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Cereal yield losses caused by lepidopterous stemborers at different nitrogen fertilizer rates in Ethiopia

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Abstract: Field trials were carried out at three locations in the cool-wet western and one location in the semiarid eastern ecozones of the Amhara State of Ethiopia to determine the effects of nitrogen fertilizer on pest infestation and yield losses caused by lepidopterous stemborers in maize and sorghum. Three N fertilizer levels, i.e. 60, 120 and 180 kg/ha for maize, and 41, 64, and 87 kg/ha for sorghum, were compared with a zero N treatment. The dominant pest species were the noctuid *Busseola fusca* (Fuller) and the invasive crambid *Chilo partellus* (Swinhoe). Leaf N content was positively related to N fertilizer dosage. In general, pest density, parasitism, plant growth and borer damage variables increased with crop growth stage. On sorghum, in the cool-wet western Amhara, increasing levels of N fertilizer also tended to increase pest density, plant growth and damage variables. In the semiarid ecozone, parasitism by the exotic parasitoid *Cotesia flavipes* Cameron tended to increase with N level. In the cool-wet ecozone, sorghum yields increased by up to 74% because of fertilization; losses caused by stemborers decreased linearly with N dosage from 49% to 36%. In maize, because of low borer densities, there were no discernable trends for pest infestation and yield losses. In the cool-wet ecozone, sorghum yields were positively related to insecticide application and plant height, and negatively to damage variables such as tunnelling and peduncle damage. In semiarid eastern Amhara, the effects of fertilizer on pest, damage and yield were low on both crops because of the higher soil fertility. The results indicate that the profitability of nitrogen fertilizer as an integrated pest management tactic in the control of cereal stemborers depends, among others, on the severity of borer damage and the soil fertility status prevailing in an area. It is concluded that N fertilizer helps minimize the impact of borers on grain yields, especially on sorghum and in the cool-wet ecozone.

Key words: Amhara, borers, cereals, fertilizer, plant N content, yield loss

1 Introduction

In Africa, over 42 million tons of maize and 20 million tons of sorghum were produced in 2002 [Food and Agriculture Organization of the United Nations (FAO) 2003]. In Ethiopia, maize and sorghum are grown on 2.4 million ha [Central Statistical Authority (CSA) 2000; Central Agricultural Census Commission (CACC) 2003], contributing about 41% to the country's annual grain production. Although maize is grown from 500 to 2400 m above sea level (Friew and Girma 2001), it thrives best in relatively wet and intermediate altitudes. By contrast, sorghum dominates the lowlands, where drought and poor harvest are common (Birhane 1977). One of the major biotic constraints to cereal production in Ethiopia is lepidopterous stemborers such as the invasive crambid *Chilo partellus* (Swinhoe) and the noctuid *Busseola fusca* (Fuller) (Assefa 1985). Yield losses vary with crop and borer species as well as agro-ecosystem, ranging from 15% to 100% (Assefa 1989; Tadesse 1989; Gashawbeza and Melaku 1996; Emana 1998).

Previous stemborer research in Ethiopia concentrated in the central and southern Rift Valley and eastern parts of the country (Birhane 1977; Assefa 1985; Emana 1998; Melaku 1999; Emana 2002). Although the Amhara State is second in maize and first in sorghum production in Ethiopia [Bureau of Agriculture (BOA) 1999; CACC 2003], little is known about the pest status of stemborers in the region. In addition, the exotic parasitoid *Cotesia flavipes* Cameron (Hym., Braconidae) was reported from semiarid eastern Amhara (Emana et al. 2003). In 1993, the International Centre of Insect Physiology and Ecology (ICIPE) introduced this parasitoid into Kenya (Overholt et al. 1994) as part of a classical biological control programme now encompassing 11 countries in East and Southern Africa. It invaded Ethiopia most probably from Somalia, where it was introduced in 1997 (Emana et al. 2003).

Low soil fertility and especially nitrogen deficiency is a major problem in much of Ethiopia (Tolessa et al. 2001; Getachew and Wondimu 2005). Improving soil fertility complements other pest control measures (Saroja et al. 1987). As shown by various authors (Sétamou et al. 1995; Chabi-Olaye et al. 2005a; Mgoo 2005) nitrogen not only enhances survival of young stemborer larvae and thereby pest infestations but it also enhances the plant's tolerance to stemborer attacks. Reports from western Africa show that the nutritional status of maize affects noctuid borer densities as well as the plant's ability to compensate for pest damage. By contrast, there is no information on how soil nutrients, and especially nitrogen, influence these tri-trophic interactions in cereal systems in East Africa, and especially the invasive *C. partellus*. Chemical fertilizers, and especially nitrogen, are commonly used in the cool-wet ecozone, and to a lesser extent in the semiarid ecozone of the Amhara state, but it is not known how they affect borer densities and yields of cereals in these regions. The present study elucidates the effect of different N levels on borer incidence, the performance of natural enemies as well as on yields of maize and sorghum, in two agroecozones of the Amhara State of Ethiopia.

2 Materials and Methods

The study was conducted in 2004/2005 in the Amhara National Regional State, located in northern Ethiopia (fig. 1). Trials were conducted in two ecologically distinct regions, the cool-wet ecozone of western Amhara, with two locations at Kola Diba and one location at Addis Zemen, and in the semiarid ecozone of eastern Amhara at one site at Chefa. Geographic and climatic information, soil characteristics of the trial sites, planting and harvest time as well as the predominant stemborer species are given in tables 1 and 2.

2.1 Cool-wet ecozone (western Amhara)

There is one rainy season that runs from June to November, with the wettest months from June to September. Maize is the most important cereal crop followed by sorghum. As stemborers are not a problem in the maize-dominated zones and especially West Gojam (W. Melaku, F. Schultness, E. W. Kairu, C. O. Omwega, unpubl. data), for both crops, trials were conducted in hot-spot areas at Kola Diba and only maize at Addis Zemen.

The 145-day maize hybrid *BH*540 and the 175-day sorghum variety *Birmash* were planted at a spacing of 0.75 and 0.30 m between and within rows, respectively [Ethiopian Seed Enterprise (ESE) 2001]. Plot size was 36 m^2, and spacings between replications and plots were 3 and 2 m, respectively. The trials were arranged in a split-plot design, replicated four times. Three nitrogen fertilizer levels and no fertilizer in two sets of insecticide treatments (treated and untreated) represented mainplots and subplots, respectively. The fertilizer levels for maize were 0, 60, 120 and 180 kg N/ha, while for sorghum they were 0, 41, 64 and 87 kg N/ha. Rates for each crop type were determined based on agronomic recommendations in each area, i.e. including suboptimal, optimal and higher than optimal levels of nitrogen (A. Assefa, pers. comm.). They are herewith referred to as N_0, N_1, N_2 and N_3, respectively. Phosphorus as P_2O_5 was given once at planting at a rate of 92 kg/ha to maize and 46 kg/ha to sorghum. N was applied as diammonium phosphate (DAP) at planting and urea as side dressing at knee height and tasseling.

The insecticide cyhalothrin 5% was applied at a rate of 16 g a.i./ha at 2, 4, 6 and 8 weeks after crop emergence using a knapsack sprayer. Two rows of high growing 'niger seed' *Guizotia abyssinica* (L.f.) Cass. (Asteraceae) were planted as guard rows around each plot to prevent insecticide drift. A 2-m-height and 20-m-long plastic sheet, enough to cover the 6 m × 6 m plot on all sides, was used to prevent drift during the time the guard rows were too short to prevent drift.

2.2 Semiarid ecozone (eastern Amhara)

In semiarid eastern Amhara, there are two distinct rainy periods, a short unreliable one from around January to May, onset of rainfall depending on specific location, and a major season from July to September. The majority of farmers traditionally plant long-duration, i.e. 240-day sorghum varieties in April, which mature in December, thus, allowing for several generations of the pest on the same crop.

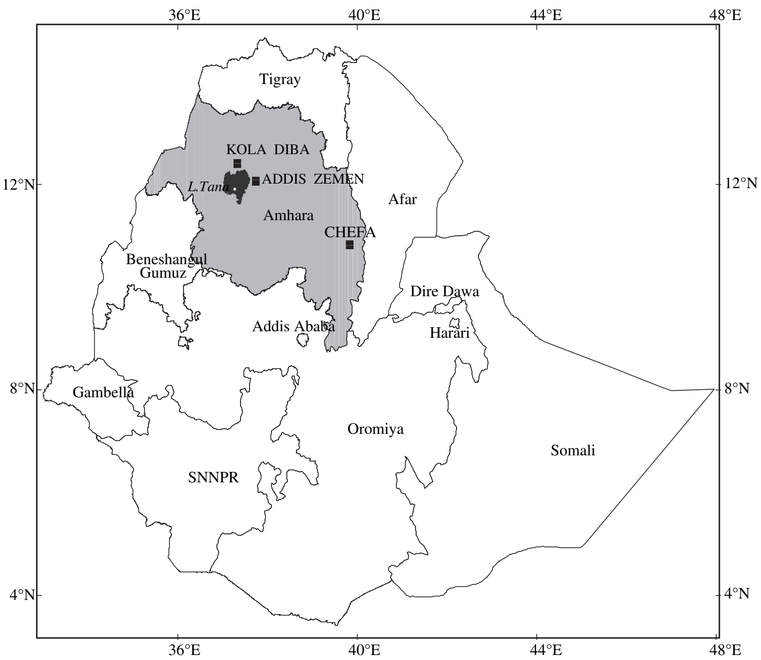

Fig. 1. *Geographic location of trial sites in cool-wet western Amhara (Kola Diba and Addis Zemen) and semiarid eastern Amhara (Chefa) of Ethiopia (shaded in grey)*

Table 1. *Geographic locations, some physiographic details and dominant borer species of experimental sites*

District	Site	Latitude	Longitude	Altitude (m)	Soil type	Drainage	Precipitation (mm)	Climate	Dominant borer species	Planting date	Harvest date
Kola Diba	Dembosage	12°25′04″N	37°19′00″E	1842	Vertisol	Waterlogged	930.7	Wet	*B. fusca*	Mid-June	End Nov
Kola Diba	Chylo Mariam	12°26′38″N	37°57′15″E	1961	Nitosols	Well drained	930.7	Wet	*B. fusca*	Mid-June	Mid-Dec.
Addis Zemen	Yifag	12°04′07″N	37°43′41″E	1830	Nitosols	Well drained	745.1	Wet	*B. fusca*	3rd week June	End Nov.
Chefa	Chefa	10°51′20″N	39°48′56″E	1479	Vertisol	Waterlogged	658.8*	Semiarid	*C. partellus*	Mid-July	End Nov.

*Rainfall was for the main season from May to December only.

The experimental procedures were the same as in cool-wet western Amhara but the sorghum variety was *Yeju* and the maize variety *Katumani*, both adapted to semiarid conditions. Both sorghum and maize trials were part of a 5-ha experimental field. Because of the shorter cropping cycle, i.e. 135 days, as opposed to 165 days, in cool-wet western Amhara, insecticide treatments were carried out at 2, 4 and 6 weeks after crop emergence only.

2.3 Sampling procedures

Sampling was carried out at different crop growth stages including the seedling stage, knee height, flag leaf, heading (sorghum), tasseling (maize), grain filling and maturity/harvest. At some trial locations, only some of these stages were assessed.

Ten plants were randomly cut at ground level from the two outermost rows on each side of the plot and dissected for determination of borer numbers according to species and natural enemies (parasitoids, predators such as ants and earwigs). Plant height and basal diameter, number of internodes and holes per plant, percent stem tunnelling, internodes bored, peduncle damage, head chaffyness, and cob damage were recorded. The borer larvae recovered were reared in the laboratory in 9×3 cm vials. They were provided with a diet of fresh pieces of maize or sorghum stems every 4 days until adult moth or parasitoid emergence. Minor pests were aphids and head bugs on sorghum and termites on maize but they were rare and, thus, not included in the analyses.

For plant nutrient analysis, 20 leaves were randomly sampled in each plot at early tasseling for maize and flag leaf stage for sorghum, at two of the three locations, i.e. Addis Zemen and Kola Diba. Leaf N sampling was not conducted in Chefa because of logistics reasons. The fresh leaf samples were kept in paper bags and first air-dried under shade, and thereafter chopped and further dried in the oven at 70°C before N content analysis. The dried samples were ground to pass a 0.5-mm mesh and their N concentration determined. Samples were digested according to Novozamsky et al. (1983), and total N was determined with an ammonium-sensitive electrode (Power et al. 1981). All plants in the six central rows (27 m^2) in each plot were harvested to determine head or cob weight per plant, 1000-grain weight and grain yield per plot.

2.4 Statistical analysis

An analysis of variance (ANOVA) was conducted using the general linear model (GLM) procedure (SAS, 1999–2000) to assess the effects of nitrogen fertilizer and insecticide application on pest variables, parasitism and yield components. Grain yield was converted from per-plot to per-hectare basis for analysis. Least squares mean values were separated using the Student–Newman–Keuls (SNK) test at $P = 0.05$. Borer density and damage symptoms were compared between fertilizer levels and insecticide treatments. For each N fertilizer level, grain yield losses caused by stem borers were calculated on a per-hectare basis by comparing mean values of insecticide-treated plots against untreated ones, calculated as percentage difference. Yield increments caused by nitrogen fertilizer were computed as the percentage differences between N_0 and N_{1-3}.

Regression analyses were conducted for cool-wet western Amhara, where response to N fertilizer was noted. Thus, multiple regressions were used to evaluate the contribution of biotic and abiotic variables as well as treatments, i.e. nitrogen fertilizer levels, and insecticide application (dummy variables,

Table 2. Soil physicochemical characteristics of experimental sites (0–20 cm soil depth)

District	Site	pH	Total N (%)	Available P (ppm)	Organic carbon (%)	Clay (%)	Silt (%)	Sand (%)	Texture
K. Diba	Chylo Mariam	6.7	0.147	3.82	1.716	44	38	18	Clay
K. Diba	Dembosgae	7.5	0.095	22.56	1.157	46	28	26	Clay
A. Zemen	Yifag	6.5	0.133	4.64	1.516	40	36	24	Clay
Chefa	Chefa	6.5	0.170	29.42	2.242	58	22	20	Clay

K. Diba and A. Zemen stand for Kola Diba and Addis Zemen, respectively.

1 = untreated, 2 = treated), plant growth variables, borer damage symptoms and borer densities to grain yield per hectare. Simple linear regressions were performed between leaf N concentration and borer density (SAS, 1999–2000). Data lacking normal distribution were transformed to stabilize variance. Percentage data were arcsine-transformed and counts $\log(x + 1)$-transformed. Significance was set at $P = 0.05$ for all analyses. In the tables, untransformed results are presented.

3 Results

3.1 Effect of N fertilizer on leaf N content

Mean leaf N content significantly increased with increasing N dosages especially at Kola Diba on both maize and sorghum (table 3). Increasing level of N fertilizer tended to eliminate differences in leaf N content between maize and sorghum (table 3).

3.2 Abundance of borers

Busseola fusca was the dominant species in cool-wet western and *C. partellus* in semiarid eastern Amhara. On sorghum at Kola Diba, *B. fusca* density tended to increase with increasing level of fertilizer on insecticide-free plots (table 4). On maize, at both Kola Diba and Addis Zemen, the trend was similar, though not significant ($F = 2.50$, $P = 0.06$ and $F = 2.49$, $P = 0.06$, respectively). For both crops at Chefa, there was no discernable trend between fertilizer application and *C. partellus* density (table 4). *Rhynchaenus niger* (Horn) (Col., Rhynchophoridae) (mean 0.02 ± 0.01, range 0–3 beetles per plant) was found on sorghum stems at Kola Diba but N levels did not affect its population significantly ($F = 0.51$, $P = 0.6815$; data not shown in the table). On both crops and for most N treatments, insecticide application significantly reduced borer population (table 4) including *R. niger* at Kola Diba ($F = 5.1$, $P = 0.0348$); in some of the N_0 and N_1 treatments, and especially at low pest densities, the insecticide had no effect. Pest infestations were higher on sorghum than on maize, at both Kola Diba and Chefa (table 4). In all sites, there was significant three-way interaction on borer density between N fertilizer, insecticide treatments and plant growth stage (i.e. at Kola Diba on maize, $F = 6.2$, $P < 0.0001$; on sorghum $F = 70.32$, $P < 0.0001$; at Addis Zemen on maize, $F = 63.4$, $P < 0.0001$; at Chefa on maize, $F = 4.2$, $P < 0.0001$, on sorghum, $F = 2.59$, $P = 0.0044$). In general, borer populations significantly increased with phenological stage up to grain filling, but declined at harvest especially on maize (table 5).

3.3 Natural enemies

Larval parasitism by *C. flavipes*, observed only in semiarid eastern Amhara, was very low. On maize, differences in parasitism between N levels were not siginficant, although it gradually increased with N (table 6). On sorghum, there were significant differences in parasitism and again it tended to increase with N level (table 6). Parasitism was generally higher in maize than in sorghum, especially on pesticide free plots. Insecticide applications significantly reduced parasitism on maize. Parasitism also increased with plant growth stage on both maize ($F = 23.58$, $P < 0.0001$) and sorghum ($F = 10.17$, $P = 0.0015$).

In addition, *Procerochasmias nigromaculatus* (Cameron) (Ichneumonidae) and the braconids *Dolichogenidea fuscivora* Walker and *Stenobracon* (*Euvipio*) *rufus* Szepligeti were each found once in cool-wet western Amhara. Earwigs and ants were commonly seen preying on *B. fusca*. The population of earwigs increased with crop phenological stage ($F = 2.45$, $P = 0.0442$) and the insecticide treatment reduced

Table 3. Per cent leaf nitrogen (N) concentration in leaves of maize and sorghum plants subjected to different nitrogen treatments (N_0–N_3) at Addis Zemen and Kola Diba

N fertilizer level	Addis Zemen	Kola Diba	
	Maize	Maize	Sorghum
N_0	0.95 ± 0.06 b	0.82 ± 0.07 c,B	1.19 ± 0.07 b,A
N_1	0.91 ± 0.06 b	0.92 ± 0.03 c,B	1.35 ± 0.07 ab,A
N_2	1.12 ± 0.10 b	1.21 ± 0.10 b,A	1.40 ± 0.05 ab,A
N_3	1.38 ± 0.10 a	1.48 ± 0.04 a,A	1.49 ± 0.06 a,A
F-value	7.12	21.25	3.95
P-value	0.0011	<0.0001	0.0182

Mean values within a column followed by the same lower case letter and within a row within Kola Diba followed by the same upper case letters are not significantly different at P ≤ 0.05 (SNK).

Table 4. *Least square mean (±SE) of* B. fusca *density per plant at Kola Diba, Addis Zemen and* C. partellus *at Chefa on maize and sorghum plants subjected to different nitrogen fertilizer dosages and insecticide treatments*

	Kola Diba				Addis Zemen		Chefa			
	Sorghum		Maize		Maize		Sorghum		Maize	
N fertilizer level	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated
N_0	0.03 ± 0.03 a,A	0.21 ± 0.06 d,A	0.01 ± 0.01 a,A	0.08 ± 0.06 a,A	0.02 ± 0.00 a,A	0.13 ± 0.08 a,A	0.3 ± 0.16 a,B	2.6 ± 0.35 a,A	0.03 ± 0.03 a,B	0.4 ± 0.13 a,A
N_1	0.08 ± 0.07 a,B	1.51 ± 0.13 c,A	0.00 ± 0.00 a,A	0.18 ± 0.11 a,A	0.05 ± 0.05 a,A	0.34 ± 0.12 a,A	0.4 ± 0.12 a,B	3.7 ± 0.39 a,A	0.05 ± 0.04 a,B	0.5 ± 0.13 a,A
N_2	0.17 ± 0.07 a,B	2.95 ± 0.19 a,A	0.02 ± 0.02 a,B	0.43 ± 0.11 a,A	0.06 ± 0.06 a,B	0.69 ± 0.22 a,A	0.2 ± 0.06 a,B	2.8 ± 0.31 a,A	0.00 ± 0.00 a,B	0.4 ± 0.12 a,A
N_3	0.14 ± 0.06 a,B	2.07 ± 0.22 b,A	0.00 ± 0.00 a,B	0.38 ± 0.13 a,A	0.05 ± 0.05 a,B	0.80 ± 0.33 a,A	0.2 ± 0.10 a,B	3.5 ± 0.39 a,A	0.00 ± 0.00 a,B	0.4 ± 0.13 a,A
F-value	0.97	65.50	1.38	2.50	0.76	2.49	0.85	2.34	1.24	0.19
P-value	0.4074	< 0.0001	0.2487	0.0619	0.5180	0.0643	0.4684	0.0754	0.2959	0.8991

For each location and crop, mean values within rows followed by the same upper case letter and within a column followed by the same lower case letter are not significantly different at $P \leq 0.05$ (SNK).

their number significantly (F = 4.34, P = 0.0436), while N fertilizer had no effect (F = 0.68, P = 0.5702).

3.4 Damage variables

At Kola Diba, in untreated plots, internode damage, and percent stems tunneled on sorghum tended to be lowest in N_0 and highest in N_3; the same trend was observed for stem tunneling at Chefa (table 7). There were no discernable trends for maize.

Insecticide application, in general, reduced stemborer damage but the differences were more often significant on sorghum than on maize. Damage symptoms significantly increased with phenological stage on both crops in all locations.

3.5 Effect on grain yield, head weight, cob weight and yield loss

On sorghum, stemborers caused between 16% and 47% reductions in head (panicle) yield and 18–49% in grain yield; and the losses generally were higher at Kola Diba than Chefa (table 8). At Kola Diba, the highest loss was recorded in unfertilized plots, and it showed decreasing trend with increasing N level (fig. 2). The effect of N was stronger on grain than head weight/ plant (table 8). The lowest yields were observed in N_0 at Kola Diba. In most cases, insecticide treated plots had significantly higher yield than untreated plots (table 8). Increments of 31.7–61.0% head weight and 59.6–74.1% grain yield were recorded by comparing N_0 with other N treatments (table 8). At Chefa, though grain yields increased gradually with N dosage, the differences were not significant.

On maize, insecticide treatments generally did not significantly improve grain yields (table 9). The exceptions were N_3 plots at Addis Zemen and Chefa, where insecticide free plots gave 30.1% and 23.6% less yield than insecticide treated plots, respectively. At Kola Diba and Addis Zemen, yields increased with N dosage; grain yield gains (increments) were greater than cob weight gain (table 9). Cob weight increments from 11.1% to 78.7% and grain yield from 51.5% to 98.7% were recorded in Addis Zemen and Kola Diba. N had no effect on maize yields at Chefa (table 9).

3.6 Relationships between yield and plant growth and damage variables, leaf nitrogen content, nitrogen fertilizer level and borer populations

In the cool-wet ecozone, multiple regression analyses on both maize and sorghum showed that grain yield per hectare (Y) was significantly positively related to N fertilizer, while other variables varied with crop species and location. On maize, grain yield was significantly positively related to both N level (x_1) and plant height (x_2) ($Y = -826.1 + 12.2x_1 + 2572.3x_2$; F = 25.3, P < 0001, $r^2 = 0.92$). Insecticide application, stem diameter, number of internodes per plant, borer damage variables and borer density did not significantly affect yield probably because of relatively lower

Table 5. *Least square mean (± SE) of* B. fusca *density per plant at Kola Diba and* C. partellus *at Chefa at different phenological stages of maize and sorghum*

Growth stage	Kola Diba Maize	Kola Diba Sorghum	Chefa Maize	Chefa Sorghum
Seedling	0.00 ± 0.0 c	0.00 ± 1.37 b	0.00 ± 0.0 c	0.00 ± 0.0 c
Flag leaf/Tassel	0.13 ± 0.02 a	0.21 ± 0.14 b	1.17 ± 0.11 a	2.0 ± 0.16 b
Heading/Grain fill	0.14 ± 0.02 a	1.61 ± 0.08 a	2.00 ± 0.12 a	2.5 ± 0.16 a
Harvest	0.05 ± 0.10 b	1.50 ± 0.08 a	0.50 ± 0.11 b	1.7 ± 0.16 a
F-value	23.45	31.11	4.41	3.68
P-value	< 0.0001	< 0.0001	0.0129	0.0310

Mean values within a column followed by the same lower case letter are not significantly different at P ≤ 0.05 (SNK).

Table 6. *Least square mean (± SE) of % larval parasitism at Chefa on maize and sorghum plants subjected to different nitrogen fertilizer dosages and insecticide treatments*

N fertilizer (kg/ha)	Maize Treated	Maize Untreated	Sorghum Treated	Sorghum Untreated
N_0	0.0 ± 0.0 a,A	2.0 ± 1.0 a,A	0.0 ± 0.0 a,A	0.2 ± 0.5 b,A
N_1	0.0 ± 0.0 a,B	5.6 ± 2.4 a,A	0.0 ± 0.0 a,A	0.8 ± 0.1 b,A
N_2	0.0 ± 0.0 a,B	6.9 ± 2.6 a,A	0.0 ± 0.0 a,A	1.3 ± 0.9 ab,A
N_3	0.6 ± 0.5 a,B	7.4 ± 2.8 a,A	1.3 ± 1.0 a,A	3.8 ± 1.6 a,A
F-value	0.99	1.13	1.00	2.84
P-value	0.3931	0.3375	0.3931	0.0383

For each crop, mean values within rows followed by the same upper case letter and within a column followed by the same lower case letter are not significantly different at P ≤ 0.05 (SNK).

Table 7. *Least square mean (± SE) of damage (% internode damage, % stem tunneling, and % peduncle damage) of maize and sorghum plants subjected to different nitrogen fertilizer dosages and insecticide treatments*

N level	% Internode damage Treated	% Internode damage Untreated	% Stem tunneling Treated	% Stem tunneling Untreated	% Peduncle (cob damage)* Treated	% Peduncle (cob damage)* Untreated
Sorghum			Kola Diba			
N_0	4.0 ± 0.7 ab,B	8.9 ± 1.1 b,A	2.8 ± 0.5 b,B	6.8 ± 1.0 b,A	4.9 ± 2.2 b,B	66.5 ± 15.6 a,A
N_1	2.7 ± 0.5 b,B	26.9 ± 1.6 a,A	1.8 ± 0.4 b,B	18.7 ± 1.3 a,A	25.9 ± 8.1 ab,B	70.1 ± 19.1 a,A
N_2	3.8 ± 0.7 ab,B	27.9 ± 1.8 a,A	2.3 ± 0.4 b,B	21.2 ± 1.6 a,A	18.2 ± 6.4 ab,B	91.4 ± 5.1 a,A
N_3	5.2 ± 0.7 a,B	28.2 ± 1.7 a,A	4.6 ± 0.7 a,B	21.5 ± 1.5 a,A	38.9 ± 5.6 a,B	93.2 ± 6.1 a,A
F-value	2.30	27.97	5.20	21.54	5.64	1.16
P-value	0.0757	< 0.0001	0.0014	< 0.0001	0.0120	0.3657
			Chefa			
N_0	2.2 ± 1.0 a,B	31.6 ± 3.9 a,A	3.0 ± 1.1 a,B	26.9 ± 3.2 b,A	1.9 ± 1.6 a,B	9.4 ± 3.0 b,A
N_1	4.4 ± 1.3 a,B	41.9 ± 4.9 a,A	4.2 ± 1.1 a,B	32.3 ± 3.7 b,A	0.3 ± 0.3 a,B	19.8 ± 4.2 a,A
N_2	3.2 ± 1.2 a,B	27.7 ± 2.9 a,A	2.7 ± 1.0 a,B	22.9 ± 2.2 b,A	1.4 ± 1.3 a,A	7.3 ± 3.0 b,A
N_3	4.8 ± 2.0 a,B	41.1 ± 3.8 a,A	2.9 ± 1.4 a,B	42.3 ± 3.4 a,A	0.5 ± 0.4 a,B	17.3 ± 4.1 a,A
F-value	0.68	3.22	0.27	6.16	0.51	2.79
P-value	0.5642	0.0245	0.8496	0.0005	0.6740	0.0423
Maize			Kola Diba			
N_0	0.1 ± 0.1 a,B	1.8 ± 0.7 a,A	0.2 ± 0.2 a,A	1.3 ± 0.6 ab,A	1.1 ± 0.96 a,A	3.8 ± 1.25 a,A
N_1	0.0 ± 0.0 a,B	1.3 ± 0.5 a,A	0.0 ± 0.0 a,B	0.8 ± 0.3 ab,A	0.1 ± 0.04 b,B	0.6 ± 0.17 b,A
N_2	0.2 ± 0.2 a,A	0.4 ± 0.2 b,A	0.4 ± 0.3 a,A	0.3 ± 0.1 b,A	0.1 ± 0.05 b,B	1.1 ± 0.39 b,A
N_3	0.0 ± 0.0 a,B	2.7 ± 0.8 a,A	0.0 ± 0.0 a,B	1.8 ± 0.6 a,A	0.3 ± 0.15 b,A	0.8 ± 0.22 b,A
F-value	1.38	3.46	0.95	3.24	2.97	8.76
P-value	0.2483	0.0164	0.4169	0.0222	0.0309	< 0.0001
			Addis Zemen			
N_0	0.0 ± 0.0 a,A	1.8 ± 1.6 a,A	0.0 ± 0.0 a,A	0.3 ± 0.3 a,A	0.5 ± 0.3 a,A	0.5 ± 0.4 a,A
N_1	0.0 ± 0.0 a,A	5.5 ± 2.3 a,A	0.0 ± 0.0 a,A	1.2 ± 0.5 a,A	0.0 ± 0.0 b,A	0.0 ± 0.0 b,A
N_2	0.0 ± 0.0 a,B	6.2 ± 2.2 a,A	0.0 ± 0.0 a,A	1.3 ± 0.6 a,A	0.1 ± 0.1 b,A	0.2 ± 0.1 ab,A
N_3	0.4 ± 0.4 a,A	5.0 ± 2.0 a,A	0.1 ± 0.1 a,A	0.5 ± 0.3 a,A	0.0 ± 0.0 b,A	0.2 ± 0.1 ab,A
F-value	0.98	0.92	0.98	1.22	14.68	2.24
P-value	0.4056	0.4360	0.4056	0.3069	< 0.0001	0.0824
			Chefa			
N_0	0.7 ± 0.4 a,B	15.8 ± 2.3 a,A	0.3 ± 0.3 a,A	6.2 ± 1.2 a,A	0.3 ± 0.2 a,A	0.6 ± 0.3 a,A
N_1	0.5 ± 0.3 a,B	9.4 ± 2.3 a,A	0.8 ± 0.7 a,A	5.7 ± 1.3 a,A	0.2 ± 0.1 a,A	0.2 ± 0.1 a,A
N_2	0.0 ± 0.0 a,B	19.2 ± 3.4 a,A	0.0 ± 0.0 a,A	8.8 ± 1.8 a,A	0.1 ± 0.1 a,A	0.4 ± 0.2 a,A
N_3	0.0 ± 0.0 a,B	14.1 ± 2.3 a,A	0.1 ± 0.1 a,A	7.1 ± 1.5 a,A	0.2 ± 0.1 a,A	0.5 ± 0.2 a,A
F-value	1.85	2.28	0.71	0.87	0.32	0.59
P-value	0.1398	0.0817	0.5493	0.4598	0.8087	0.6241

For each location and crop, mean values within rows followed by the same upper case letter and within a column followed by the same lower case letter are not significantly different at P ≤ 0.05 (SNK).
*% peduncle damage for sorghum and % cob damage for maize.

Table 8. Least square mean values of sorghum head and grain weight at Kola Diba, and Chefa at different levels of nitrogen fertilizer and insecticide application, Amhara State, Ethiopia

N fertilizer level	Head weight (g per plant)		HWL (%)	% Increment (head weight)[1]		Grain yield (kg/ha)		GWL (%)	% Increment (grain yield)[1]	
	Treated	Untreated		Treated	Untreated	Treated	Untreated		Treated	Untreated
					Cool-wet western Amhara					
Kola Diba										
N_0	19.8 c,A	18.3 b,A	–	–	–	798.3 b,A	407.8 b,B	48.9	–	–
N_1	34.3 b,A	34.2 a,A	–	42.3	46.5	1975.6 a,A	1133.2 a,B	42.6	59.6	64.0
N_2	43.4 a,A	29.5 a,B	32.0	54.4	38.0	2158.2 a,A	1200.7 a,B	44.4	63.0	66.0
N_3	50.7 a,A	26.8 ab,B	47.1	60.9	31.7	2456.5 a,A	1575.4 a,B	35.7	67.5	74.1
					Semiarid eastern Amhara					
Chefa										
N_0	147.2 a,A	109.6 a,B	25.5	–	–	2225.7 a,A	1766.4 a,A	–	–	–
N_1	142.3 a,A	105.9 a,B	25.6	–	–	2684.3 a,A	2233.8 a,A	–	–	–
N_2	149.7 a,A	125.1 a,B	16.4	–	–	2703.9 a,A	2200.8 a,B	18.6	–	–
N_3	145.7 a,A	112.0 a,B	23.2	–	–	2728.9 a,A	2022.1 a,B	26.0	–	–

For a given location, mean values within rows followed by the same upper case letter and within a column followed by the same lower case letter are not significantly different at $P \leq 0.05$ (SNK).
–, indicates no effect of insecticide or fertilizer.
[1]Only when differences between means were significant, % yield increment was calculated by comparing N_0 with N_1, N_2 and N_3.
HWL and GWL stand for head weight loss and grain weight loss, respectively.

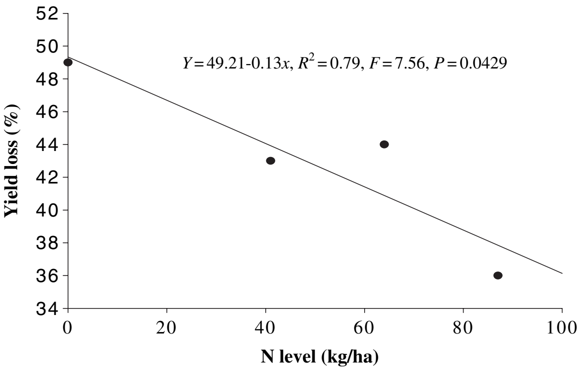

Fig. 2. The relationship between N fertilizer level and grain yield loss on sorghum at Kola Diba, cool-wet western Amhara, Ethiopia

borer density on maize than sorghum in western Amhara. On sorghum, grain yield per ha was significantly affected by N level (x_1), insecticide (x_2), and negatively by percent tunnelling (x_3) ($Y = -2292.8 + 13.0x_1 + 573.7x_2 - 27.7x_3$; F = 16.9, P < 0001, $r^2 = 0.89$). Borer density, plant height, stem diameter, number of holes per plant and per cent damaged had no effect.

On maize, parasitism (Y) was not affected by N and borer density while on sorghum N (x_1) and insecticide treatment (x_2) were significant ($Y = 1.33 + 0.58x_1 - 1.23x_2$; F = 3.2, $r^2 = 0.02$, P = 0.0237).

Simple regressions between percent total leaf nitrogen content (Y) and N fertilizer level (x_1), and between leaf N and borer density (x_1), showed significant positive relationships for both crops ($Y_{sorghum} = 0.816 + 0.00314x_1$, $r^2 = 0.88$, F = 43.19, P = 0.0006; $Y_{maize} = 1.195 + 0.00338x_1$, $r^2 = 0.99$, F = 222.32, P = 0.0045; $Y_{sorghum} = 0.118 + 0.0029x$, $r^2 = 0.65$, F = 11.33, P = 0.0151; $Y_{maize} = 0.432 + 0.0263x$, $r^2 = 0.72$, F = 5.04, P = 0.1539).

4 Discussion

The percent N content in leaves in maize increased linearly with N fertilization while in sorghum the differences between no fertilizer and the first two N levels were not significant. N content was generally higher in sorghum than maize. Jiang and Schulthess (2005) reported differences in plant N content between fertilized and unfertilized plants (i.e. between N_0 and N_1–N_3, but not between N_1, N_2 and N_3). In general, soil fertility is low in the Amhara state (Esilaba et al. 2000; Getachew and Wondimu 2005), as also shown in table 2, and any nitrogen input may have an immediate effect on leaf N. In Cameroon, plant N content increased when maize was planted following a leguminous cover crop (Chabi-Olaye et al. 2005a). In eastern Amhara, there was no clear trend between fertilization and *C. partellus* density. Thus, the present discussion of the effect of N is based mostly on the results in the cool-wet western Amhara.

Busseola fusca was the major stemborer species in western and *C. partellus* in semiarid eastern Amhara as also reported by Emana et al. (2001) and Ferdu et al. (2001). In Africa, reports generally indicate that *C. partellus* is a low to medium elevation and *B. fusca* a higher elevation borer (Ingram 1958; Seshu Reddy 1983; Assefa 1985; Overholt et al. 1997). *Rhynchaenus niger* was first reported by Emana et al. (2001) from sorghum in Ethiopia. Its importance, biology and ecology are largely not known and so far it has never been reported from other cereal crops, apart from sorghum. *R. niger* is known as flee weevils boring stems of wild trees (Anonymous 2000).

Plant N content, borer density, damage, and yield tended to increase with increasing N fertilizer level, especially on insecticide free plots. Numerous studies showed a positive effect of N nutrients on borer incidence and survival in cereals (Archer et al. 1987; Martin et al. 1989; Sétamou et al. 1993, 1995;

Table 9. *Least square means of maize cob weight and grain weight at different levels of nitrogen fertilizer and insecticide application, at Kola Diba, Addis Zemen and Chefa, Amhara State, Ethiopia*

N fertilizer level	Cob weight (g plant^{-1})		CWL %	% Increment (cob weight)[1]		Grain yield (kg/ha)		GWL %	% Increment (grain yield)[1]	
	Treated	Untreated		Treated	Untreated	Treated	Untreated		Treated	Untreated
Kola Diba					Cool-wet western Amhara					
N_0	28.3 c,A	23.1 d,A	–	–	–	32.5 c,A	181.1 b,A	–	–	–
N_1	47.3 b,B	56.8 c,A	–	40.2	59.3	907.5 b,A	1144.1 a,A	–	98.4	84.2
N_2	104.2 a,A	97.6 b,A	–	72.8	76.3	2085.8 ab,A	1651.1 a,A	–	98.4	89.0
N_3	105.9 a,A	108.3 a,A	–	73.3	78.7	2540.9 a,A	2152.4 a,A	–	98.7	91.6
Addis Zemen										
N_0	101.4 d,A	103.4 c,A	–	–	–	872.8 c,A	859.7 b,A	–	–	–
N_1	114.0 c,A	99.9 c,B	12.4	11.1	–	3216.7 b,A	1773.5 b,A	–	72.9	51.5
N_2	142.0 b,B	178.3 a,A	–	28.6	42.0	5144.4 a,A	4388.1 a,A	–	83.0	80.4
N_3	161.6 a,B	186.3 a,A	–	37.3	44.5	5802.1 a,A	4057.2 a,B	30.1	85.0	78.8
Chefa					Semiarid eastern Amhara					
N_0	156.9 a,A	134.1 a,A	–	–	–	1559.6 a,A	1569.7 a,A	–	–	–
N_1	144.0 a,A	123.1 a,A	–	–	–	1455.3 a,A	1273.3 a,A	–	–	–
N_2	155.8 a,A	149.8 a,A	–	–	–	1628.2 a,A	1435.3 a,A	–	–	–
N_3	156.0 a,A	135.5 a,A	–	–	–	1660.4 a,A	1269.1 a,B	23.6	–	–

For a given location, means within rows followed by the same upper case letter and within a column followed by the same lower case letter are not significantly different at $P \leq 0.05$ (SNK); - indicates no effect of insecticide or fertilizer; [1] only when differences between means were significant, % yield increment was calculated by comparing N_0 with N_1, N_2 and N_3; HWL and GWL stand for head weight loss and grain weight loss, respectively.

Rustamani et al. 2001; Chabi-Olaye et al. 2005a; Jiang and Schulthess 2005). According to Singh and Singh (1969), N leads to tilting of balance of the carbon to nitrogen ratio in the plant. Greater N supply causes the formation of thin, succulent cell walls that enhance survival of young borer larvae.

The lack of response of plants and pests to N fertilizer in semiarid eastern Amhara might be explained by the relatively high soil fertility status, i.e. high N, P and organic carbon. A similar study carried out in Tanzania showed that yield losses linearly decreased with an increase in N level (Mgoo 2005).

The number of borers increased with crop phenological stage up to grain filling and then decreased at harvest. Ferdu (1991) and Assefa (1982) reported highest borer density in southern Ethiopia at 4–6 weeks after the emergence of maize plants corroborating the present findings. Ndemah et al. (2001) reported low borer density at maturity due to migration, adulthood, or parasitism and predation. Sorghum carried higher borer density and suffered more damage than maize. Similarly, Sétamou et al. (2005) reported a higher *C. partellus* larval weight and survival on sorghum compared with maize.

Parasitism on maize was low with mean values ranging from 0% to 7.4%, even lower on sorghum. Nevertheless, it tended to increase with N level on both maize and sorghum corroborating reports by Jiang and Schulthess (2005). The present field studies confirm results of previous laboratory studies, which showed that *C. flavipes* was attracted more to maize than sorghum (Ngi-Song et al. 1996). In another study by W. Melaku, F. Schultness, E. W. Kairu and C. O. Omwega (unpubl. data), parasitism on late-maturing 240-day sorghum varieties were around 30%. These varieties allow for more than one generation of borers on the same plant, which facilitates host finding by the parasitoid because they only have to search within the same or neighboring plants.

In cool-wet western Amhara, borer populations steadily increased with leaf nitrogen concentration in sorghum and tended to increase in maize. According to Sétamou et al. (1993) and Chabi-Olaye et al. (2005a), this was mainly the result of a higher survival of young larvae on plants with higher leaf N concentration.

Yield losses tended to decrease with increase in nitrogen fertilizer on sorghum at Kola Diba, where borer infestations and damage were high. Several workers reported decreasing yield loss with an increase in soil N (Sétamou et al. 1995; Chabi-Olaye et al. 2005a; Mgoo 2005). Ingram (1958) reported that when the growth of sorghum was poor and the plants were dwarfed and thin-stemmed, *C. partellus* often caused 100% yield loss.

In general, multiple regressions showed that fertilizer and insecticide treatment had a positive and borer and damage variables a negative effect on yield. Stem tunneling was regarded to be a good indicator of the degree of plant damage and, thus, yield loss in many countries in Africa (Bosque-Perez and Mareck 1991; Van Den Berg and Van Rensburg 1991; Gounou et al. 1994; Kalule et al. 1994; Sétamou et al. 1995; Kalule et al. 1997; Songa et al. 2001; Ndemah and Schulthess 2002). By contrast, on sorghum in Nigeria, Macfarlane (1990) reported that percentage damaged internodes due to *B. fusca* was a better indicator for grain loss than tunnelling. Numbers of borer at harvest are not reliable indicators of the extent of infestation since many of them became adults and left the plant, get killed by natural enemies or migrate to other plants (Van Rensburg 1988; Sétamou et al. 1995; Ndemah et al. 2001; Chabi-Olaye et al. 2005b).

Our objective in this study was to assess borer damage and yield losses as affected by nitrogen fertilizer in the Amhara State of Ethiopia. Sorghum yield loss was 36–49% in western and 19–26% in semiarid eastern Amhara, while losses in maize were 0–30% in both regions. Yield increment due to N fertilizer was 0–69% on sorghum and 41–88% on maize in cool-wet western Amhara, but there was no increment in semiarid eastern Amhara. Differences between region and crop could be explained by differences in soil fertility and overall pest densities, and it can be concluded that the beneficial effect of N is especially strong in areas with low soil fertility and high pest pressure.

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