ± 3.47^{a}	2.15 ± 0.04^{a}	236.08 ± 4.27^{b}	1.96 ± 0.03^{a}
100	246.63 ± 3.43^{a}	2.20 ± 0.04^{a}	252.85 ± 2.91^{a}	2.04 ± 0.03^{a}

Means within columns followed by the letter do not differ significantly at $P \leq 0.05$ (SNK)

4.5 Effect of carbofuran treatment on stem borer density, damage and growth variables

4.5.1 Effect of carbofuran treatment on stem borer density, damage and growth variables at pre-tasseling stage

In the first (short) rainy season, infestation by stem borers in carbofuran treated plots was not recorded in all plots except one, where only two plants were infested. This implies that carbofuran application gave sufficient protection to infestation by stem borers. At Kibaha, there were significant differences in numbers of *C. partellus* and *S. calamistis* during the short rainy season and *C. partellus* only during the long rainy season between treated and untreated plots. Growth and damage differences were also significantly different between carbofuran applied and control plots. At SUA, plant height was significantly different between treated and untreated plots. *Chilo partellus* density at SUA was significantly different between treated and untreated plots during both seasons, although it was extremely low (Table 7). Carbofuran application had a deleterious effect on stem borer activity and application of the insecticide highly reduced damage by stem borers (Tables 8 and 9). A very low stem borer infestation was found in two insecticide treated plots with no nitrogen application but not in any other plots. In both seasons at SUA, and long rainy season at Kibaha, there was no infestation in the insecticide treated plots (Tables 8 and 9). Carbofuran is a systemic broad-spectrum insecticide capable of protecting crop plants from most chewing and sucking insect pests. When applied to the soil, it is transported systematically and kills pests feeding on the plant tissues. Kumar (1995) found that, when the rice varieties TKM6, BPIRi2, BPIRi4, IR22, IR36, IR60, IR66 and IR74 were treated with carbofuran at the time of peak oviposition by *S.*

incertulas in the field, the damage (dead heart) on all the varieties was significantly reduced in comparison with the untreated plots

Table 8: Effect of carbofuran application on number of stem borers per plant (mean ± SE) at different nitrogen rates

N - levels (kg Nha^{-1})	Seasons											
	Short rainy season						Long rainy season					
	C. partellus		*S. calamistis*		*C. orichalcociliollus*		*C. partellus*		*S. calamistis*		*C. orichalcociliollus*	
	TP	UTP	TP	UTP	TP	UTP	TP	UTP	TP	UTP	TP	UTP
KIBAHA												
0	0.00^{b}	2.15^{aB}	0.03^{b}	0.10^{a}	0.00	0.00	0.00^{b}	0.75^{a}	0.00	0.00	0.00	0.00
50	0.00^{b}	2.08^{aB}	0.00^{b}	0.03^{b}	0.00	0.00	0.00^{b}	1.10^{a}	0.00	0.00	0.00	0.05
75	0.00^{b}	3.15^{aA}	0.00^{b}	0.05^{a}	0.00	0.00	0.00^{b}	0.83^{a}	0.00	0.00	0.00	0.00
100	0.00^{b}	3.23^{aA}	0.00^{a}	0.00^{a}	0.00	0.00	0.00^{b}	1.33^{a}	0.00	0.00	0.00	0.08
P - value	<0.0001		0.0487		1.000		<0.0001		1.000		0.0895	
SUA												
0	0.00^{b}	0.05^{a}	0.00	0.00	0.00	0.00	0.00^{b}	0.30^{aBC}	0.00	0.00	0.00	0.00
50	0.00^{b}	0.08^{a}	0.00	0.00	0.00	0.00	0.00^{a}	0.15^{ac}	0.00	0.00	0.00	0.00
75	0.00^{b}	0.03^{a}	0.00	0.00	0.00	0.00	0.00^{b}	0.83^{aA}	0.00	0.00	0.00	0.00
100	0.00^{b}	0.10^{a}	0.00	0.00	0.00	0.00	0.00^{b}	0.50^{aAB}	0.00	0.00	0.00	0.00
P - value	0.0423		1.000		1.000		<0.0001		1.000		1.000	

TP = Treated plots with carbofuran, UTP = Untreated plots. Means within rows and columns followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

Table 9: Effect of carbofuran on damage variables (mean ± SE) at pre-tasseling stage of maize

	Season											
	Short rains						Long rains					
	Damaged internodes (%)		Number of holes bored		Tunnel length (cm)		Damaged internodes (%)		Number of holes bored		Tunnel length (cm)	
N - levels (kg Nha^{-1})	TP	UTP	TP	UTP	TP	UTP	TP	UTP	TP	UTP	TP	UTP
KIBAHA												
0	0.63^{b}	30.45^{a}	0.23^{b}	6.80^{aB}	0.36^{b}	8.87^{aB}	0.00^{b}	11.52^{a}	0.00^{b}	1.60^{aB}	0.00^{b}	2.06^{a}
50	0.00^{b}	28.76^{a}	0.00^{b}	7.40^{aB}	0.00^{b}	9.33^{aB}	0.00^{b}	11.49^{a}	0.00^{b}	1.93^{aB}	0.00^{b}	2.20^{a}
75	0.00^{b}	39.59^{a}	0.00^{b}	10.85^{aA}	0.00^{b}	11.38^{aA}	0.00^{b}	9.60^{a}	0.00^{b}	2.78^{aA}	0.00^{b}	2.24^{a}
100	0.00^{b}	25.96^{a}	0.00^{b}	9.13^{aA}	0.00^{b}	13.15^{aA}	0.00^{b}	13.07^{a}	0.00^{b}	3.10^{aA}	0.00^{b}	3.27^{a}
P- value	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
SUA												
0	0.00	1.11	0.00^{b}	0.13^{a}	0.00^{b}	0.15^{a}	0.00^{b}	1.43^{aB}	0.00^{b}	0.15^{aB}	0.00^{b}	0.13^{aB}
50	0.00	0.25	0.00^{b}	0.15^{a}	0.00^{b}	0.16^{a}	0.00^{b}	1.05^{bB}	0.00^{b}	0.10^{B}	0.00^{b}	0.11^{aB}
75	0.00	0.28	0.00^{b}	0.23^{a}	0.00^{b}	0.13^{a}	0.00^{b}	2.21^{aB}	0.00^{b}	0.65^{AB}	0.00^{b}	0.93^{aAB}
100	0.00	1.23	0.00^{b}	0.23^{a}	0.00^{b}	0.74^{a}	0.00^{b}	3.78^{aA}	0.00^{b}	0.68^{A}	0.00^{b}	1.00^{aA}
P-value	0.4561		0.0235		0.0215		<0.0001		<0.0001		0.0030	

TP = Treated plots with carbofuran, UTP = Untreated plot. Means within rows and columns followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

4.5.2 Effect of carbofuran treatment on stem borer density, damage and growth variables at harvesting

Results of plant damage during harvesting time of maize are presented in Table 10. The efficacy of carbofuran to reduce damage appeared to depend on the time of application. It has also been observed that in older maize plants, the translocation of the systemic insecticide from the roots to the stem is not sufficient to have an effect on stem borer feeding. However, significant differences between treated and untreated plots were found for all damage variables (Table 10).

Although stem borers infested most of treated plots during harvesting time, the overall reduction in plant damage was highly significant. Damaged internodes were reduced by 81.87 %, bored holes by 88.75 %, and tunnel length by 85.78 % at Kibaha during the short rainy season. In the long rainy season an overall reduction of 85.62 % was recorded for percentage damaged internodes, 92.33 % in bored holes, and 87.28 % for tunnel length. At SUA, the overall reduction of 83.97 %, 83.04 %, and 71.32 % was recorded for damaged internodes, bored holes and tunnel length, respectively, during the short rainy season. During the long rainy season the values were as follows; 94.17 % for damaged internodes, 96.38 % for bored holes, and 95.41 % for tunnel length.

An assessment of yield loss of sorghum and pearl millet due to stem borer damage showed that efficient control of stem borers was obtained when the crop was protected between 15 and 30 days after seedling (Taneja and Nwanze, 1989). Sétamou *et al.* (1995) found that carbofuran application at 35 days after planting did not give full protection against natural infestation by four species of stem borers. Carbofuran application in maize, between 21 and 63 days after planting, was also found to result in significant protection of different stem borers infestation in Cameroon (Ndemal *et al.*, 2002). Although single treatment with carbofuran treatment (35 days after planting) did not give full protection, significant differences in stem borer days (mean number of borers observed on a consecutive sampling multiplied by sampling interval) of *S. calamistis* and *E. saccharina* were obtained between infested and Carbofuran treated plots (Sétamou *et al.*, 1995). Lewis *et al.* (1996) conducted a study in Iowa (USA) to determine whether *Beauveria bassiana* in combination with *Bacillus thuringiensis* or carbofuran was an effective tactic for season-long management of *Ostrinia nubilalis*. Mostly, damage was considerably reduced when carbofuran was applied to whorl-stage maize.

Table 10: Effect of carbofuran on damage variables (mean ± SE) of maize at harvest

N-levels Nha^{-1}	Season											
	Short rains						Long rains					
	% Damaged internodes		Bored holes		Tunneling length (cm)		% Damaged internodes		Bored holes		Tunneling length (cm)	
	TP	UTP	TP	UTP	TP	UTP	TP	UTP	TP	UTP	TP	UTP
KIBAHA												
0	6.50	35.46	2.00	9.68	4.57	17.56	2.29	14.88	0.28	3.67	1.14	8.93
50	6.83	37..07	2.18	14.53	4.95	24.40	2.58	15.67	0.53	5.15	1.60	11.99
75	3.60	42.07	1.00	20.53	2.72	36.65	3.78	19.31	0.60	5.90	2.71	15.45
100	5.55	46.45	2.10	19.95	4.09	36.23	1.39	19.97	0.25	6.93	1.29	16.61
P-value	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
SUA												
0	0.39	1.72	0.23	0.55	0.31	1.04	0.46	2.34	0.20	1.45	0.32	2.11
50	0.54	1.34	0.1	0.68	0.88	0.74	0.00	2.76	0.00	1.25	0.00	2.17
75	0.83	2.70	0.20	0.98	0.29	1.43	0.00	2.45	0.00	2.00	0.00	3.63
100	0.67	4.18	0.15	1.80	0.33	3.10	0.21	3.94	0.05	2.20	0.24	4.29
P-value	0.2562		0.3861		0.560		<0.0001		<0.0001		<0.0001	

TP = Treated plots UTP = Untreated plots. Means within columns followed by the same letter do not differ significantly at P≤ 0.05 (SNK)

4.6 Stem borers damage and maize yield losses

4.6.1 Effect of nitrogen on maize yield and stem borer infestation

During both seasons, there was a direct relationship between nitrogen levels and maize yields (Figures 3 and 4). The variations in both cob and grain yield between seasons and locations were expected because there were obvious variation in stem borer densities between seasons and also variation in soil types between locations.

4.6.1.1 Nitrogen rates effect on maize cob yield and stem borer infestation

Analysis of variance (SAS 1997) indicated that application of nitrogen resulted to a linear increase in cob weight at both locations and seasons . During the first season, cob weight increased from 81.94 g/plant in 0 kg Nha^{-1} to 190.38 g/plant in 100 kg Nha^{-1} ($P<0.0001$). Likewise, during the long rainy season, cob weight increased linearly from 95.33 g/plant in 0 kg Nha^{-1} to 178.32 g/plant in 100 kg Nha^{-1} ($P<0.0001$) at Kibaha. At SUA, cob weight increased from 160.08 g/plant in 0 kg Nha^{-1} to 232.00 g/plant in 100 kg Nha^{-1} ($P<0.0001$), and from 149.13 g/plant in 0 kg Nha^{-1} to 234.91 g/plant in 100 kg Nha^{-1} ($P<0.0001$) in the short and long rain seasons, respectively (Figure 3).

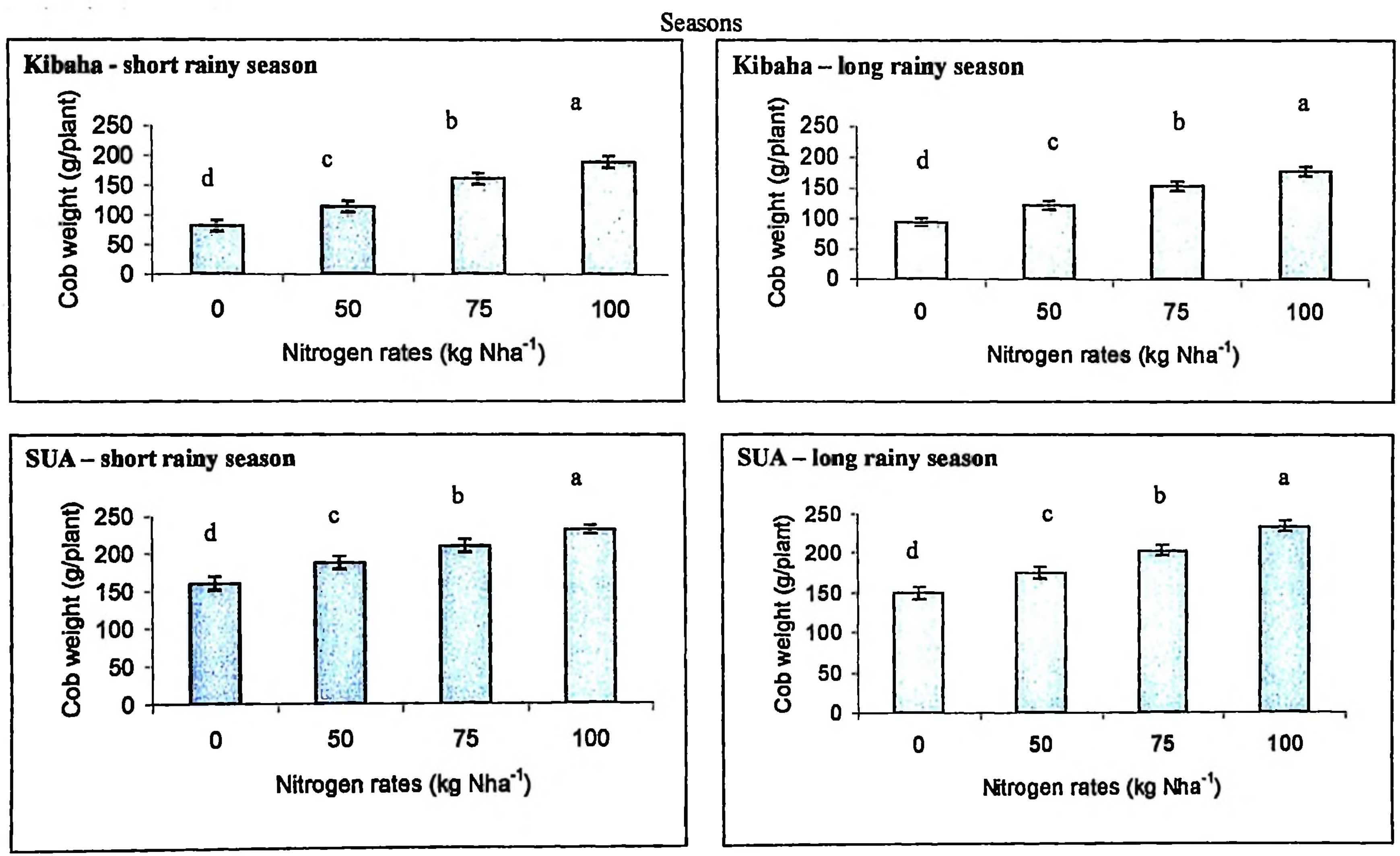

Figure 3 : Effect of nitrogen application on cob weight at different stem borers infestation levels

Bars followed by the same letter do not differ significantly at P $P \leq 0.05$ (SNK)

4.6.1.2 Effect of nitrogen application rates on maize grain yield under stem borer infestation pressure

Analysis of variance (SAS, 1997) clearly showed that there was a significant effect of nitrogen application rates on maize grain yield. Grain weight increased from 44.04 g/plant in 0 kg Nha^{-1} to 111.13 g/plant in 100 kg Nha^{-1} at Kibaha during the short rainy season ($P < 0.0001$), while during the long rainy season grain weight increased from 67.81 g/plant in 0 kg Nha^{-1} to 124.60 g/plant in 100kg Nha^{-1} ($P < 0.0001$), and from 96.34 g/plant in 0 kg Nha^{-1} to 150.39 g/plant in 100 kg Nha^{-1} ($P < 0.0001$) (Figure 4).

Generally, the density of a crop population is expressed in terms of the leaf area index (LAI), which is defined as the leaf area of the plants per unit area of the soil. When the nutrient supply is sub optimal, the leaf growth rate, and thus the LAI, can be limited by low rates of net photosynthesis or insufficient cell expansion or both of these factors. This is particularly evident with sub optimal supply of nitrogen. In plants suffering from nitrogen deficiency, elongation rates of leaves may decline before there is any reduction in net photosynthesis (Chapin *et al.*, 1988): this decline being the result of decrease in both number and duration of extension of epidermal cells (MacAdam *et al.*, 1989). Besides hormonal effect, a decrease in root hydraulic conductivity might be involved, leading to a decrease in water availability in expanding leaf blades (Radin and Boyer, 1982). The small size of leaf blades in nitrogen deficient plants is the result of impaired cell expansion (Hecht-Buchholz, 1967). In many instances, a transient deficiency of nitrogen during early growth of maize might reduce final yield not as a consequence of smaller leaf area but as a result of lower number of grains per cob (Römer and Schilling, 1996; Barry and Miller, 1989).

In the present study, nitrogen concentration in maize stems from the plots where nitrogen was applied was higher than in the control and was highest in plots that received 100 kg Nha^{-1} (Figure 4). Nitrogen concentration in the stems was significantly and positively correlated with grain yield. This implies that nitrogen application enhanced photosynthetic efficiency of maize plants and therefore resulted in higher grain yield.

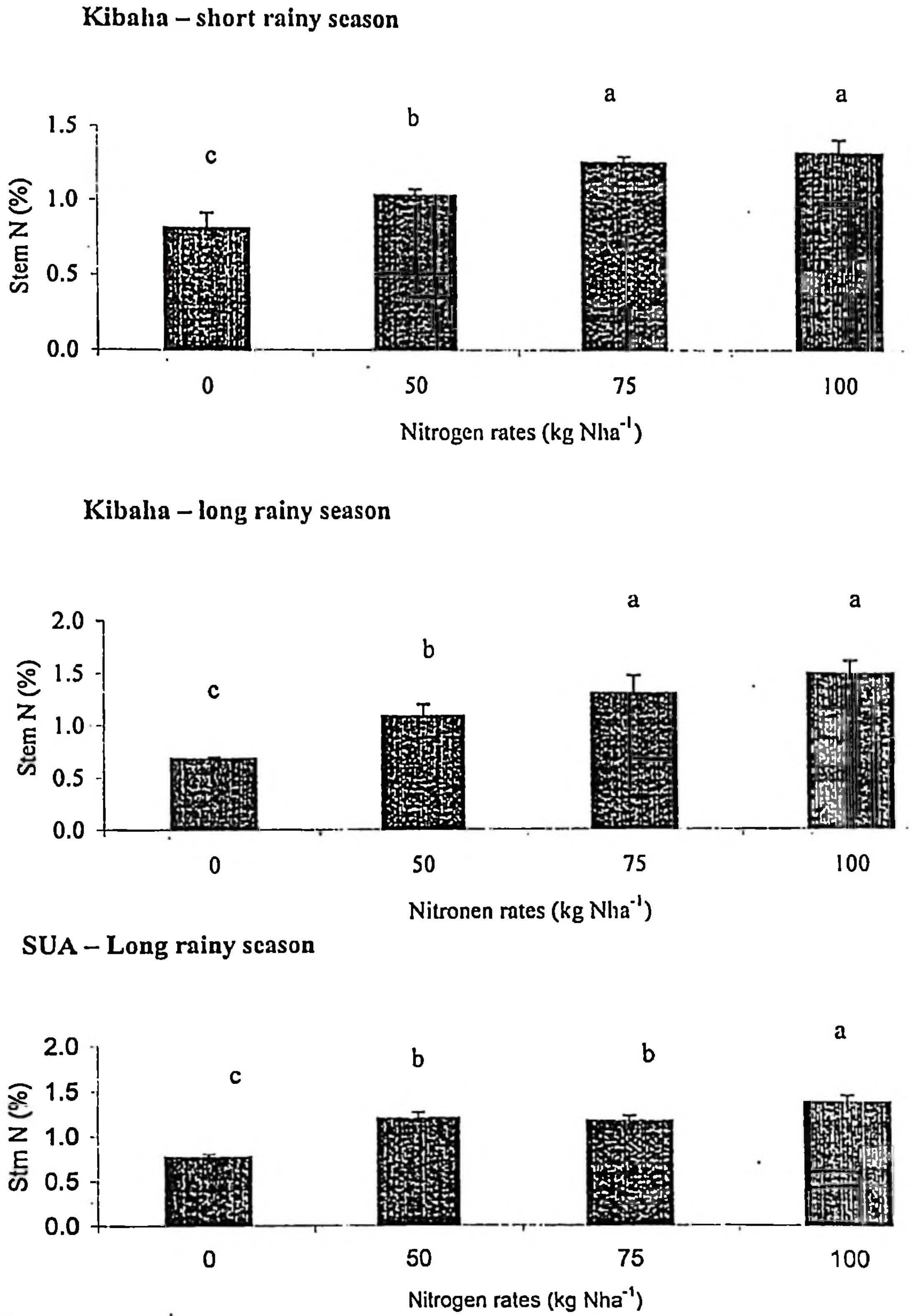

Figure 4: Stem nitrogen (%) in maize at pre-tasseling stage

Bars followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

Mineral nutrients are also required for chloroplast formation, either for synthesis of protein or chloroplast pigments. In green leaf cells, for example, up to 75 % of total organic nitrogen is located in the chloroplasts, mainly as enzyme protein. A deficiency of mineral nutrients that are directly involved in synthesis of protein or chloroplast pigments therefore results in the formation of chloroplasts with lower photosynthetic efficiency (Spencer and Possingham, 1960).

Variations in nitrogen availability affect growth and development of maize and may lead to changes in crop physiological conditions at flowering and in grain set. Uhart *et al.* (1995) in their study on nitrogen deficiency effects on crop growth, development, dry matter partitioning, and kernel set in maize, revealed a delay in both vegetative and reproductive phenological development, slightly reduced leaf emergence rate, and strongly diminished leaf expansion rate and leaf area duration due to nitrogen deficiency. Nitrogen deficiencies reduced radiation interception as much as radiation use efficiency and their effects on the ear dry matter/total dry matter ratio at harvest were associated with crop growth rate reductions at flowering. Dry matter partitioning to reproductive sinks at flowering and the ear dry matter/total dry matter ratio at harvest were reduced by nitrogen shortages.

Nitrogen is an important nutrient whose application directly influences photosynthetic efficiency and hence yields of maize and other non-leguminous crop plants. Several studies have been conducted on the relationship between nitrogen fertilizer applications and maize yield in various areas. In 1986, cycles 0, 2, 4 and 6 of CIMMYT Population 43, improved using full- sib family selection for grain yield and other traits, were evaluated at 0, 80, and 160 kg Nha^{-1} at six locations in Ghana, West Africa. Cycle responses showed that grain yield and plant height increased. The greatest response to applied nitrogen was observed at 80 kg Nha-1 for all traits (Sallah *et al.*, 1998).

Workayehu (2000) evaluated the effects of four levels of nitrogen fertilizer (0, 46, 92, 138 kg Nha^{-1}) and four plant population densities (44000, 53000, 67000 and 89000 plants ha^{-1}) on grain yield of maize over four years (1995-98) at Awassa Research Centre. Both the linear and quadratic responses to nitrogen application were significant. His results showed that, increased application of nitrogen fertilizer resulted in higher yields and accounted for 83% of the variation. Continuous maize cv. TZE-SR-White was compared with maize/cowpea cv. TVX 4569-13-C-IK rotation. Both cropping systems received 0 or 80 kg Nha^{-1} as urea and 0 or 60 kg Pha^{-1} as Volta phosphate rock. Maize grain yields and nutrient accumulation were higher with rotation than continuous cropping. Root length densities of maize were significantly lower under continuous cropping than rotation. In a pot experiment, maize growth was much better in the soil from crop rotation than from the continuously cropped plots, provided phosphorus was not a limiting factor (Horst *et al.*, 1994). The higher root length densities and much better growth rate in maize/cowpea rotation were due to more nitrogen added by cowpea as nitrogen fixing plant in maize/cowpea cropping system

Considerable reductions in yield losses in higher nitrogen application rates suggest that, nitrogen enhances plant vigor and suppressed the negative effect of increased borer damage. This implies that nitrogen fertilization enhances plant's tolerance to borer attack. It increases stem diameter and height, as well as root system and hence enhance plant vigor that can tolerate stem borer infestations. Singh and Singh (1969) showed that nitrogen induced a better root system. Masand *et al.* (1993) in their field experiment on an Alfisol during the kharif [monsoon] seasons of 1981-82 at Palampur, Himachal Pradesh, used 0, 120 or 150 kg Nha^{-1} treatments. They hypothized that, nitrogen application increased yield and water use efficiency. This is indicated by the increased plant height and stem diameter obtained in increased nitrogen application.

Correlations between nitrogen application rates, stem nitrogen concentration, growth variables and yield of maize were very strong. Nitrogen application rate was significantly positively correlated with nitrogen concentration in maize stem, as well as growth variables and maize yield. Likewise, nitrogen concentration in maize stems was significantly positively correlated with growth variables and maize yields (Table 11). Chabi-Olaye *et al.* (In press) found that maize plant height at 35 days after planting was significantly positively ($r = 0.73$, $P = 0.001$) correlated with nitrogen concentration in maize leaves. These results imply that concentration of nitrogen in maize plant parts (source and sinks), increases with nitrogen application rates, and therefore yield of maize is significantly increased.

Table 11: Correlation matrixes of nitrogen rate, stem nitrogen, growth and yield variables at harvest

	1	2	3	4	5	6
Kibaha short rainy season						
1. Nitrogen rate	-					
2. Stem nitrogen	0.847***	-				
3. Dry matter	0.289	0.289	-			
4. Plant height	0.785***	0.736***	0.297	-		
5. Stem diameter	0.849***	0.814***	0.400	0.711***	-	
6. Cob weight	0.820***	0.766***	0.251	0.763***	0.824***	-
7. Grain weight	0.822***	0.819***	0.162	0.770***	0.816***	0.964***
Kibaha long rainy season						
1. Nitrogen rate	-					
2. Stem nitrogen	0.838***	-				
3. Dry matter	0.563*	0.493*	-			
4. Plant height	0.767***	0.685**	0.380	-		
5. Stem diameter	0.895***	0.744***	0.356	0.901***	-	
6. Cob weight	0.846***	0.754***	0.419	0.786***	0.787***	-
7. Grain weight	0.857***	0.737**	0.369	0.822***	0.834***	0.978***
SUA long rainy season						
1. Nitrogen rate	-					
2. Stem nitrogen	0.879***	-				
3. Dry matter	0.486	0.484	-			
4. Plant height	0.256	0.687	0.120	-		
5. Stem diameter	0.664**	0.683**	0.329	0.559*	-	
6. Cob weight	0.713**	0.550*	0.314	0.674**	0.762***	-
7. Grain weight	0.739**	0.568*	0.364	0.570**	0.702**	0.981***

*** = Significant at $P \leq 0.001$, ** = Significant at $P \leq 0.01$, * = Significant at $P \leq 0.05$.

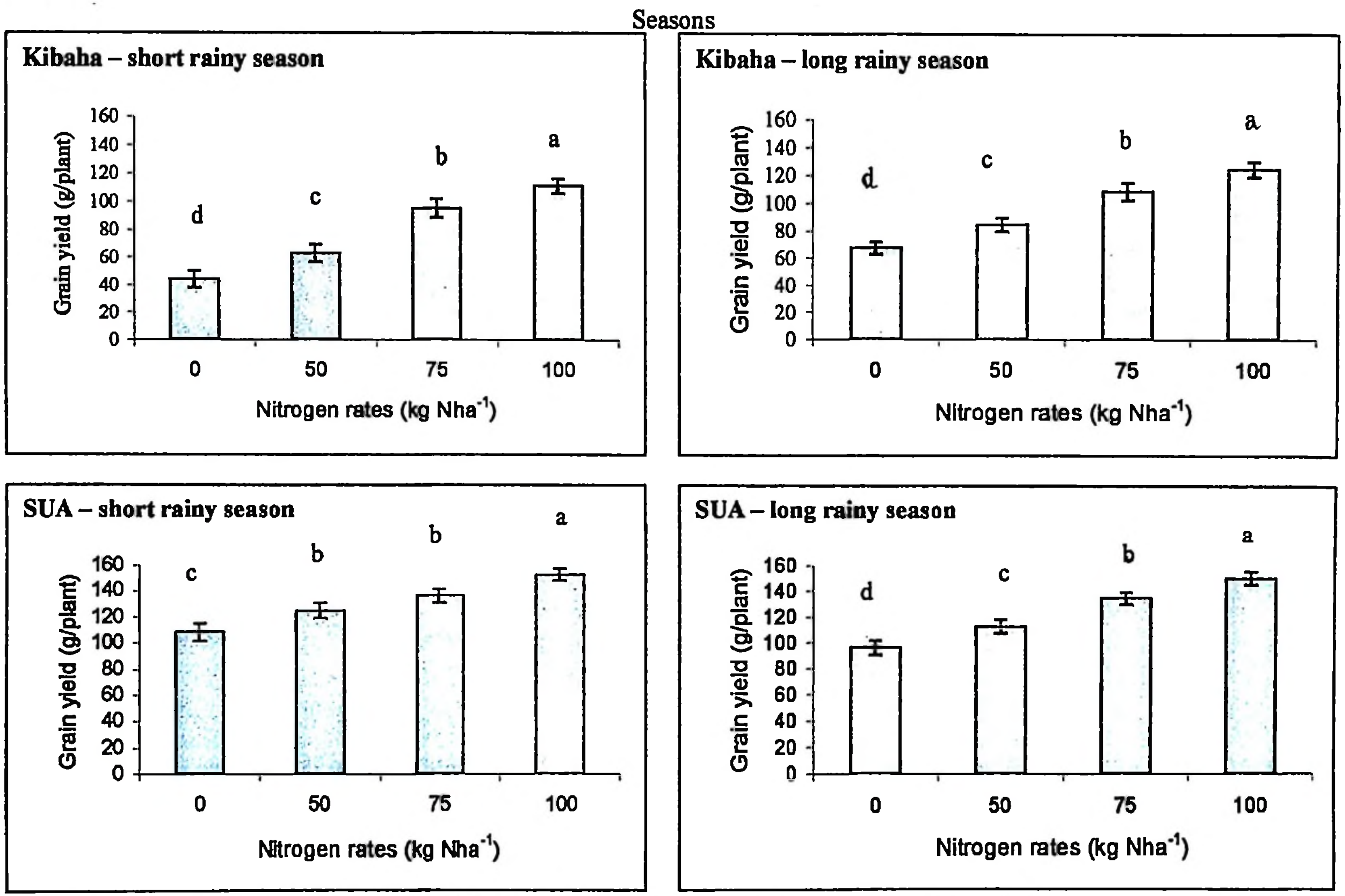

Figure 5: Effect of nitrogen application rates on grain yield under different stem borer infestation pressure

Bars followed bv the same letter do not differ significantlv at $P < 0.05$ (SNK)

4.6.2 Percentage dead hearts at different nitrogen rates in control and untreated plots

The number of dead hearts varied with location and season (Table12). More dead hearts were observed during the short than the long rainy seasons at Kibaha. At SUA there were no "dead heart" damage symptoms in both seasons. There were more plants with dead heart symptoms at Kibaha during the short rainy season, attributed to higher number of stem borers as compared with the long rainy season, The absence of dead hearts at SUA was due to very low borer density in both seasons.

In both seasons the percentage dead hearts recorded was very low (Table 11), it cannot simply be added to final yields differences because the surviving plants profited from competition lower between plants for soil nutrients and light. Harris (1962) observed an increase of average cob weight with increasing stand loss due to stem borers. He stated that, when soil fertility is not a limiting factor and stand loss is not high, adequate compensation for loss of stand might be achieved for maize.

Table 12: Percentage dead hearts in the treated and untreated plots at different nitrogen application rates.

Nitrogen rates (kg Nha^{-1})	% Dead hearts	
	Treated (control)	Untreated
Kibaha short rains		
0	0.00 ± 0.00^{b}	6.94 ± 1.50^{aA}
50	0.00 ± 0.00^{b}	6.25 ± 2.40^{aAB}
75	0.00 ± 0.00^{b}	4.51 ± 3.28^{aB}
100	0.00 ± 0.00^{b}	4.52 ± 1.33^{aB}
Kibaha long rains		
0	0.00 ± 0.00^{b}	0.36 ± 0.72^{aAB}
50	0.00 ± 0.00^{b}	$1.05 \pm 1.33^{aA[illegible]}$
75	0.00 ± 0.00^{b}	0.00 ± 0.00^{bB}
100	0.36 ± 0.36^{b}	$1.40 \pm. 0.98^{aA}$
SUA short rains		
0	0.00 ± 0.00	0.00 ± 0.00
50	0.00 ± 0.00	0.00 ± 0.00
75	0.00 ± 0.00	0.00 ± 0.00
100	0.00 ± 0.00	0.00 ± 0.00
SUA long rains		
0	0.00 ± 0.00	0.00 ± 0.00
50	0.00 ± 0.00	0.00 ± 0.00
75	0.00 ± 0.00	0.00 ± 0.00
100	0.00 ± 0.00	0.00 ± 0.00

Means within rows and columns followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

4.6.3 Maize yield losses

4.6.3.1 Growth variables in insecticide treated and untreated plots at harvest

Growth variables recorded at harvesting time are presented together with grain yield loss values in Table 13.The increases in growth variables in the treated plots at different nitrogen levels were significantly higher. In the insecticide treated plots, the increase in plant height was 11.35 %, and 19.74 % in untreated plots from 0 to 100 kg Nha^{-1} during the short rains at Kibaha. Stem diameter increased by 21.81 % in treated plots and by 29.3 % in the plots that were not protected by an insecticide. During the long rain season the increases in plant height were 14.47 % in treated plots, and 14.60 % in the stem borer infested plots. Stem diameter increased by 19.10 %, and 23.49 % in the treated and untreated plots, respectively. There were no significant differences in plant height and stem diameter at SUA during the short rain season between insecticide treated and untreated plots in different nitrogen application rates. However, plant height increased by 5.78 % and 3.70 % in the treated and untreated plots, respectively. The increases in stem diameter were 24.60 % in the treated plots, and 12.80 % in the untreated plots. During the long rain season at SUA, plant height increased by 7.64 % in the control plots, and 7.25 % in the infested plots. Likewise, stem diameter increased by 17.14 % and 17.24 % in the control and infested plots, respectively.

4.6.3.2 Cob weight losses

Cob weight loss decreased with increasing nitrogen application rates at both locations except during the short rainy season at SUA. In the short rainy season at Kibaha the average cob weight losses due to stem borer activity decreased from 49.9 % in 0 kg Nha^{-1} to 22.0 % in 100 kg Nha^{-1} application. Likewise, during the long rain season, cob weight losses decreased from 26.4 % to 16.3 %. There was no cob weight losses recorded at SUA in the short rainy season. However, in the long rainy season the reduction in cob weight loss was 14.1% in 0 kg Nha^{-1} to 0 % in 100 kg Nha^{-1} (Figure 6).

4.6.3.3 Maize grain weight losses

Grain weight loss was 52.75 % in 0 kg N/ha^{-1} and 19.38 % in 100 kg Nha^{-1} at Kibaha during the short rainy season, while during the long rainy season grain weight loss was 27.09 % in 0 kg Nha^{-1} and 14.84 % in 100 kg N/ha^{-1}. Since stem borer infestation at SUA was extremely low during the short rainy season no yield losses occurred. In the long rainy season grain yield loss was reduced by 13.19 % in 0 kg Nha^{-1} to 0.4 % in 100 kg Nha^{-1} (Table 13). By contrast a reduction in yields from 20 % in 0 kg Nha^{-1} to 11 % in 120 kg Nha^{-1} treatment was obtained by Sétamou *et al.* (1995) in Benin. In their study, they evaluated the relationship between nitrogen rates and yield of maize under stem (*S. calamistis* and *E. saccharina*) and cob (*Mussidia nigrivenella* and *Cryptophlebia leucotreta*) borers' infestations.

An on-farm experiment was conducted in two contrasting locations, Kasonga (9 farms) and Songani (8 farms) in southern Malawi that examined the effects and interactions of applying fertilizers and crop residues to soils. Nitrogen fertilizer inputs were 0, 20, 40 and 60 kg Nha^{-1} with small amounts of accompanying phosphorus (0-13 kg Pha^{-1}). Analysis of variance of maize grain yield revealed significant effects of location ($P<0.001$) and fertilizer addition ($P<0.001$). Fertilization resulted in maize yields ranging between 901 $kgha^{-1}$ with no fertilizer to 1955 $kgha^{-1}$ with addition of 60 kg Nha^{-1} and 13 kg Pha^{-1} (Mwato *et al.*, 1999).

Mineral nutrition may exert secondary, often unpredicted influences on the growth and yield of plants; by affecting changes in growth pattern, plant morphology and anatomy, and particularly chemical composition, Mineral nutrients may either increase or decrease the resistance or the tolerance of plants to pests (Marschner, 2002). Although resistance and tolerance are genetically controlled, they are considerably influenced by environmental factors. In this context mineral nutrition of plants can be considered as an environmental factor that can be manipulated relatively easily. Although frequently unrecognized, this factor has always been an important component of pest control (Hubner and Wilhelm, 1988). For example, liming of soils or application of mineral fertilizer in different amounts and forms not only affects the growth and composition of the plants directly, but also has profound effects on microbial activity in the soil and rhizosphere and plant resistance and tolerance to root and shoot pathogens and pests indirectly.

With respect to tolerance, there is a general pattern that in plants suffering from mineral deficiency, tolerance to pest and diseases is lower and can be increased by supplying the deficient nutrient. Such a relationship is based on the fact that more vigorously growing plants usually have higher capacity to compensate for example, for losses of leaf or photosynthates, damage due to feeding activities of pests, and root surface area due to infection or feeding (Marschner, 2002).

Fertilizer placements can affect root system morphology and distribution within the soil profile and hence tolerance to pests. This can be used as a tool to improve maize tolerance to pest's infestation. In a study on corn response to fertilizer placement treatments in an irrigated no-till system, when phosphorus fertilizer was placed with the seed and nitrogen fertilizer was placed in a 5- by 5-cm band, maize plants had 185 kg/root pull resistance, 0.26 g/shoot phosphorus accumulation, and 10.5 tons/ha grain yield. However, when phosphorus and nitrogen fertilizers were applied to the soil surface, maize plants had significantly less root pull resistance (151 kg/root), phosphorus accumulation (0.22 g P/shoot) and grain yield (10.1 tons/ha) (Riedell *et al.*, 2000).

The effects of broadcasting nitrogen at sowing, or split banded application at sowing and cultivation, on root larval feeding damage, root pull resistance, grain yield and survival of larvae to adult stage under different levels of controlled root-worm larval infestation were investigated. Root systems were generally larger (greater root pull resistance) under banded N (85 kg/plant) (Riedell *et al.*, 1996).

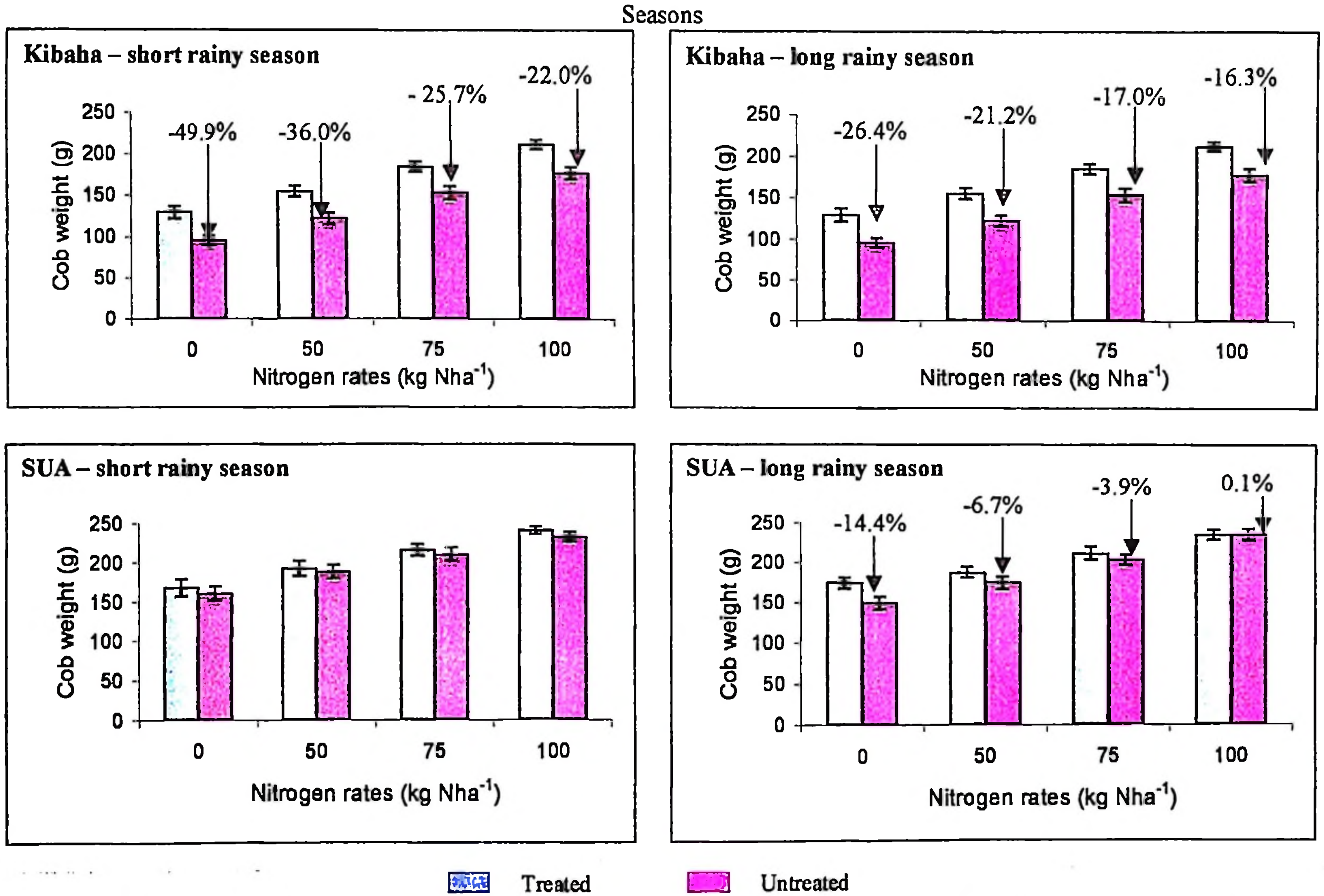

Figure 6: Cob yield and yield losses at different nitrogen rates and different stem borers infestation pressure during two rain seasons

Table 13: Growth variables and grain yield losses (%) of maize subjected to different nitrogen application rates during two rainy seasons

	Seasons													
	Short rainy season							Long rainy season						
N-levels	Plant height (cm)		Stem diameter (cm)		Grain yield (g/plant)		Yield loss (%)	Plant height (cm)		Stem diameter (cm)		Grain yield (g/plant)		Yield loss (%)
Nha^{-1}	TP	UTP	TP	UTP	TP	UTP		TP	UTP	TP	UTP	TP	UTP	
KIBAHA														
0	202.7	168.2	1.88	1.74	93.20	44.04	52.75	202.5	183.6	1.78	1.66	93.01	67.81	27.09
50	205.6	167.2	1.99	1.87	104.28	62.80	39.78	201.5	191.4	1.83	1.77	108.50	84.83	21.82
75	217.0	194.1	2.22	2.12	125.15	95.28	23.89	226.4	201.1	2.00	1.95	130.06	109.04	16.16
100	225.7	201.4	2.29	2.25	137.85	111.13	19.38	231.8	210.4	2.12	2.05	146.32	124.60	14.84
P- value	<0.0001		<0.0001		0.0009			<0.0001		<0.0001		<0.0001		
SUA														
0	237.2	237.8	1.87	1.95	110.12	108.17	0.00	240.7	235.8	1.75	1.74	110.98	96.34	13.19
50	239.3	243.5	2.02	2.05	123.10	124.71	0.00	238.8	225.0	1.87	1.85	119.87	112.80	3.90
75	248.9	244.8	2.18	2.15	138.38	136.40	0.00	239.2	236.1	1.94	1.95	138.76	134.96	2.74
100	250.9	246.6	2.33	2.20	153.01	152.53	0.00	259.1	252.9	2.05	2.04	151.01	150.39	0.40
P value	<0.0001		<0.0001		0.0009			<0.0001		<0.0001		0.0009		

TP= Treated plots with carbofuran, UTP= Untreated plot.

4.6.4 Important variables explaining the variability in maize yield

During harvesting time *C. partellus* larvae are often not present because they have already pupated. For the evaluation of the effect of stem borer feeding on yield, cumulative pest measures rather than pest numbers are the important variables for regression analyses (data from Kibaha short rainy season were used in the regression analyses, because of the higher damage levels).

Multiple regression of yield (g/plant) on nitrogen level (x_1) and stem tunnel (x_2) resulted in :

$Y = 24.764 + 26.24x_1 - 0.42x_2$ .... (iii)

N =160 $r^2 = 0.33$

with $P<0.0001$, for x_1 and $P= 0.011$ for x_2. Nitrogen level was significantly ($P<0.0001$) and positively related to yield while, stem tunnel was negatively related to yield ($P= 0.011$). When growth variable (plant height, x_1 and stem diameter, x_2) and damage variable (stem tunnel, x_3), were included in the model the results were as follows:

$Y = -60.69 + 0.356x_1 + 39.142x_2 - 0.147x_3$..(iv)

N =160 $r^2 = 0.254$

with P=0.004 for x_1, P<0.0001 for x_2, and P = 0.377 for x_3.

This shows that growth variables are significantly and positively related to grain yield while damage variable (tunnel length) is negatively related to grain yield. This of stem and cob borers on maize subjected to different nitrogen treatments. He hypothesized that nitrogen and growth variables (i. e. plant height and stem diameter) were significantly and positively related to yield, while stem borer damage (stem tunnel) was negatively related to yield of maize. The best relationship with phenological stage, stem diameter and arcsine square root percentage transformed stem tunneled appeared to be a good indicator of plant fitness (Gounou *et al.*, 1994). The regression coefficient obtained from the covariance analysis showed that grain yield decreases by 0.761 ± 0.08 g for each increase in the extent of stem tunneling (Chabi-Olaye *et al.*, 2005).

In the final regression model all damage variables below and above the cob were included and the results are presented in Table 14. Growth variables were positively related to yield, while damage variables were negatively related to yield except tunnel length above the cob, which tended to be positively related to yield. Only plant height was significantly and positively related to yield (Y = - 9. 913 + 0.494x t = 5.48*** r^2 = 0.202). Percentage damaged internodes below the cob was significantly and negatively related to yield (Y. =-9.913 – 0.167x, t = 2.12* r^2 = 0.202).

Table 14: Regression of maize grain yield on growth and damage variables

Variable	b	SE	t-values
Plant height (cm)	0.494	0.090	5.48***
Stem diameter (cm)	0.699	0.380	1.84
Bored holes before cob	1.025	0.554	1.85
Bored holes after cob	-0.991	0.706	-1.40
Tunnel length before cob (cm)	-0.043	0.411	-0.11
Tunnel length after cob (cm)	0.585	0.452	1.29
Bored nodes before cob (%)	-0.353	0.167	2.12*
Bored nodes after cob (%)	-0.119	0.134	0.89

Intercept = -9.913, $r^2 = 0.202$, N = 160

*** = Significant at $P \leq 0.001$, * = Significant at $P \leq 0.05$

4.7 Effect of nitrogen application on rate of parasitism of c. partellus larvae by its larval parasitoid Cotesia flavipes

4.7.1 Effect of nitrogen application on the frequency and amount of frass produced by stem borers, C. partellus, in maize stems in relation to parasitism rates.

4.7.1.1 Effect of nitrogen application rates on the frequency of frass production in relation to response of parasitoids to host frass.

Several studies have confirmed that volatile materials in the frass produced by larvae of most insects' during their feeding activities are used by parasitoids to locate the larvae for parasitization (Ngi-Song and Overholt, 1997). The waste (frass) produced by larvae during their feeding activity in maize stems, contain some info-chemicals or volatiles, which enable the parasitoid to locate the horst for parasitism. Some other studies have investigated the influence of frass produced by some lepidopteran larvae on searching ability of their potential parasitoid. For example, Ngi-Song and Overholt (1997) observed that, when *Cotesia flavipes* and *C. sesamiae* were given a choice between volatiles from frass and from wet cotton wool, they preferred the volatiles from the frass regardless of the stem borer species that produced the volatiles or the plant species upon which the host had fed. Tanaka *et al.* (2001) investigated the response of the tachinid fly, *Exorista japonica*, to host frass or its extracts to clarify the host location mechanisms of female flies in a potential host habitat. Host searching time in a patch and the number of patch visits were analyzed using a frass-containing patch which was excreted by host larvae, *Mythimna separata* (Lepidoptera: Noctuidae), and patches to which host frass extracts were applied. *Exoristica. japonica* females were arrested in response t the host-frass-containing patch after contacting the frass with their front tarsi, thereby spending most of the time to search the patch and to revisit the host-frass patch. The female flies also exhibited area-restricted searching with methanol extracts of the host frass. Area-restricted searching activity increased with the concentration of host-frass extract. They concluded that *E. japonica* females likely employ chemicals in host frass as arrestants in host location.

In study of info-chemicals mediating the foraging behavior of *Aleochara bilineata* Gyllenhal adults as sources of attractants, it was noted that, the sources of info-chemicals in the infested rutabaga were the cabbage maggot larvae themselves and their frass (Royer and Boivin, 1999). However, in a choice test, adults preferred the effluvia of the larvae to that of the damaged rutabaga from which those larvae were obtained.

There was a big variation in numbers of plants found with stem borer's frass. More plants with frass were found at Kibaha during the short rainy season. No plants were found with frass at SUA during the short rainy season. Out of the 160 sampled plants, 51.88 % and 12.5 % had frass at Kibaha during short and long rainy seasons, respectively. At SUA, very few plants (5.63 %) with frass were recorded during the long rainy season. At Kibaha, during the short rainy season, the numbers of plants with frass were highest (65.%) in 100 kg Nha^{-1} followed by 75 kg Nha^{-1} (57 %) plots. The percentage of plants found with frass of *C. partellus* at different nitrogen levels are given in Table 15.

Table 15: Effect of nitrogen application on stem borer's frass production in maize plants

Location	Nitrogen level (kg Nha^{-1})	Number of plants with stem borer's frass (%)	
		Short rainy season	Long rainy season
KIBAHA	0	42	5.0
	50	42	15.0
	75	57	7.5
	100	65	22.5
SUA	0	0	7.5
	50	0	5.0
	75	0	5.0
	100	0	5.0

The results in Table 15 indicate that, the frequency of frass production increased with increasing nitrogen level at Kibaha. At SUA the trend was different. probably due to very low stem borer density during both seasons. The increase in number of percentage of plants with stem borer frass with increasing nitrogen application indicates that, there is a positive relationship between parasitoids searching ability and their host (larvae) frass. Evidence for the influence of stem borers frass to successive parasitism by the parasitoids is also confirmed in some other studies. Hailemichael *et al.* (1994) hypothesized that increased numbers of probes by the parasitoid *Xanthopimpla stemmator* were associated with an increase in successful parasitization. Host seeking activity in *X. stemmator,* was stimulated by the presence of larval frass, host odor, and movement of host pupae. It is concluded that *X. stemmator* is a good candidate for biological control of *D. saccharalis* and possibly other factitious stalk borer.hosts.

4.7.1.2 Effect of nitrogen application on the quantity of *C. partellus* frass

The amount of frass was quantified from each infested plant in different nitrogen levels. The weight of fresh frass increased with increasing nitrogen levels and was significantly different between nitrogen treatments. The results also showed significant differences between fresh and dry weight of frass at different nitrogen application rates. Plots that received 100 kg Nha^{-1} had fresh frass weight which differed significantly from fresh frass weight recorded in 0 and 50 kg Nha^{-1} (Table 16). By contrasts Boeve *et al.* (1996) investigated the effect of infestation by larvae of the European apple sawfly (*Hoplocampa testudinea*) on the emission of volatiles from apple fruitlets. Healthy apples emitted a blend of terpenoids and a few aromatic and short aliphatic compounds. Infested apples emitted the same compounds as healthy apples.

Table 16: Mean (± SE) weights of fresh and dry stem borer frass sampled at pre-tasseling stage of maize.

Nitrogen rates (kg Nha^{-1})	Frass weights (g/plant)	
	Fresh weight	Dry weight
Kibaha short rainy season		
0	0.051 ± 0.020^{aB}	0.023 ± 0.010^{a}
50	0.049 ± 0.015^{aB}	0.017 ± 0.005^{a}
75	0.092 ± 0.029^{aAB}	0.039 ± 0.013^{b}
100	0.132 ± 0.036^{aA}	0.038 ± 0.009^{b}
Kibaha long rainy season		
0	0.027 ± 0.026	0.001± 0.001
50	0.022 ± 0.011	0.007 ± 0.005
75	0.008 ± 0.006	0.002 ± 0.001
100	0.026 ± 0.010	0.004 ± 0.002
SUA short rainy season		
0	0.000 ± 0.000	0.000 ± 0.000
50	0.000 ± 0.000	0.000 ± 0.000
75	0.000 ± 0.000	0.000 ± 0.000
100	0.000 ± 0.000	0.000 ± 0.000
SUA long rainy season		
0	0.011 ± 0.010	0.006 ± 0.005
50	0.004 ± 0.004	0.001 ± 0.001
75	0.011 ± 0.010	0.020 ± 0.001
100	0.002 + 0.002	0.001 ± 0.003

Means within rows and columns followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

However, trans, trans-alpha-farnesene, trans-beta-ocimene and another terpenoid were emitted in significantly larger amounts, whereas the other volatiles showed no quantitative change. The possible ecological significance of the increased emission of terpenoids by infested apples is related to a parasitic wasp (the ichneumonid *Lathrolestes ensator*) that attacks the sawfly larvae.

4.7.2 Effect of nitrogen application rates on the parasitism rate of stem borers by their larval parasitoids

All stem borer larvae were collected, labeled and reared in separate containers according to nitrogen levels. The larvae were reared in the laboratory for two weeks and supplied with their natural diet at intervals of three days. All parasitized larvae were recorded and each cocoon mass that emerged from each larva was kept in separate vial with proper labeling.

In the short rainy season at Kibaha, a total of 430 stem borer larvae were collected and 69 were parasitized (11, 15, 19 and 25 larvae from 0, 50, 75, and 100 kg N/ha plots respectively), which is equivalent to 16.05 % of all sampled stem borers. The number of parasitized stem borers increased with increasing nitrogen application although it did not differ significantly at $P \leq 0.05$ (Table 17).

Other studies on different crops and parasitoids have reported similar results on the effect of nitrogen application on larval parasitism. Reeves *et al.* (1996) studied the effect of nitrogen fertilizer applied to *Euphorbia pulcherrima* on the parasitization of *Bemisia argentifolii* by the parasitoid *Encarsia formosa.* It was found that, more individuals of the aphelinid *Encarsia formosa* were found on fertilized poinsettias (*Euphorbia pulcherrima*) than on non-fertilized plants. Parasitism of *Bemisia argentifolii* by *E. formosa* was higher on plants treated with calcium nitrate than on those treated with ammonium nitrate or on control plants. In a no-choice test, host feeding by *E. formosa* was higher when hosts were on fertilized plants than when hosts were on control plants. Variability in the parasitism of *B. argentifolii* by *E. formosa* appeared to be due to host plant-mediated differences in the aleyrodids. *Encarsia formosa* may be influenced by the nutritional suitability of the host to continue to oviposit, feed or disperse (Reeves *et al.*, 1996).

Table 17: Mean number of parasitized and parasitism rates of borer larvae at different nitrogen levels

	Nitrogen levels (kg Nha^{-1})			
Parasitism rates	0	50	75	100
Mean number of sampled stem borers	22.25	21.00	32.32	32.00
Parasitized borers per nitrogen level	2.25	3.25	5.00	6.25
% Parasitized borers per nitrogen level	15.87	16.65	15.28	19.94
% Parasitized borers out of total collected borers	2.76	3.07	4.83	5.81

In the present study, it was found that infestation levels have considerable effect on the amount of frass produced. Under high stem borer pressure more frass was produced. Frequency and amount of frass increased and differed significantly with nitrogen application implying that, nitrogen has indirect positive influence on larval parasitism.

4.8 effect of nitrogen application on stem borer development

The stem borer; *C. partellus,* from each nitrogen level were weighed soon after sampling, and number of larvae varied among different nitrogen levels. Highest records were found at Kibaha and lowest at SUA during the short rainy season.

Weights of larvae at both locations according to nitrogen levels, is as shown in Figure 7. Weights of stem borer larvae collected from SUA during the short rainy season are not included because there were only 6 larvae with high variation in instars. The results showed significant differences in larvae weight in the short rainy season at Kibaha, and long rainy season at SUA between nitrogen levels. Highest values of borer weights were recorded in plots, which received 100 kg Nha^{-1} (Figure 7). Wheeler and Halpern (1999) obtained similar results. In their study, the larvae of *Samea multiplicalis* were fed leaves of *Pistia stratiotes* plants that had been fertilized (NPK) at high and low rates. The leaves of the fertilized plants had a 4.3-fold increase in nitrogen (dry weight) and a 1.6-fold increase in water content. The results suggested that no compensatory increases occurred in larvae fed leaves from the low fertilized plants as no changes were found in fresh mass consumption or nitrogen utilization efficiency. Consequently, development time from second- or third-instars to pupation was delayed for about 3 days compared with larvae on fed the high nitrogen leaves. Furthermore, consumption of nitrogen was only 30 % and its accumulation into larval tissues was only 60 % compared with larvae fed on the high-fertilized leaves. The resulting larvae had both a final biomass and a growth rate that were reduced by 40 %.

Furthermore, The impact of balsam fir, *Abies balsamea,* flowering on nutritional and allelochemical quality of pollen, current-year and one-year-old foliage was studied in relation to *Choristoneura fumiferana* growth, development and utilization of food and nitrogen (Carisey and Bauce, 1997). It was found that, because of the high nutritive value of pollen, insects from flowering trees reached the 5^{th} instar five days earlier than those from non-flowering trees, and had heavier dry- and nitrogen-weights at the beginning of the 5^{th} instar. At bud break, switching from pollen to current-year foliage negatively affected conversion efficiencies and digestibilities of food and nitrogen. The switch from pollen to new foliage had a detrimental impact on fifth-instar survival and on newly molted 6th-instar dry- and nitrogen-weights. Moreover, during the 5^{th} instar, balsam fir flowering reduced the nutritive value of current-year foliage, which in turn, might have contributed to the reduced larval growth. Current-year foliage from flowering trees contained less nitrogen, total soluble sugars and total monoterpenes.

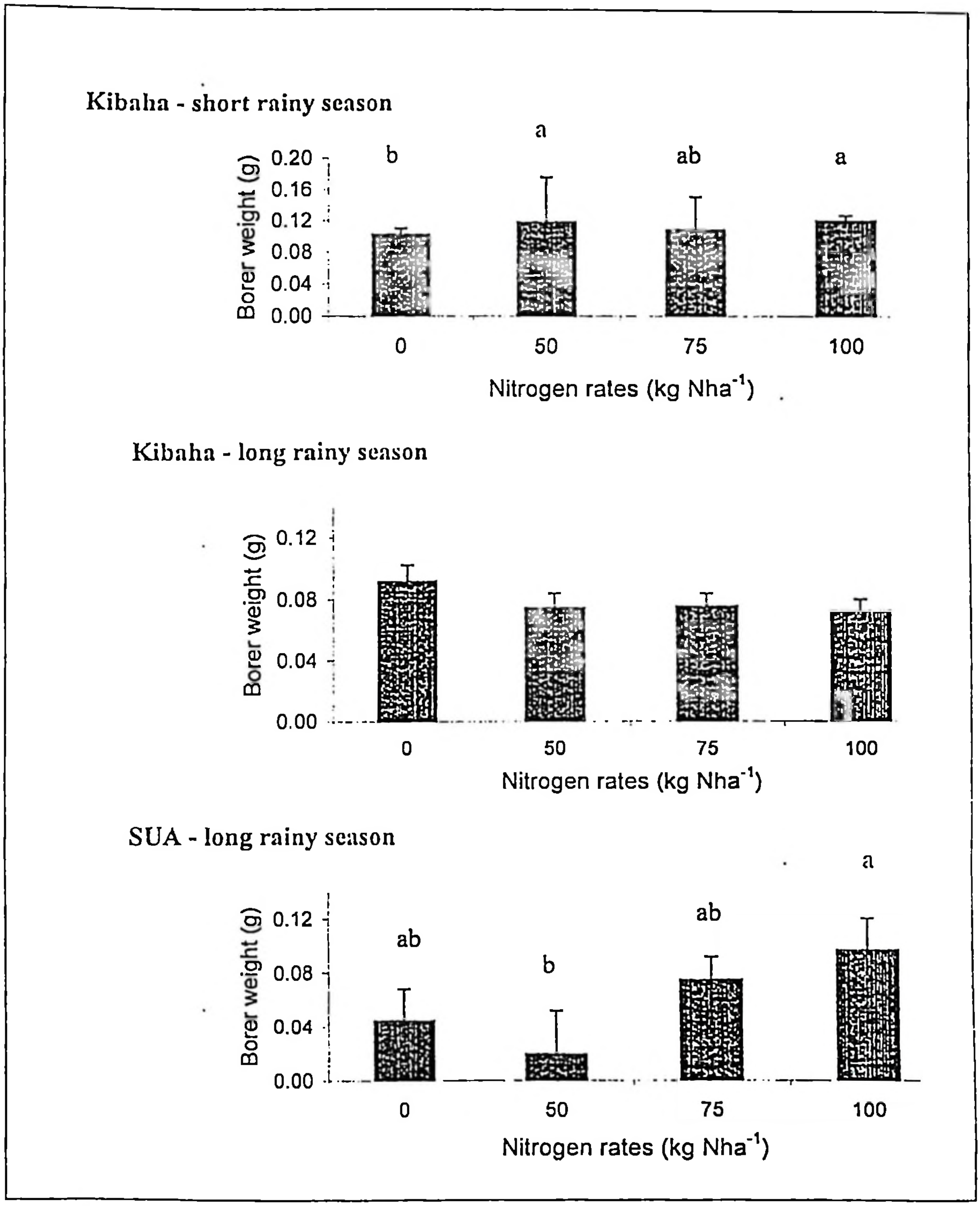

Figure 7: Weights of *C. partellus* subjected to different rates of nitrogen

Bars followed by the same letter do not differ significantly at $P \leq 0.05$ (SNK)

In general, the proportion of soluble nitrogen increases with elevated levels of nitrogen supply. Total nitrogen and 'crude protein' are the sum of protein and soluble nitrogen (as well as amino acids and amides) (Marshner, 2002). This implies that, plants that received more nitrogen application rates had higher quality (protein) food for stem borer development. This influenced higher growth rates, and hence, more weight of larvae that fed from plants applied with higher rates of nitrogen.

4.9 Distributions and effect of stem borer damage on maize yields in the humid zone of Morogoro region, eastern Tanzania.

4.9.1 Distribution and Densities of stem borers at early (pre-tasseling) stage of maize growth

As reported by Nsami *et al.* (2001), *C. partellus* was widely distributed at Kilosa District and accounted for 98.58 %, of the stem borers while *S. calamistis* accounted for 1.42 %. During this survey *C. partellus* was found in all sampled fields and *S. calamistis* in 13 % of the fields.

Significantly more larvae of *C. partellus* were collected in plants with more tunnel lengths and in infested than in healthy plants (P<0.0001, Table 1). There were no significant differences between the numbers of *S. calamistis* collected from plants with different tunnel lengths (P = 0.1568) and between healthy and infested plants (P = 0.1275). Field infestations ranged from 0 to 60 %, with an average of 33 % per field. Four (4) fields had more than 50 % infested plants, while two fields had no infestation. The percentage of plants infested was 46 % while healthy plants were 64

%. The number of larvae ranged from 0 to 72 per field and 70 % of sampled fields had more than 20 larvae per field.

4.9.2 Distribution and densities of stem borers at the maturity stage of maize.

Chilo partellus and *S. calamistis* were found feeding on maize at maturity. However, densities were very low compared to the early (pre-tasseling) growth stage. *Sesamia calamistis* were found feeding on both stems (73 %) and cobs (27 %) and were more abundant (64 %) than *C. partellus* (36 %). In this study, three categories of stems tunneled below the cob were used for all analyses rather than total stem tunneled. Stem tunneling is the best indicator of yield loss because it reduces translocation of nutrients to the ear (Bosque-Pérez and Mareck, 1991; Gounou *et al.*, 1994; Sétamou *et al.* 1995; Ndemah, 1999) and has the systemic effect on grain filling (Bosque-Pérez and Mareck, 1991; Sétamou *et al.* 2000) and hence on the development of entire ear. For quick assessment of stem tunneling and especially for genotypes with long stems, it is recommended to use stem tunneling below the cob only (Cardwell *et al.* 1997 and Ndemah *et al.* 2001).

The numbers of both species were significantly higher in plants with greater tunnel length (P<0.0001) and between healthy and infested plants (P<0.0001) (Table 18). At harvest, densities of borers are normally low because they have pupated and emerged, or killed by their natural enemies. Both stem borer species, particularly *S. calamistis,* attacked the maize at both growth stages. During harvest, *S. calamistis* was 7.5 times the population collected at pre-tasseling stage and considerable numbers were found on cobs. Sétamou and Schulthess (1994) also found *S.*

calamistis feeding on both maize stem and cob. In West Africa, *S. calamistis* takes two seasons to build up damaging infestation levels (Bosque-Pérez and Mareck 1990; Gounou *et al.* 1994). It passes the dry season on alternate and mostly inferior wild grass hosts, which causes their population to decline to close to zero by the beginning of the next cropping season (Sémeglo, 1997; Schulthess and Ajala, 1999; Ndemarh *et al.*, 2000) The female emerging from such hosts are small with low fecundity (Bowden, 1976; Sétamou *et al.*, 1993; Shanower *et al.*, 1993). Lower population density of *C. partellus* at harvest is due to the fact that this species normally attacks maize at early (seedling to pre-tasseling) stages.

Table 18: Stem borer larvae densities (mean ± SE) at pre-tasseling and harvesting stages in three different stem tunnel categories.

	Stem tunnel length (cm)				Infestation level		
Variables	< 1 (P[H])	1 – 15	> 15	*P* - value	P/H	P/I	*P*- value
Pre-tasseling stage							
C. partellus	0.31 ± 0.04^{c}	1.76 ± 0.09^{b}	3.54 ± 0.59^{a}	<0.0001	0.31 ± 0.04^{b}	1.97 ± 0.11^{a}	<0.0001
S. calamistis	0.01 ± 0.004	0.02 ± 0.01	0.00 ± 0.00	0.1568	0.01 ± 0.004	0.02 ± 0.01	0.1275
Harvesting stage							
C. partellus	0.03 ± 0.01^{b}	0.12 ± 0.03^{a}	0.15 ± 0.05^{a}	<0.0001	0.03 ± 0.01^{b}	0.13 ± 0.02^{a}	<0.0001
S. calamistis	0.02 ± 0.07^{b}	0.23 ± 0.05^{a}	0.39 ± 0.07^{a}	<0.0001	0.02 ± 0.07^{b}	0.28 ± 0.04^{a}	<0.0001

Means within rows fallowed by same letter are not significantly different at $P = 0.05$ (SNK). P/H = healthy plants, P/I = infested plants.

4.9.3 Relationship between centimeter stem borer tunnel length and growth variables, percentage stem tunnel length, bored internodes and holes at pre-tasseling stage.

It was found that the longer the tunnel length, the more the numbers of bored (tunneled) internodes and holes. Hence, bored internodes and holes significantly increased with increasing stem borer tunnel length (Tables 19). Stem tunnel lengths had no significant effect on both plant height and stem diameter. The numbers of damaged (tunneled) internodes and bored holes were positively and significantly correlated to tunnel length (r = 0.7677***, r = 0.8032***, respectively) (Table 21).

Only *C. partellus* and *S. calamistis* were feeding on maize stems. The number of *C. partellus* was 69.2 times greater than that of *S. calamistis*. To determine the relative importance of the two borer species, the damage variable 'centimeter stem tunneled' (y) was regressed against borer numbers ($y = 1.36 + 1.35x_1 + 0.61x_2$, N = 1200. $r^2 = 0.22$). *Chilo partellus* (x_1) numbers were significantly related to stem tunneled ($P<0.0001$) while *S. calamistis* (x_2) were not ($P = 0.5603$). In contrast, Sétamou and Schulthes (1995) found that *S. calamistis* and *E. sacharina* were both significantly related to centimeter stem tunneled. In this study, *S. calamistis* were not significantly related to stem tunneling probably due to the fact that the numbers were very low (15 out of 1053 borers) *Chilo partellus* was the dominant stem borer species and caused most damage (tunneled) on maize stems.

Table 19: Damage and growth variables (mean ± SE) in Kilosa district at pre-tasseling maize crop stage

	Stem tunnel length (cm)				Infestation levels		
Variables	< 1 (P[H])	1 – 15	> 15	*P*- value	P/H	P/I	*P* - value
Damage variables							
% Damaged internodes	0.00 ± 0.00^c	25.03 ± 0.71^b	41.45 ± 2.48^a	<0.0001	0.00 ± 0.00^b	26.89 ± 0.747^a	<0.0001
% Stem tunneling	0.00 ± 0.00^c	4.95 ± 0.20^b	17.69 ± 1.18^b	<0.0001	0.00 ± 0.00^b	6.41 ± 0.30^a	<0.0001
Boring holes	0.01 ± 0.01^c	4.70 ± 0.19^b	10.59 ± 0.81^a	<0.0001	0.01 ± 0.01^b	5.37 ± 0.21^a	<0.0001
Growth variables							
Plant height	125.62 ± 1.08	126.08 ± 1.67	128.55 ± 5.59	0.4555	125.62 ± 1.08	125.36 ± 1.62	0.49582
Stem diameter	2.26 ± 0.01	2.27 ± 0.02	2.25 ± 0.04	0.50481	2.26 ± 0.01	2.20 ± 0.01	0.5638
N	800	354	46		800	400	

Means within rows fallowed by same letter are not significantly different at $P = 0.05$ (SNK). P/H = healthy plants, P/I = infested plants.

4.9.4 Relationship between tunnel length and bored internodes, percentage stem tunnel length and bored holes at maturity stage

Damage variables at three different categories of tunnel lengths and between healthy and infested plants during harvest time, are presented in Table 20. All damage variables significantly increased with increasing stem tunnel lengths and between healthy and infested plants.

At harvest stem tunneling was positively and significantly (r = 0.8293***) related to percentage bored (damaged) internodes and bored holes (r = 0.7387***). Cob weight and grain weight were negatively significantly related to percentage damaged internodes (r = -0.1478***, r = -0.1692***), bored holes (r = -1022***, r = -0.1543***), and stem tunneling (r = -0.1316***, r = 0.1647* ·*) (Table 21). However, the relationship was not very strong. There were weak relationships between the numbers of *C. partellus* and *S. calamistis* to yield and damage variables. This indicates that density at harvest is not a reliable indicator of pest status. Therefore, for evaluation of the effect of borers on yield, damage symptoms such as stem tunneling are more stable and meaningful measures for plant damage than mere pest numbers (Van Rensburg *et al.*, 1988; Gounou *et al.* 1994; and Sétamou *et al.* 1995).

Table 20: Stem borer densities and maize damage variables at harvest (mean ± SE) in Kilosa district

Variables	Stem tunnel (cm)				Infestation levels		
	< 1 (P/I)	1 – 15	> 15	*P*- value	P/H	P/I	*P* - value
Bored internodes							
% Bored internodes total	1.44 ± 0.18^{c}	17.91 ± 0.72^{b}	31.01 ± 1.23^{a}	<0.0001	1.44 ± 0.18^{b}	21.78 ± 0.70^{a}	<0.0001
% Bored internodes before cob	0.00 ± 0.00^{c}	24.86 ± 0.86^{b}	45.27 ± 1.69^{a}	<0.0001	0.00 ± 0.00^{b}	30.87 ± 0.92^{a}	<0.0001
% Bored internodes after cob	3.22 ± 0.42^{c}	9.07 ± 1.09^{b}	12.42 ± 1.91^{a}	<0.0001	3.22 ± 0.42^{b}	10.06 ± 0.95^{a}	<0.0001
Bored holes							
Bored holes total	0.33 ± 0.05^{c}	4.25 ± 0.24^{b}	7.74 ± 0.49^{a}	<0.0001	0.33 ± 0.05^{b}	5.28 ± 0.24^{a}	<0.0001
Bored holes before cob	0.00 ± 0.00^{c}	3.15 ± 0.16^{b}	6.30 ± 0.41^{a}	<0.0001	0.00 ± 0.00^{b}	4.08 ± 0.18^{a}	<0.0001
Bored holes after cob	0.33 ± 0.05^{c}	1.09 ± 0.16^{b}	1.43 ± 0.25^{a}	<0.0001	0.33 ± 0.05^{b}	1.19 ± 1.34^{a}	<0.0001
Stem tunneling							
% Stem tunneling total	0.33 ± 0.06^{c}	3.61 ± 0.18^{b}	12.51 ± 0.59^{a}	<0.0001	0.33 ± 0.06^{b}	6.23 ± 0.30^{a}	<0.0001
% Stem tunneling before cob	0.00 ± 0.00^{c}	2.75 ± 0.11^{b}	10.70 ± 0.43^{a}	<0.0001	0.00 ± 0.00^{b}	5.09 ± 0.24^{a}	<0.0001
% Stem tunneling after cob	0.33 ± 0.06^{c}	0.87 ± 0.13^{b}	1.80 ± 0.37^{a}	<0.0001	0.33 ± 0.06^{b}	1.14 ± 0.14^{a}	<0.0001
N	680	254	106		680	360	

Means within rows fallowed by same letter are not significantly different at $P = 0.05$ (SNK). P/H = healthy plants, P/I = infested plants.

Table 21: Correlation matrixes of stem borer species, damage variables and yield at pre-tasseling and maturity stages of maize crop

	1	2	3	4	5	6
Pre-tasseling stage						
1.Bored internodes (%)	-					
2. Tunnel length (cm)	0.7677***	-				
3. Bored holes	0.7903***	0.8032***	-			
4. *C. partellus*	0.4633***	0.4669***	0.4954***	-		
5. *S. calamistis*	0.0375	0.0078	0.0170	0.0487		
Harvest (maturity) stage						
1. Cob weight (g)	-					
2. Grain weight (g)	0.8608***	-				
3. Bored internodes (%)	-0.1478***	-0.1692***	-			
4. Tunnel length (cm)	-0.1022***	-0.1647***	0.8050***	-		
5. Bored holes	-0.1316***	-0.1534***	0.8293***	0.7387***		
6. *C. partellus*	-0.0017	-0.0645*	0.1720***	0.1939***	0.1446***	-
7. *S. calamistis*	-0.2226	0.0308	0.2975	0.2572***	0.2221***	0.4568***

*** = Significant at $P \leq 0.001$, * = Significant at $P \leq 0.05$

During on-farm surveys, fields are sampled once but it is difficult to get information on the history of the crop (soil fertility status, fertilizer applications, age of the crop, climate, etc.). Indicators of plant vigor that are positively related to yield (i.e. plant height and stem diameter) are easily determined (Gounou *et al.*, 1994). As shown by Gounou *et al.* (1994) and Sétamou *et al.* (1995), a multiple regression of cob weight and grain weight on plant growth and damage variables showed that plant height (x_1) and stem diameter (x_2) were positively correlated to centimeter stem tunnel (x_3) and cob damage (x_4) and negatively correlated to both cob and grain yields.

Cob weight: $y = 3.83 + 0.146x_1 + 73.026x_2 - 0.664x_3 - 0.643x_4$......................(vii)
$N = 1200$, $r^2 = 0.16$, with $P = 0.0084$, $P<0.0001$, $P<0.0001$ and $P = 0.0107$ for x_1, x_2, x_3 and x_4 respectively.

Grain weight: $y = 16.96 + 0.05x_1 + 39.08x_2 - 0.610x_3 - 0.40x_4$......................(viii)
$N = 1200$, $r^2 = 0.11$, with $P = 0.143$, $P<0.0001$, $P<0.0001$ and $P = 0.0213$ for x_1, x_2, x_3 and x_4 respectively.

4.9.5 The impact of stem borer damage on maize yields.

It was observed that cob and grain weight significantly decreased with increasing tunnel length ($P = 0.0002$ and $P<0.0001$, respectively (Table 22). The average tunnel length of infested plants (P/I) at harvest was 12.46 cm. Cob weight of damaged plants was 7.08 % less than in healthy plants, while grain weight of damaged plants was 10.14 % less than in healthy plants. Cob and grain yield losses of plants with tunnel length greater than 15 cm were 13.52 % and 16.63 %, respectively. Plants with 1-15 cm tunnels had cob weight that was 4.38 % less than those with no tunnels, but the difference was not significant. However, grain weight of the plants with 1–15 cm tunnels was significantly lower than in plants with no stem tunnels. Similar results were obtained in the semi-arid zone of eastern Kenya where *C. partellus* was the dominant stem borer species (Songa *et al.*, 2001), They found that grain yield of damaged plants was 30 % less than non-damaged plants, and yield of plants with tunnel length greater than 20 cm was 42 % lower than plants with no stem borer tunnels.

Table 22: Growth variables, maize yields and yields losses at harvest (mean ± SE) in Kilosa District

Variables	Stem tunnel length (cm)				Infestation levels		
	< 1 (P/H)	1 – 15	> 15	*P* - value	P/H	P/I	*P* - value
Plant height (cm)	249.71 ± 1.31	246.71 ± 2.25	250.36 ± 4.13	0.3616	249.71 ± 1.31	247.49 ± 1.81	0.3208
Stem diameter (cm)	2.13 ± 0.01	2.14 ± 0.02	2.09 ± 0.04	0.3237	2.13 ± 0.01	2.13 ± 0.30	0.6454
Cob weight (g)	196.51 ± 2.37^{a}	187.91 ± 4.22^{a}	169.94 ± 6.49^{b}	0.0002	196.51 ± 2.37^{a}	182.60 ± 3.56^{b}	0.0009
Grain weight (g)	115.58 ± 1.63^{a}	106.99 ± 2.84^{b}	96.36 ± 34.13^{c}	<0.0001	115.58 ± 1.63^{a}	103.86 ± 2.36^{b}	<0.0001
Cob weight loss (%)	0.00	4.38	13.52		0.00	7.08	
Grain yield loss (%)	0.00	7.43	16.63		0.00	10.14	
N	680	254	106		680	360	

Means within rows fallowed by same letter are not significantly different at $P = 0.05$ (SNK). P/H= healthy plants, P/I = infested plants

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- The present study shows that increasing soil nitrogen enhances plant tolerance to stem borer attack. The thicker and taller plants obtained as a result of higher rates of nitrogen application gave an indication of plant tolerance to borer attack.
- It was also observed that nitrogen application favors stem borer damage as well as population growth in the field. However, plants have the ability to compensate for damage at higher nitrogen applications.
- Yield losses decreased with increasing nitrogen application due to increased plant vigor. Therefore, the manipulation of time of nitrogen application may achieve a compromise between using low levels of nitrogen for low stem borer infestation and using high levels for better yields.
- Fertilizer in combination with other stem borer management strategies like cultural and biological control can be used to increase maize yield in areas with higher stem borers infestation pressure.
- Although no previous work on the relationship between stem borer parasitism and nitrogen application has been reported, this study shows that there is positive effect of nitrogen application on *C. partellus* larval parasitism.

5.2 Recommendations

- High levels of nitrogen can be used for better maize yield and it is important to integrate environmentally friendly stem borer control measures/strategies depending on the location.
- Depending on time of nitrogen application low levels can be used for low stem borer infestation and using high levels for better yields especially in areas and seasons with low stem borer pressure
- Thorough studies (especially laboratory experiments) should be conducted on the effect of nitrogen application rates on stem borer larvae parasitism. Analysis of info- chemicals/volatiles contained in the frass of stem borers need to be further investigated in relation to parasitism by parasitoids.
- The effect of nitrogen on stem borer larval development should also be thoroughly investigated at all crop and larval stages.

REFERENCES

Ajayi, O. (1987). Insecticidal control of the sorghum stem borer. In: *Cereals Research Programme. Cropping Scheme Report,* 1987. Institute for Agricultural Research, Samaru, Zaria, Nigeria, pp. 35 - 38.

Ajayi, O. (1991). Yield reduction in sorghum caused by *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson. *Paper presented at the 9th Conference of the African Association of Insect Scientists.*, 23 - 27 September 1991, Accra Ghana.

Ajayi, O., (1998). Sorghum: West Africa. In: *African Cereal Stem Borers; Economic Importance, Taxonomy, Natural Enemies and Control: (Edited by Polaszek A.)* CAB international Wallingford, Uk. in association with: The ACP-EU Technical Centre for Agricultural and Rural Co-operation, Wageningen The Netherlands. pp 39 – 45.

Ampofo, J. K. O., (1996). Maize stalk borer (Lepidoptera: Pyralidae) damage and plant resistance. *Journal of Environmental Entomology* 15: 1124 - 1129.

Anonymous, (1969). *Insect pest management and control.* National Academy of Science Publication No 1965. United States.

AOAC, (1990). Association of Official Analytical Chemist. *Official methods of analysis.* 15th edition. Virginia, United States of America, pp 69 - 88.

Banda, T. E., (1993). Sorghum and bulrush millet in Tanzania, situation and outlook. In: *National Workshop on Sorghum and Millet marketing and Utilization for food Security and Development.* (Edited by Minde I. J. and Rohrobach D. D.). 3 - 5 May 1993, Arusha Tanzania.

Barrow, M. R. (1987). The effect of first generation maize stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), on yield of different maize genotypes. *Journal of the Entomological Society of Southern Africa* 50: 291– 98.

Barry, D. A. J. and Miller, M. H. (1989). Phosphorus nutritional requirement of maize seedlings for maximum yield. *Agronomy Journal* 81: 95 - 99.

Berger, A. (1981). *Biological Control of the Spotted Stalkborer, Chilo partellus* (Swinhoe) *in Maize by Using the Bacteria Bacillus thuringiensis.* Project UNDP/FAO MOZ/75/009, Report, Instituto Nacional de Investigacao Agronomica, Maputo, Mozambique.

Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E. and Clack, F. E. (1965). Methods of Soil Analysis. Part 2. *Agronomy Monograph* 9. ASA and SSSA, Madison, Wisconsin, USA.

Boeve, J. L., Lengwiler, U., Tollsten, L., Dorn, S. and Turlings,T. C. J. (1996). Volatiles emitted by apple fruit lets infested by larvae of the European apple sawfly. *Phytochemistry* 42 (2): 373 - 381.

Bosque-Pérez, N. A. and Mareck, J. H. (1990). Distribution and species composition of Lepidoptera maize borers in southern Nigeria. *Bulletin of Entomological Research* 80: 363 - 368.

Bosque-Pérez, N. A. and Mareck, J. H., (1991). Effect of the stem borer *Eldana saccharina* (Lepidoptera: Pyralidae) on the yield of maize. *Bulletin of Entomological Research* 81: 243 – 47

Bosque-Pérez, N. A. and Schulthes, F., (1998). Maize: West and Central Africa. In: *African Cereal Stem Borers; Economic Importance, Taxonomy, Natural*

Enemies and Control. (Edited by Polaszek A.) CAB international Wallingford, Uk. in association with: The ACP-EU Technical Centre for Agricultural and Rural Co-operation, Wageningen The Netherlands. pp 11-24

Bowden, J. (1976). Stemborer ecology and strategy for control. *Annals of Applied Biology* 84: 107 - 111

Bowdish, T. I. and Stirling, P. (1998). The influence of salt and nitrogen on herbivore abundance: direct and indirect effects. *Oecologia* 113 (3): 400 - 405.

Bremner, J. M. and Mulvaney, C. S. (1982). Total nitrogen. In: *Methods of Soil Analysis: Part 2 Agronomy monogragh. Number 9. (Edited by Page, A. L., Miller, R. H. and Keeney, D. R.)* American Society of Agronomy. Madison. Wisconsin. pp 149 – 157.

Brenière, J. , Bordat, D. , Vercambre, B., Hamza, H., and Renand, M. (1985). Les opérations de lutte biologique contre le foreur du mais *Chilo partellus* (Swinhoe). Lepidoptera. dans l'Ile de Ngazidja. *Tropical Agronomy* 40: 157 - 166.

Cardwell. K. F., Schulthess, F., Ndemah, R. and Ngoko, Z. (1997). A system approach to assess crop health and maize yield losses due to pests and diseases in Cameroon. *Agriculture, Ecosystems and Environment* 65: 33 - 47.

Carisey, N. and Bauce, E. (1997). Impact of balsam fir flowering on pollen and foliage biochemistry in relation to spruce budworm: *Choristoneura fumiferana* growth, development and food utilization. *Entomologia Experimentalis et Applicata* 85 (1): 17 - 31

Chabi-Olaye, A., Nolte, C., Schulthess, F. and Borgemeister, C. (2005). Effects of grain legumes and cover crops on maize yield and plant damage by *Busseola fusca* (Fuller) (Lepidoptera: Noctudae) in the humid forest of southern Cameroon. *Agriculture, Ecosystems and Environment* 108: 17 - 28.

Chapin, F. S. III (1988). Ecological aspects of plant mineral nutrition. In: *Advances in plant nutrition Vol. 3 (Edited by Tinker, B. and Läuchli, A.)* Praeger, New York. pp. 161-191.

CIMMYT, (1992). CIMMYT World Maize Facts and Trends: *Maize Research Investments and Impacts in Developing Countries*. CIMMYT. Mexico D. F.

de Groote, D., (2002). Maize yield losses from stem borers in Kenya; *Insect Science and its Application* 22 (2): 89 - 96.

Delobel, A. (1975). *Chilo orichalcociliollus* Strand (Lepidoptera; Pyralidae), foreur des tiges du sorgho et du maïs a Madagascar II. Premeres donnees biologiques. *ORSTOM Series Biologie* 10: 11 - 16.

Department of Crop Science, Makerere University (1999). Effect of fertilizer and mulching on bean infestation, and damage by bean fly. *African Crop Science Journal* 9 (4): 599 - 604.

Duerden, J. C., (1953). Stem borers of cereal crops at Kongwa, Tanganyika 1950-1952. *East African Agricultural and Forest Journal* 19: 105 – 19.

Emana, G. and Tsedeke, A. (1999). Management of maize stem borers using sowing date at Arsi-Negele. *Pest Management Journal of Ethiopia* 3: 47 - 52.

FAO (2000). FAOSTAT Agricultural data. [http://apps. Fao.org] site visited on 3/11/2004.

Gounou, S., Schulthess, F, Shanower, T., Hammond, W. N. O., Braima, H., Olaleye, I., Cudjoe, A.R., Adjakloe, R., and Antwi, K.K., (1993). *Stem and Ear Borers of Maize in Ghana*. Plant Health Management Division, Research. Monogragh,: International Institute of Tropical Agriculture. Ibadan, Nigeria 84pp.

Gounou, S., Schulthess, F., Shanower, T., Hammond, W. H. O., Braima, H., Cudjoe, A. R., Adjakloe, R., Antwi, K. K., and Olaleye, I. (1994). Stem and ear borers of maize in Ghana. *Plant Health Management Research Monograph. 4*. International Institute of Tropical Agriculture. Ibadan, Nigeria 23pp.

Hailemichael, Y, Smith, J. W. Jr. and Wiedenmann, R. N. (1994). Host-finding behavior, host acceptance, and host suitability of the parasite *Xanthopimpla stemmator Entomologia Experimentalis et Applicata*. 71 (2): 155 - 166.

Harris, K.M., (1962). Lepidopterous stem borers of cereals in Nigeria. *Bulletin of Entomological Research* 53: 139 - 71.

Haseman, L. (1946). Influence of soil minerals on insects. *Journal of Economic Entomology* 39: 8 - 11.

Hecht-Buchhlolz, C. (1967). Über die Dunkeltärbung des Blattgrüns bei Phosphorman-gel. *Zeitschrift fuer Pflanzenernäehrung und Bodenkunde* 118: 12 - 22.

Hellevang, K. J. (1995). Grain moisture content effects and its management. North Dakota State University (NDSU). Extension services. [http://www.ext.nodak.edu/extpubs/plantsci/Crops/ae905W.htm] site visited on 15/11/ 2004.

Horst, W. J. and Hardter, R. (1994). Rotation of maize with cowpea improves yield and nutrient use of maize compared to maize monocropping in an alfisol in the northern Guinea Savanna of Ghana. *Plant and Soil* 160 (2): 171 - 183

Huber, D. M. and Wilhelm, N. S. (1988). The role of manganese in resistance to plant diseases, In: '*Manganese in Soils and plants*' (Edited by Graham, R. D. Hannan, R. J. Uren, N. C.) Kluwer Academic, Dorgrecht. pp. 155 - 173.

Kaltofen, H. (1988). Warum Steigert Stickstoffdiingung oft den Ligningehalt von Gräsern (Why does nitrogen fertilization increase the lignin content of grasses?). *Arch Acker- Pflanzenbau Bodenkd.* Berlin 21: 255 - 260.

Kfir, R., (1998). Maize and Grain Sorghum: Southern Africa. In: *African Cereal Stem Borers: Economic Importance, Taxonomy, Natural Enemies and Control: (Edited by Polaszek, A.)* CAB international Wallingford, Uk. in association with: The ACP-EU Technical Centre for Agricultural and Rural Co-operation, Wageningen The Netherlands. pp. 29 – 37.

Kiraly, Z. (1964). Effect of nitrogen fertilization, on phenol metabolism, and stem rust susceptibility of wheat. *Phytopathology Zeitschrift* 51: 252 - 261.

Kjeldahl, J. (1883). Neue Methde zur Bestimmung des Stickstuffs in organischen Korpern (Anew method for the determination of nitrogen in organic matter). *Zeitschrift fuer Analytiche Chemie* 22: 366 - 382.

Kumar, H. (1995). Varietal resistance, population dynamics and timing insecticidal application with peak oviposition by *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae) on rice. *Annals of Applied Biology* 127 (2): 221 - 228.

Letourneau, D. K. (1994) Bean fly management practices and biological control in Malawian subsistence agriculture. *Agriculture, Ecosystems and Environment* 50 (2): 103 - 111.

Lewis, L. C. , Berry, E. C., Obrycki, J. J. and Bing L A (1996). Aptness of insecticides (*Bacillus thuringiensis* and carbofuran) with endophytic *Beauveria bassiana*, in suppressing larval populations of the European corn borer. *Agriculture, Ecosystems & Environment* 57 (1): 27 - 34.

MacAdam, J. W., Volenec, J. J. and Nelson, C. J. (1989). Effect of nitrogen on mesophyll cell division and epidermal cell elongation in tall fescue leaf blades. *Plant physiol*ogy 89: 549 – 556.

Marschner. H. (2002). *Mineral Nutrition of Higher Plants.* Institute of Plant Nutrition. University of Hohenheim. Germany. 721 pp.

Masand, S. S., Kapur, O. C., and Jaggi, R. C. (1993). Effect of tillage and nitrogenous fertilizer on water use and yield of rained maize on sloping and level lands. *Journal of the Indian Society of Soil Science* 41 (3): 426 – 429.

Matsuyama, N. and Dimond, A. E. (1973). Induction by copper ions of ethylene production in *Spiodela oligorrhiza*: Evidence for a pathway independent of 1-amminoclopropane-1-carboxylic acid. *Journal of Plant Physiol*ogy 123: 193 - 202.

McFarlane, J., (1990). Damage assessment and yield losses in sorghum due to the stem borer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in northern Nigeria. *Tropical Pest Management* 36 (2): 131– 37.

McLean, F. O. (1982). Soil pH and and lime requirements. In: *Methods of Soil Analysis: Part 2 Agronomy monogragh. Number 9. (Edited by Page, A. L.,* *Miller, R. H. and Keeney, D. R.)* American Society of Agronomy, Madison, Wisconsin. pp 199 - 224.

Moore, D, and Clements, R. O. (1984). Stem-boring Diptera in perennial ryegrass in relation to fertilizer. nitrogen levels and forms. *Annals of Applied Biology* 105 (1): 1 - 6.

Moshi, A., Anandajayasekeram, P., Kaliba, A., Martella, D., Mwangi, W., and Shao, F., (1997). *Economic Impact of Maize research in Tanzania.* Southern African Centre for Cooperation in Agricultural and Natural Resource Research and Training.

Muyango, S. (1987). Les chenilles foreuses des tiges du maïs et du sorgho: écologie et lutte. In: *Seminaire sur les maladies et lesravageurs des principale cultures vivriéres d'Afrique Centrale* (Stemborers of maize and sorghum: Ecology and control. In: *Seminars on key diseases and pests on major staple crops in Central Africa).* Centre Technique de Coopération Agricole Rarale (CTA), Ede/Wageningen, pp.117 - 126.

Mwato, I. Mkandawire, A. and Mughogho, S. (1999). Combined inputs of crop residues and fertiliser for smallholder maize production in Southern Malawi. *African Crop Science Journal* 9, 7(4): 365 – 373

Ndemah, R., Schuthess, F., Poehling, M. and Borgemeister, C., (2000). Species composition and seasonal dynamics of lepidopterous stemborers on maize and the elephant grass, *Pennisetum purpureum* (Moench) (Poaceae), at two forest margin sites in Cameroon. *African Entomology* 8: 265 - 272.

Ndemah, R., Schuitless, F., Korie, S., Borgemeister, C. and Cardwell, K. F. (2001). Distribution, relative importance and effect of lepidopterous borers on maize yields in the Forest Zone and Mid-altitude of Cameroon. *Journal of Economic Entomology* 94 (6): 1434 -1444.

Ndemah, R. and Schulthess, F., (2002). Yield of maize in relation to natural field infestations and damage by lepidopterous borers in the forest and forest/savannah transition zones of Cameroon. *Insect Science and its Application* 22: 183 - 193.

Nelson, D. W. and Sommers, L. E. (1982). Total carbon, organic carbon and organic matter. In: In: *Methods of Soil Analysis: Part 2 Agronomy monogragh. Number 9. (Edited by Page, A. L., Miller, R. H. and Keeney, D. R.)* American Society of Agronomy. Madison. Wisconsin. pp. 539 – 579.

Ngi-Song, A. J. and Overholt, W. A. (1997). Host Location and Acceptance by *Cotesia flavipes* Cameron and *C. sesamiae* (Cameron) (Hymenoptera: Braconidae), Parasitoids of African Gramineous Stemborers: Role of Frass and Other Host Cues. *Biological control* 9: 136 - 142.

Niyibigira, E. I., Abdallah, Z. S., Overholt, W. A., Lada, V. Y., and Huis, V. (2001). Distribution and abundance in maize and sorghum, of lepidopteran stem borers and associated indigenous parasitoids in Zanzibar. *Insect Science and its Application* 21 (4): 335 - 346.

Nsami, E., Pallangyo, B., Mgoo, V. H., and Omwega, C. O., (2001). Distribution and species composition of cereal stem borers in the eastern zone of Tanzania. *Insect Science and its Application* 21 (4): 347 - 351.

Nyambo. B. T., and Kabisa, J. C., (1988). The status of maize stalkborers in Tanzania. A review with emphasis on possible future research proposals. In: *Proceedings of the First Tanzania National Maize Research Workshop.*

Agricultural research Organization (Edited by Moshi, A. J., and Ramson, J. K.). 6 - 7 June 1988, Arusha Tanzania, pp. 224 - 228.

Nye, I. W. R., (1960). *The insect pests of graminaceous crops in East Africa.* Colonial Research Studies 31. London. 128 pp.

Ofomata, V. C., Overholt, W. A., Egwuatu, R. I., (1999). Diapause termination of *Chilo partellus* (Swinhoe) and *Chilo orichalcociliellus* Strand (Lepidoptera: Pyralidae). *Insect Science and its Application* 19: 187 - 91.

Olsen, S. R. and Sommers, L. E. (1982). Phosphorus. In: In: *Methods of Soil Analysis: Part 2 Agronomy monogragh. Number 9 (Edited by Page, A. L., Miller, R. H. and Keeney, D. R.)* American Society of Agronomy. Madison, Wisconsin. pp 539 – 575

Omwega, C. O., Overholt, W. A., Mbapila, J. C., and Kimani-njogu, S. W., (1997). Establishment of *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae), an exotic endoparasitoid *of Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in Tanzania. *African Entomology* 5: 71 - 75.

Overholt, W. A., Ngi-Song, A. J., Mbapila, J., Lammers, P. M., and Kioko, E. (1994). Ecological considerations of the introduction of *Cotesia flavipes* Cameron (Hymenoptera : Braconidae) for biological cotnrol of *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae), in Africa. *Biological news and information* 15 (2): 19-24

Pallangyo, B., and Omwega, C.O., (2002). Distribution and species composition of cereal stem borers in Tanzania .*A paper presented at IPM conference in Kampala Uganda* (Unpublished).

Radin, J. W. and Boyer, (1982). Control of leaf expansion by nitrogem nutrition in sunflower plants: role of hydrolic conductivity and turgor. *Plant physiology* 69: 771 - 775.

Reeves, J. A. J. III, Barbosa, P., and Francis, B. (1996). The effect of nitrogen fertilizer applied to *Euphorbia pulcherrima* on the parasitization of *Bemisia argentifolii* by the parasitoid *Encarsia formosa*. *Entomologia Experimentalis et Applicata* 78 (1): 105 - 110.

Riedell, W. E., Schumacher, T. E. and Evenson, P. D. (1996). Nitrogen fertilizer management to improve crop tolerance to corn rootworm larval feeding damage. *Agronomy Journal* 88 (1): 27 - 32

Riedell, W. E., Beck, D. L. and Schumacher, T. E. (2000). Corn response to fertilizer placement treatments in an irrigated no-till system. *Agronomy Journal* 92 (2): 316 - 320.

Römer, W. and Schilling, G. (1986). Phosphorus requirements of the wheat plant in various stages of its life cycle. *Plant soil* 91: 221 - 229.

.Roth, G. W., Calvin, D. D., and Lueloff, S. M. (1995). Tillage, nitrogen timing, and planting date effects on western corn rootworm injury to corn. *Agronomy Journal* 87 (2): 189 – 193.

Royer, L. and Boivin, G. (1999). Infochemicals mediating the foraging behavior of *Aleochara bilineata* Gyllenhal adults: sources of attractants *Entomologia Experimentalis et Applicata* 90 (2): 199 - 205.

Sallah, P., Ehlke, N. and Geadelmann, J. (1998). Progress from selection in la posta maize population evaluated under three nitrogen fertilizer levels. *African Crop Science Journal* 6 (3): 241 - 248.

Saroja, R., Jagannathan, R. and Raju, N., (1987). Effect of nitrogen nutrition and rice variety on leaffolder (LF), yellow stem borer (YSB) and grain yield. *International Rice Research Newsletter* 12: 11 - 12.

SAS Institute, (1997). SASA/STATISTICAL software: Changes and Enhancement, Through Releases 6.12. SAS Institute, North Carolina

Schulthess, F., and Ajala, S. O. (1999). Recent advances at IITA in the control of stembores in West ans Central Africa, In: *Proceedings of a Regional Maize workshop on Strategy for Sustainable Maize Production in West and Central Africa.* 21 - 25 April 1997, IITA Cotonou Benin Republic, pp. 35 - 52.

Schulthess, F., Neuenschwander, P., and Gounou, S. (1997). Multi-trophic interactions in cassava: *Manihot esculenta*, cropping systems in the sub humid tropics of West Africa *Agriculture, Ecosystems and Environment* 66 (3): 211 - 222.

Shanower, T. G., Schulthess, F., and Bosque-Pérez, N. A. (1993). The effect of larval diet on the growth and development of *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and *Eldana sacchanina* Walker (Lepidoptera: Pyralidae). *Insect Science and its Application.* 14: 681 - 685.

Segeren, P., Rafae, E. and Sitoi, V. (1991). Milho. Principais doenças e pragas (Millet: Damage and pests). Relatório de Ensaios realizados no regadio do Chokwe, 1986/1990. INIA *Serie Investigação* 10: 15 - 18.

Sémeglo, A. K. (1997). *Etude comparativede la bioecologie de trois Noctudae foreuses de tige de céréales* (*Sesamia calamistis* Hampson, *S. poephaga* Tams and Bowden and *Busseola fusca* Fuller) (Study on the comparative bioecology of three noctuids cereal stemborers (*Sesamia calamistis* Hampson, *S. poephaga* Tams and Bowden and *Busseola fusca* Fuller)). Memoeres Ingenieur Agronom UNB, Republic of Benin.

Seshu Reddy, K. V., (1983). Sorghum stem borers in eastern Africa. *Insect Science and its Application* 4: 3-10.

Seshu Reddy, K. V. (1988). Assessment of on-farm yields losses in sorghum due to insect pests. *Insect Science and its Application* 9: 679 – 85.

Seshu Reddy, K. V. and Sum, K. O. S., (1991). Determination of economic injury level of the stem borer, *Chilo partellus* (Swinhoe) in maize, *Zea mays* L. *Insect Science and its Application* 12: 269 – 74.

Seshu Reddy, K. V., and Sum, K. O. S., (1992). Yield–infestation relationship and determination of economic injury level of the stem-borer, *Chilo partellus* (Swinhoe) in three varieties of maize, *Zea mays* L. *Maydica* 37: 37 – 376.

Seshu Reddy, K. V. (1998). Maize and Sorghum: East Africa; In *African Cereal Stem Borers: Economic Importance, Taxonomy, Natural Enemies and Control. (Edited by Polaszek A.)* CAB international Wallingford, Uk. in association with: The ACP-EU Technical Centre for Agricultural and Rural Co-operation, Wageningen The Netherlands. pp. 25 – 27.

Seshu Reddy, K. V., Sum, K. O. S. and Lubega, M. C. (1989). Empirical models for predicting yield loss in sorghum caused by *Chilo partellus* (Swinhoe). *Discovery and Innovation* 1: 90 - 94.

Sétamou, M. and Schulthess, F. (1995). The influence of egg parasitoids belonging to the *Telenomus busseolae* (Hyminoptera: Scelionidae) species complex on Sesamia calamistis (Lepidoptera: Noctuidae) populations in maize fields in southern Benin. *Biocontrol Science and Technology* 5: 69 - 81.

Sétamou, M., Schulthess, F., Bosque Perez, N. A. and Odjo Thomas, A. (1993). Effect of plant nitrogen and silica on the bionomics *of Sesamia calamistis* (Lepidoptera: Noctuidae). *Bulletin of Entomological Research* 83 (3): 405 - 411.

Sétamou, M., Schulthes, F., Bosque Perez, N. A. and Thomas Odjo, A. (1995). The effect of stem and cob borers on maize subjected to different nitrogen treatments *Entomologia Experimentalis et Applicata* 77 (2): 205 – 210.

Singh, T. P. and Singh, R. (1969). Incidence of stem borer (*Chilo zonellus* Swinhoe) and lodging in Jaunpur variety of maize under different levels of nitrogen. *Indian Journal of Entomology* 31: 158 - 160.

Singh, S. P. and Singh, V. P. (1983). Incidence of stalk borer in sugarcane varieties as influenced by nitrogen levels and raw spacing. *Indian Sugar Crops Journal* 9: 1 - 18.

Sithole, S. Z. (1987). The effect of date of planting on shootfly and stem borer infestations on sorghum. In: *Proceedings of the Third Regional Workshop on Sorghum and Millets for Southern Africa:* 6-10 October 1986, Lusaka Zambia. ICRISAT Patancheru, pp. 174 - 183.

Sithole, S. Z., (1990). Status and control of the stem borer *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in, southern Africa. *Insect Science and its Application* 11: 481 - 88.

Songa, J. M., Guofa Z., and Overholt, W. A., (2001). Relationship of stem borer damage and plant physical conditions to maize yield in a semi-arid zone of eastern Kenya. *Insect Science and its Application* 21 (3): 243 - 249.

Spenser, D. and Possingham, J. V. (1960). The effect of nutrient deficiencies on the Hill reaction of isolated chloroplasts from tomato. *Australian Journal of Biological Science* 13: 441 – 445.

Starks, K. J. (1969). *Some cereal crop insects in East Africa.* East African Agriculture and Forestry Research Organization, Serere Research Station, Uganda (Unpublished).

Tams, W. H. T. and Bowden, J. (1953). A revision of the African species of *Sesamia* Guenee and related genera (Agrotidae-Lepidoptera). *Bulletin of Entomological Research* 43: 645 - 78.

Tams, W. H. T., (1932). New species of African Heterocera. *Entomologists* 65, 1241-49.

Tanaka C, Kainoh Y, and Honda H (2001). Host frass as arrestant chemicals in locating host *Mythimna separata* by the tachinid fly *Exorista japonica Entomologia Experimentalis et Applicata* 100 (2): 173 - 178.

Taneja, S. L., Nwanze, K. F., (1989). Assessment of yield loss of sorghum and pearl millet due to stem borer damage. *International Workshop for Sorghum Stem Borers*, (Edited by Nwanze, K.F.) ICRISAT Patancheru India, pp 95 - 104.

Uhart, S. A., and Andrade, F. H. (1995). Nitrogen deficiency in maize: I. Effects on crop growth, development, dry matter partitioning, and kernel set. *Crop Science* 35 (5): 1376 - 1383.

Ukwungwu, M. N. (1985). Effect of nitrogen and carbofuran on gall midge (GM) and white stem borer (WSB) infestation in Nigeria. *International Rice Research Newsletter* 10: 19 - 20.

Van den Berg, J. Nur, A. F., and Polaszek, A. (1998). Cultural control. In: *African Cereal Stem Borers: Economic Importance, Taxonomy, Natu.al Enemies and Control: (Edited by Polaszek A.)* CAB International Wallingford, Uk. in association with: The ACP-EU Technical Centre for Agricultural and Rural Co-operation, Wageningen The Netherlands. pp. 333 – 347.

van Hamburg, H., (1979). The grain-sorghum stalk-borer, *Chilo partellus* (Swihnoe) (Lepidoptera: Pyralidae): seasonal changes in adult populations in grain sorghum in the Transavaal. *Journal of the Entomological Society of South Africa* 42: 1 - 9.

Van Keulen, A., (1990). *Effect of fertilizer and insecticide on stemborer attackin maize under farmers' conditions. An on-farm trial to assess biological yield and profitability of these inputs*. Department of Entomology, Wageningen University, Internal publication No. 184: 62 pp.

Van Rensburg, J. B. J., Giliomee, J. H. and Walters, M. C. (1988). Aspects of the injuriousness of the maize stalk borer, Busseola fusca (Fuller) (Lepidoptera: Noctuidae). *Bulletin of Entomological Research* 78: 101 - 110.

Walker, P. T., (1981). The relation between infestation by lepidopterous stem borers and yield in maize. *European Plant Protection Bulletin* 11: 101 - 106

Warui, C. M., Kuria, J. N., (1983). Population, incidence, and the control of maize stalk-borers *Chilo partellus* (Swinhoe), and *Chilo orichalcociliellus* Strand, and *Sesamia calamistis* Hampson. in Coast Province, Kenya. *Insect Science and its Application* 4 (1-2): 11 – 18.

Wheeler, G. S. and Halpern, M. D. (1999). Compensatory responses of *Samea multiplicalis larvae* when fed leaves of different fertilization levels of the aquatic weed *Pistia stratiotes. Entomologia Experimentalis et Applicata* 9 (2): 205 – 216.

Workayehu, T. (2000). Effect of nitrogen fertilizer rates and plant density on grain yield of maize *African Crop Science Journal.* 8 (3): 273 – 282.

Youdeowei, A., (1989). Major arthropod pests of food and industrial crops of Africa and their economic importance. In: *Biological Control: A Sustainable Solution to Crop Pest Problems in Africa. (Edited by. Yanninek, J. S. and Herren, H. R.)* International Institute of Tropical Agriculture Ibadan Nigeria. 210 pp.

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