Effects of Nitrogen and Potassium Combinations on Yields and Infestations of Maize by *Busseola fusca* (Lepidoptera: Noctuidae) in the Humid Forest of Cameroon

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ABSTRACT Field trials were set up in the humid forest zone of Cameroon to investigate the effects of combinations of different rates of nitrogen (N) (0, 60, and 120 kg N ha^{-1}) and potassium (K) (0, 80, and 160 kg K ha^{-1}) applied to the soil on the incidence and damage of the noctuid stemborer *Busseola fusca* (Fuller), and on maize, *Zea mays* L., yield. Each N/K combination had an insecticide control to assess yield losses due to borers. In contrast to N, K had no effect on plant growth and borer incidence and damage. Across seasons and days after planting, total plant dry matter (DM) production increased with N level and it was 1.2–1.9 and 1.7–2.2 times, respectively, higher at 60 and 120 kg N ha^{-1} compared with 0 kg N ha^{-1}. Total DM at harvest was strongly related to the N content of the plant at 63 d after planting. At the early growth stage, borer abundance and stem tunneling tended to increase with N level, but percentages of dead hearts did not vary with treatment. Maize grain yields increased linearly with N level, but grain yield losses decreased depending on season. Grain yield losses were 11–18.2 times higher with 0 kg N ha^{-1} compared with 120 kg N ha^{-1}. The findings so far indicated that, soil application of N improves the nutritional status of maize, which consequently enhanced its tolerance to stemborer attacks. Improving soil fertility can thus be a very effective means of complementing integrated stemborer control in the humid forest zone of Cameroon.

KEY WORDS *Busseola fusca*, stemborer, maize, nitrogen and potassium, yield loss

Maize, *Zea mays* L., is the predominant cereal in terms of both acreage and tonnage in sub-Saharan Africa (SSA). In Cameroon, maize is among the two main staples, and it is grown from sea level to the highlands of up to 2,000 m. With an average of 1.8 mg ha^{-1}, maize yields in Cameroon are still considerably below the 4.3 mg ha^{-1} world average (FAOSTAT 2002). Reasons for these low yields are, among others, lepidopterous stem- and ear borers (Cardwell et al. 1997, Schulthess et al. 1997a, Ndemah et al. 2001) and low soil fertility (Hauser and Nolte 2002; Hauser et al. 2002, Chabi-Olaye et al. 2005a, 2005c).

Common borer species in the humid forest zones of Cameroon are the noctuid *Busseola fusca* (Fuller), which is the most widely distributed and abundant species, and the pyralid *Eldana saccharina* (Walker), which can become important during the second season (Cardwell et al. 1997, Schulthess et al. 1997a, Ndemah et al. 2001, Chabi-Olaye et al. 2006a). Yield reductions due to borers occur as a result of leaf feeding, stem tunneling, direct damage to grain (Bosque-Pérez and Mareck 1991, Cardwell et al. 1997, Sétamou et al. 2000), and yields are aggravated by the poor nutritional status of the plant (Sétamou et al. 1995, Chabi-Olaye et al. 2005b).

Plant nutritional conditions have been found to influence the susceptibility of plants to several herbivorous insects and diseases (Haseman 1946, McNeil and Southwood 1978, Mattson 1980). However, the effects of mineral fertilizers to complement various pest control measures vary greatly with insect and host plant species. Saroja et al. (1987) reported that every increase in nitrogen (N) levels resulted in an increase in incidence of both pests [e.g., *Scirpophaga incertulas* Walker (Lepidoptera: Pyralidae, Schoenobiinae)] and rice yield. Archer et al. (1987) found that N increased pest infestations and stem damage, whereas phosphorus (P) decreased it, and combinations of N and P were not different from the control (zero application of N and P). Previous laboratory and field studies in West and Central Africa showed that N has a positive effect on the plant's tolerance to stemborer attacks (Sétamou and Schulthess 1995), whereas soil magnesium (Mg) and potassium (K) were, respectively, positively and negatively related to *B. fusca* densities (Ndemah 1999). Study by Chabi-Olaye et al. (2005b) on the short-term effect of grain legumes and cover crops on the incidence of *B. fusca* and maize yield demonstrated the significant role of legumes in

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rotation for improving the supply of mineral N in the soil and for enhancing the yield of a subsequent maize crop through lower plant damage by *B. fusca* in the humid forest of Cameroon (Chabi-Olaye et al. 2005b). However, no or little information is available on the effects of mineral N and K on the incidence of *B. fusca* and maize yields. Thus, field trials were set up in the humid forest of Cameroon to assess efficiency of N and K as mineral fertilizer in reducing borer's incidence and increasing maize yields.

Materials and Methods

Experimental Site. The experiments were conducted from 2003 to 2004 at Nkometou (4° 05′ N, 11° 33′ E; 596 m above sea level), a village 40 km west of Yaoundé. They were carried out during both the first (the long) and second (the short) growing seasons of each year. The long and short rainy seasons last from mid-March to mid-July and from mid-August to end of November, respectively. Average annual precipitation is 1,500 mm. The trials were laid out in a 2–3-yr-old natural regrowth fallow dominated by *Chromolaena odorata* (L.) R. M. King & H. Rob. (Asteraceae), on a Rhodic Kandiudilt soil. The soil physical and chemical proprieties were quite similar to those reported by Chabi-Olaye et al. (2005b). The chemical analysis of the top soil (0–20 cm) revealed a pH(H_2O) of 5.6, 0.13% total N, 1.85% organic carbon, 11.3 $\mu g\ g^{-1}$ available P (Mehlich-III extract), and 0.23 cmol(+) 100 g^{-1} exchangeable K.

Experimental Procedure. The treatments consisted of combinations of different levels of N and K fertilizers and insecticide (treated or untreated). Three levels of N (0, 60, and 120 kg N ha^{-1}) were combined with three levels of K (0, 80, and 160 kg K ha^{-1}), giving a total of nine N_iK_j combinations. Each N_iK_j combination had a control plot (IFP versus ITP, where IFP is insecticide-free plot and ITP is insecticide-treated plot), making it 18 treatments. The 18 treatments were arranged in a completely randomized block design with four replications. Plots were 6 by 6 m each. The four blocks were established at a distance of 150–200 m from each other to reduce interactions between treatments. The distance between plots within a block was 1.5 m.

Maize was planted at 75 cm between rows and 50 cm within rows. Four seeds of the 110-d open pollinated maize 'Cameroon Maize Series (CMS) 8704′ were sown per hill, and the stands were thinned to two plants per hill 14 d after planting (DAP). CMS 8704 is bred by the Institut de la Recherche Agronomique. It is a yellow flint maize suited to the humid forest lowlands. CMS 8704 is the most used cultivar in the country (Ndemah 1999, Aroga et al. 2001). The yield potential can reach 7 tons/ha, depending of soil fertility and water availability.

At planting, the plots received P at the rate of 30 kg ha^{-1} in form of P_2O_5. N and K were applied in form of urea and KCl, respectively in two to three dosages. N and K dosages of 60 kg ha^{-1} were given as two split-dosages 14 and 28 DAP, whereas those $>$ 60 kg ha^{-1} were split into three, i.e., 14, 28, and 56 DAP. Plots were kept weed free. Insecticides were applied 21 and 42 DAP by using carbofuran at ≈1.5 active ingredient (AI) kg ha^{-1}) by placing the granules in the whorl.

Plant Analyses. For plant nutrient analyses, four plants were randomly taken from each plot. Fresh biomass samples were oven-dried at 65°C for ≈1 wk until constant weight. The dried samples were manually ground with a mortar to pass a 0.5-mm mesh for determination of N concentrations. Samples were digested according to Novozamsky et al. (1983). Total N was determined with an ammonium sensitive electrode (Powers et al. 1981). The N contents of stems were measured at 63 DAP and at harvest. K was analyzed by the PerkinElmer 30303B atomic absorption spectrophotometer (PerkinElmer Life and Analytical Sciences, Boston, MA).

Data Collection. During the long and short rains of 2003, the total dry matter content of plant components (leaves, stems, cobs, and dry weight of grains) was assessed at 42 and 63 d after planting and at harvest, in all plots. For this, four maize plants were randomly uprooted per plot, weighed and dried at 65°C in the oven for ≈1 week. N and K concentrations in the total plant dry matter were determined at 63 d after planting. During 2004, the total plant dry matter was assessed at harvest only.

To monitor borer abundance and damage, 12 plants per plot were sampled destructively at 42, 56, and 70 d after planting. The samples were taken from the middle of the plot, leaving the first border row untouched, to reduce interaction between treatments. At each sampling occasion the two plants in a hill were uprooted, and plants next to previously sampled hill were avoided. Data recorded in insecticide-free plots were the number of borers, plant damage variables (i.e., percentage of plant infested, and percentage of plants with dead-heart symptoms).

At harvest, yield and plant damage variables were recorded in all plot. For this, each plot was divided into four quadrants and one predetermined, untouched subplot of 1.5 m^2, containing four hills (eight maize plants) was harvested per quadrant, given a total of 32 plants per plot. A subsample of 12 plants was randomly selected from the 32 plants to assess the total plant height and an estimate of borer tunnel length (centimeters). For this, three plants were taken from each subplot. In addition, cobs were dehusked, weighed, and the percentage of grains consumed by borers was assessed using a 1-to-5 rating scale (1, 0–5%; 2, 6–25%; 3, 26–50%; 4, 51–75%; and 5, 76–100% grains damage) developed by Bosque-Pérez and Mareck (1991). Thereafter, all cobs were pooled per plot and weighed. A moisture multi grain tester (KETT electronic PM-410) was used to determine the grains moisture at harvest. For this, several samples were taken from different plots. Cobs were harvested at moisture content between 18 and 25% and dried to 13.5% in the laboratory. For this, a subsample of 16 cobs per plot was weighed and dried at 65°C for ≈1 wk. Then, the dry grain was removed and weighed again to determined grain dry matter yield.

Table 1. Plant height and biomass production of maize crop subjected to different levels of N and K fertilizer combinations

Season	Fertilizer dose[a]	2003								2004			
		Total plant dry matter (mg ha^{-1})						Plant ht (cm)		Total dry matter at harvest (mg ha^{-1})		Plant ht (cm)	
		42DAP		63DAP		Harvest (mg ha^{-1})							
		IFP	ITP	IFP	ITP	IFP	ITP	IFP	ITP	IFP	ITP	IFP	ITP
Long rains	N_0K_0	0.555	0.604	3.001	2.969	6.99	7.17	228.4	232.9	6.91	7.01	178.2	191.8
	N_0K_{80}	0.664	0.733	3.051	3.237	7.36	7.61	230.9	233.5	7.14	7.08	193.1	211.4
	N_0K_{160}	0.711	0.780	3.124	3.309	7.54	7.68	231.3	234.2	7.06	6.98	195.3	207.4
	$N_{60}K_0$	1.176	1.144	4.337	4.257	11.81	12.25	250.1	252.6	8.40	9.50	192.2	225.8
	$N_{60}K_{80}$	1.224	1.128	4.220	4.176	13.01	12.56	251.9	255.4	9.30	10.48	206.2	229.3
	$N_{60}K_{160}$	1.220	1.130	4.437	4.452	12.83	13.04	248.1	250.0	8.60	10.40	214.7	237.5
	$N_{120}K_0$	1.287	1.315	5.173	5.512	13.14	14.07	260.5	262.2	9.97	11.99	232.0	245.0
	$N_{120}K_{80}$	1.407	1.343	5.417	5.475	13.71	14.63	258.9	260.8	9.99	11.70	226.5	240.3
	$N_{120}K_{160}$	1.331	1.360	5.125	5.451	13.47	14.53	263.9	263.3	9.71	13.13	231.8	249.3
	F value[b]	21.56		31.71		174.46		6.62		32.17		17.12	
	LSD	0.1842		0.4851		0.6365		14.327		0.9768		14.652	
	df (i, j)[c]	(17, 36)		(17, 36)		(17, 36)		(17, 36)		(17, 36)		(17, 36)	
Short rains	N_0K_0	0.480	0.576	2.668	2.789	6.31	6.77	175.9	192.6	3.643	4.136	156.9	171.8
	N_0K_{80}	0.583	0.665	2.659	2.936	6.45	6.90	178.2	202.2	4.640	5.380	164.1	184.4
	N_0K_{160}	0.643	0.737	2.837	3.127	6.89	7.28	180.2	201.5	4.119	4.745	170.5	182.0
	$N_{60}K_0$	0.939	0.904	3.581	3.765	9.76	10.82	195.9	207.7	6.415	7.367	174.1	204.0
	$N_{60}K_{80}$	1.060	1.044	3.812	3.613	9.91	10.88	213.8	229.4	7.003	7.679	181.7	205.3
	$N_{60}K_{160}$	0.993	1.027	3.983	4.057	10.45	10.92	208.5	225.0	7.124	8.648	186.2	209.7
	$N_{120}K_0$	1.080	1.133	4.623	5.056	12.24	12.89	213.4	225.3	7.811	9.565	201.6	212.9
	$N_{120}K_{80}$	1.291	1.177	5.051	4.800	11.91	12.84	226.2	218.1	8.116	9.513	213.9	227.1
	$N_{120}K_{160}$	1.295	1.237	4.971	4.959	13.08	13.23	221.3	231.8	8.664	9.685	215.5	234.5
	F value	8.29		13.68		127.55		5.75		27.9		15.6	
	LSD	0.2606		0.6885		0.6485		21.379		1.0966		16.369	
	df (i, j)	(17, 36)		(17, 36)		(17, 36)		(17, 36)		(17, 36)		(17, 36)	

[a] For each variable and DAP, the 18 treatments are presented in two different groups (IFP and ITP) to allow comparison between IFP and ITP plots. IFP, insecticide-free plot; ITP, insecticide-treated plot with furadan.

[b] For each variable, *P* value of *F* was = 0.0001 (one-way ANOVA).

[c] Degrees of freedom in the F test, where i and j are df of treatments and error, respectively.

Statistical Analyses. The analyses were done separately for each cropping season. Differences in plant height, total dry matter, grain weight, and damage variables were analyzed by analysis of variance (ANOVA) by using the general linear model (GLM) procedure of SAS (SAS Institute 1997). Least significant difference (LSD) values at the 5% significant level were computed for plant growth and yield variables. The variation in *B. fusca* abundance over sampling days was analyzed by ANOVA, by using the mixed model procedure of SAS with repeated measures (SAS Institute 1997). The treatments were considered as fixed effects, whereas plants within replications were considered as a random factor. Least squares means (LSM) were separated using the *t*-test. The significance level was set at $P = 0.05$. Whenever possible, the 18 means of each variable are presented in two different groups to allow comparison between infested and treated plots (IFP versus ITP), by using the LSD estimated for the 18 treatments.

Maize grain yield losses due to stemborers were assessed on an area basis as follows:

$$100 \times (Y_i - Y_t) / Y_i$$

where Y_i and Y_t are the mean yields of protected and nonprotected plots, respectively.

The total gross benefit, net benefit and the marginal rate of return were calculated for each treatment using the average crop yield calculated over seasons and both years. The following prices were taken for calculating the total gross benefit and net benefit: maize, US\$0.2778 kg^{-1}; urea, = US\$0.4259 kg^{-1}; KCl, US\$0.4259 kg^{-1}; superphosphate [$Ca3(PO_4)_2 + 2H_2SO_4 \rightarrow Ca(H_2PO_4)_2 + 2CaSO_4$], US\$0.4815 kg^{-1}; and carbofuran, US\$4.6296 kg^{-1}, with US\$1 = 540 FCFA.

The marginal rate of return (MRR) is a return from one extra unit of output or the addition to gross return from using one extra unit of input. For a given treatment T_i, the MRR is calculated as follows:

$$MRR = (NB_{Ti} - NB_{T0}) / CI_{Ti}$$

where T_0 is the control treatment (N_0K_0 without insecticide application), and NB and CI are the net benefit and total costs of inputs related to treatment T_i, respectively.

Marginal analysis in partial budgeting is a method of organizing data and information about the costs and benefits of various alternative treatments/technologies (CIMMYT 1988, Alimi and Manyong 2000). Marginal analysis is the comparison of change in total cost with change in net benefit. This comparison reveals the increase in benefits associated with a given increase in cost for using a technology. The calculation is based on a unit area (1-ha farm size). The relevant costs used in marginal rate of return are costs that vary

Table 2. Means of N and K content (%) in the stem dry matter at 63 DAP and at harvest of maize

Sampling period	Fertilizer dose[a]	Long rainy season				Short rainy season			
		% N		% K		% N		% K	
		IFP	ITP	IFP	ITP	IFP	ITP	IFP	ITP
63 DAP	N_0K_0	0.458	0.519	1.253	1.356	0.517	0.532	1.415	1.417
	N_0K_{80}	0.476	0.506	2.320	2.144	0.535	0.557	2.114	2.100
	N_0K_{160}	0.494	0.521	2.722	2.753	0.521	0.567	2.467	2.495
	$N_{60}K_0$	0.679	0.675	1.154	1.469	0.612	0.695	1.054	1.114
	$N_{60}K_{80}$	0.659	0.703	1.717	1.941	0.626	0.644	1.660	1.770
	$N_{60}K_{160}$	0.723	0.677	2.399	2.470	0.639	0.651	2.267	2.390
	$N_{120}K_0$	0.865	0.968	1.336	1.283	0.842	0.880	1.310	1.207
	$N_{120}K_{80}$	0.835	0.949	1.739	1.942	0.800	0.873	1.666	1.834
	$N_{120}K_{160}$	0.859	0.873	2.439	2.319	0.879	0.952	2.563	2.505
	F value	11.74		7.24		26.59		5.54	
	P value	0.001		0.001		0.0001		0.001	
	LSD	0.1421		0.7026		0.0813		0.638	
	df (i, j)	(17, 36)		(17, 36)		(17, 36)		(17, 36)	
At harvest	N_0K_0	0.247	0.267	0.965	1.091	0.280	0.275	1.094	1.125
	N_0K_{80}	0.222	0.254	1.454	1.449	0.251	0.281	1.639	1.599
	N_0K_{160}	0.235	0.267	1.646	1.777	0.250	0.290	1.764	1.936
	$N_{60}K_0$	0.332	0.323	1.021	1.144	0.302	0.332	0.957	1.179
	$N_{60}K_{80}$	0.335	0.344	1.356	1.464	0.324	0.315	1.325	1.345
	$N_{60}K_{160}$	0.313	0.330	1.608	1.733	0.298	0.319	1.527	1.683
	$N_{120}K_0$	0.477	0.451	0.981	1.108	0.467	0.425	0.965	1.047
	$N_{120}K_{80}$	0.456	0.471	1.350	1.527	0.436	0.442	1.293	1.439
	$N_{120}K_{160}$	0.462	0.437	1.470	1.583	0.478	0.476	1.518	1.717
	F value	22.4		2.76		6.47		2.58	
	P value	0.0001		0.0051		0.0001		0.0084	
	LSD	0.0547		0.4524		0.0924		0.5266	
	df (i, j)	(17, 36)		(17, 36)		(17, 36)		(17, 36)	

[a] For each variable, the 18 treatments are presented in two different groups (IFP and ITP) to allow comparison between IFP and ITP plots. IFP, insecticide-free plot; ITP, insecticide-treated plot with furadan.

between alternative treatments, which for this study are pesticide and fertilizer cost, and their application (labor) cost. These costs are added together to obtain total cost of inputs that vary (CI), which is subtracted from the total gross benefits to give net benefit. The labor cost was estimated at 1.8518 $ per person-day. Correlation coefficients were calculated using data pooled across seasons and treatments.

Results

Effect of N and K on Plant Growth Variables. The average plant height at harvest and total dry matter at different days after planting and at harvest were not significantly affected by K fertilizer. However, they significantly increased with the increasing N dosages applied (Table 1).

During the long and short rainy season of 2003 and 2004, plants were shorter in the 0 kg ha^{-1} than the 60–120 kg ha^{-1} treatments, but differences were not significant among the latter (Table 1). During both 2003 and 2004, plants grown during the long rainy season were generally taller by, respectively, 16.2 and 10.5% than plants grown during the short rainy seasons.

Across seasons and days after planting the dry matter (DM) production increased with N fertilizer, and the values were twofold higher in plots with 120 kg N ha^{-1} compared with plots with 0 kg N ha^{-1} (Table 1). The total DM production at harvest was positively correlated to that at 42 and 63 DAP (r = 0.98 and 0.96 for 42 and 63 DAP, respectively, with P = 0.0001).

Effects of Mineral Fertilization on Nutrient Status of Maize. N and K concentrations in DM varied significantly among treatments (Table 2). The nutrients concentrations at 63 d after planting were positively correlated with the total amount of fertilizer applied to the soil (r = 0.96 and 0.90 for N and K, respectively, with P = 0.0001). N and K concentrations were 2 and 1.5 times lower, respectively, at harvest compared with 63 d after planting (Table 2). The differences between insecticide-free plot and treated plot were not significant. The total DM produced at harvest was strongly related to the N content of the plant at 63 d after planting (r = 0.90, P = 0.001), but no relationship was found for K (Fig. 1).

Effects of Mineral Fertilization on Abundance of Stemborers. In plots with the same level of N fertilizer, increasing doses of K fertilizer had no effect on borer infestations. But average number of borer per plant varied significantly with N level applied (Table 3). During the long and short season of 2003, however, the differences in borers abundance were only significant at 42 DAP. Thereafter, the average borer per plant significantly decreased with days after planting (Table 3). During the long and short rainy season of 2004, difference in numbers of borer per plant were significant at 42 and 56 DAP (Table 3), but no difference in borer abundance was found between plots with 60 and 120 kg N ha^{-1}, and their average was 2.5-fold higher

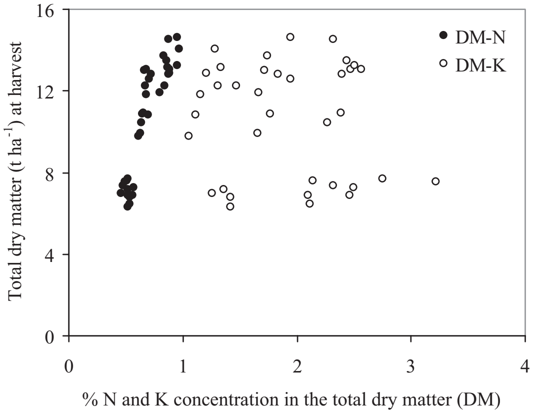

Fig. 1. Relationship between nutrient concentration in the dry matter at 63 d after planting and total dry matter produced at harvest. DM-N and DM-K, dry matter related to N and K, respectively.

compared with 0 kg N ha^{-1}. At harvest, larvae were collected on both insecticide-free plots and treated plots, but borer abundance was significantly lower on insecticide-treated plots, during both years (Table 3).

Effects of Mineral Fertilization on Plant Damage Variables and Yield Loss. As for plant growth variables and borer abundance, application of K fertilizer did not significantly affect plant damage variables (percentage of plants infested, percentage of dead-heart, percentage of plant tunneling, and % percentage of cob damage) (Table 4). However, percentages of plant infested and plant tunneling varied significantly with N applied (Table 4); across seasons; the lowest and highest percentage of plants infested and plant tunneling were found with 0 and 120 kg N ha^{-1}, respectively. With each additional application of 60 kg N ha^{-1}, the percentage of plant infested increased 1.3–1.7-fold compared with 0 kg N ha^{-1}. During the long rainy season of 2003, no significant difference in plant tunneling was found between plots with 0 and 60 kg N ha^{-1}. By contrast, no significant difference in stem tunneling was found between plots with 60 and 120 kg N ha^{-1}, in the short rainy season of 2003. Application of 60 and 120 kg N ha^{-1} increased plant tunneling by 1.8 and 2.2 times compared with 0 kg N ha^{-1}, in the, respectively, long and short rainy season of 2004.

Across seasons, percentage dead hearts and cob damage did not significantly (Table 4) differ among treatments and their average ranged between 1.3–4.0 and 1.1–6.0%, respectively. There was no difference in percentage of cob damage between insecticide-free and insecticide-treated plots. However, the amount of plant tunneled in the insecticide-treated plot was significantly lower compared with insecticide-free plot (Table 4).

Across seasons, maize grain yields increased linearly threefold from 0 to 120 kg N ha^{-1}. Depending on the N dosage, grain yields in the insecticide-treated plot were 1.0–1.7 times higher than in the untreated plots (Table 5). Consequently, grain yield losses decreased significantly (Table 5) from 0 to 120 kg N ha^{-1}.

Table 3. Effects of N and K fertilizer combination on the abundance of *B. fusca* on maize planted during the long and short rainy season

Yr	Fertilizer dose	Long rainy season					Short rainy season				
		42 DAP	56 DAP	70 DAP	Harvest		42 DAP	56 DAP	70 DAP	Harvest	
					IFP	ITP				IFP	ITP
2003	N_0K_0	1.39 b	1.03	0.25	0.39	0.14	1.94 b	1.36	0.89	0.47	0.11
	N_0K_{80}	1.36 b	0.94	0.28	0.33	0.11	1.83 b	1.22	1.08	0.42	0.11
	N_0K_{160}	1.31 b	0.96	0.28	0.31	0.08	1.53 b	1.19	1.06	0.39	0.06
	$N_{60}K_0$	3.03 a	1.33	0.45	0.47	0.22	4.25 a	1.83	1.11	0.50	0.06
	$N_{60}K_{80}$	2.89 a	1.25	0.44	0.47	0.25	4.17 a	1.56	1.11	0.53	0.14
	$N_{60}K_{160}$	2.86 a	1.22	0.39	0.44	0.19	4.08 a	1.64	0.86	0.50	0.08
	$N_{120}K_0$	3.22 a	1.41	0.42	0.53	0.22	4.58 a	2.08	1.08	0.58	0.11
	$N_{120}K_{80}$	3.11 a	1.36	0.45	0.50	0.19	4.50 a	1.86	1.19	0.56	0.08
	$N_{120}K_{160}$	3.14 a	1.33	0.39	0.47	0.17	4.50 a	2.02	1.11	0.50	0.11
	P value	0.001	0.308	0.811	0.0001		0.001	0.110	0.992	0.0001	
	SE	0.19	0.18	0.11	0.07		0.39	0.33	0.26	0.09	
	df (i, j)	(8, 18)	(8, 18)	(8, 18)	(17, 36)		(8, 18)	(8, 18)	(8, 18)	(17, 36)	
2004	N_0K_0	1.58 b	0.81 b	0.69	0.42	0.14	2.11 b	1.50 b	1.19	0.69	0.17
	N_0K_{80}	1.55 b	0.78 b	0.67	0.39	0.08	2.03 b	1.47 b	1.25	0.72	0.11
	N_0K_{160}	1.47 b	0.69 b	0.64	0.36	0.08	1.94 b	1.42 b	1.22	0.67	0.14
	$N_{60}K_0$	3.58 a	1.11 a	0.81	0.44	0.06	4.78 a	1.92 a	1.28	0.75	0.17
	$N_{60}K_{80}$	3.55 a	0.98 a	0.83	0.47	0.14	4.86 a	1.89 a	1.28	0.72	0.22
	$N_{60}K_{160}$	3.50 a	1.00 a	0.75	0.47	0.11	4.64 a	1.88 a	1.25	0.69	0.17
	$N_{120}K_0$	4.00 a	1.22 a	0.89	0.56	0.17	5.28 a	2.17 a	1.22	0.86	0.22
	$N_{120}K_{80}$	4.03 a	1.11 a	0.86	0.50	0.11	5.20 a	2.19 a	1.25	0.81	0.14
	$N_{120}K_{160}$	4.11 a	1.17 a	0.80	0.47	0.11	5.22 a	2.14 a	1.22	0.83	0.17
	P value	0.001	0.003	0.464	0.0001		0.001	0.001	1	<0.0001	
	SE	0.14	0.09	0.09	0.07		0.27	0.11	0.1	0.07	
	df (i, j)	(8, 18)	(8, 18)	(8, 18)	(17, 36)		(8, 18)	(8, 18)	(8, 18)	(17, 36)	

Within column, means followed by the same lowercase letter are not significantly different at $P < 0.05$ (*t*-test). IFP, insecticide-free plot; ITP, insecticide-treated plot with furadan.

Table 4. Effects of N and K combination on the damage caused by *B. fusca* to maize

Season	Fertilizer dose	2003						2004					
		% plants infested	% dead-heart	Plant tunneling		% cob damage		% plants infested	% dead-heart	Plant tunneling		% cob damage	
				IFP	ITP	IFP	ITP			IFP	ITP	IFP	ITP
Long rains	N_0K_0	20.0 d	2.3	19.5 b	2.7	4.0	2.8	26.5 d	2.0	16.7 c	3.5	6.0	2.9
	N_0K_{80}	22.0 cd	1.7	16.5 b	2.7	3.5	1.3	27.2 cd	1.7	17.7 c	2.8	4.9	2.7
	N_0K_{160}	23.5 cd	1.7	17.2 b	4.0	1.3	1.6	26.4 d	1.3	16.5 c	2.4	3.9	2.1
	$N_{60}K_0$	32.5 cb	2.0	23.4 b	3.2	2.9	2.0	32.7 bc	2.0	31.3 b	3.0	3.8	3.9
	$N_{60}K_{80}$	37.8 ab	2.0	21.6 b	3.8	3.2	1.9	35.3 b	1.7	32.0 b	3.7	4.0	3.1
	$N_{60}K_{160}$	34.5 ab	1.7	21.5 b	5.2	1.8	1.4	32.3 bc	2.0	31.8 b	2.4	5.3	4.1
	$N_{120}K_0$	44.2 a	2.7	32.0 a	4.8	1.9	1.3	47.7 a	1.7	35.8 aA	3.3	5.6	2.6
	$N_{120}K_{80}$	42.7 a	2.0	30.5 a	5.1	2.1	1.1	46.5 a	2.0	36.3 aA	3.5	3.9	2.8
	$N_{120}K_{160}$	43.5 a	2.3	31.8 a	3.5	1.6	1.3	47.8 a	2.3	38.0 a	3.3	4.8	2.3
	P value	0.001	0.896	0.001		0.732		0.001	0.977	0.001		0.859	
	SE	3.92	0.54	1.84		0.99		2.01	0.60	1.42		1.48	
	d.f. (i, j)	(8, 18)	(8, 18)	(17, 36)		(17, 36)		(8, 18)	(8, 18)	(17, 36)		(17, 36)	
Short rains	N_0K_0	32.3 c	2.0	22.0 b	3.9	5.5	2.9	30.2 b	3.0	19.7 c	5.1	3.9	3.5
	N_0K_{80}	33.3 c	2.3	27.6 b	2.7	2.0	2.5	34.2 b	2.3	20.3 c	5.0	3.2	4.0
	N_0K_{160}	32.8 c	2.0	25.2 b	2.0	1.2	2.6	30.0 b	2.0	17.2 c	3.8	2.4	3.5
	$N_{60}K_0$	42.3 b	2.7	48.7 a	2.8	5.0	2.1	52.7 a	2.7	35.4 b	4.5	2.1	3.4
	$N_{60}K_{80}$	44.2 b	2.7	53.4 a	5.9	1.7	3.0	55.3 a	2.7	32.1 b	6.6	2.9	4.4
	$N_{60}K_{160}$	40.5 b	3.3	55.3 a	3.2	3.0	3.0	55.2 a	2.3	34.3 b	4.1	2.9	3.4
	$N_{120}K_0$	57.3 a	2.7	59.8 a	2.7	3.6	1.7	60.2 a	2.3	44.1 a	4.0	2.2	3.9
	$N_{120}K_{80}$	52.5 a	4.0	62.2 a	5.6	1.8	2.3	58.8 a	3.0	41.2 a	6.4	2.7	3.6
	$N_{120}K_{160}$	55.0 a	3.0	66.4 a	3.9	1.4	1.4	61.0 a	2.7	42.8 a	4.0	2.4	3.9
	P value	0.001	0.715	0.001		0.555		0.001	0.993	0.001		0.93	
	SE	3.63	0.79	6.99		1.22		4.51	0.82	1.89		0.96	
	df (i, j)	(8, 18)	(8, 18)	(17, 36)		(17, 36)		(8, 18)	(8, 18)	(17, 36)		(17, 36)	

Within column, means followed by the same lowercase letter are not significantly different at $P < 0.05$ (*t*-test). IFP, insecticide-free plot; ITP, insecticide-treated plot with furadan.

Comparative Advantage and Efficiency of Maize Production Systems by Using Mineral Fertilizer and Insecticide. In both insecticide-free and -treated plots, application of 80–160 kg K ha^{-1} did not significantly (Table 6) increase the yield, but increased the inputs costs by 34.8 and 62.9%, respectively (Table 6). The highest total gross benefit and cost of inputs were found with fertilizer combination of 120 kg N ha^{-1} + 160 kg K ha^{-1} ($N_{120}K_{160}$), whereas the treatment $N_{120}K_0$ earned the highest net benefits. By contrast, the highest marginal rate of return was found with $N_{60}K_0$ (2.49 and 1.80 for insecticide-free and treated plot, respectively).

Discussion

In the field, fertilizer applications might affect pests and diseases directly via the nutritional status of the plant (Schulthess et al. 1997b, Denké et al. 2000) and indirectly by producing dense stands and alterations in light interception and humidity within a crop (Marschner 2002). In the current study, nutrient concentrations in maize dry matter tended to increase with N and K dosages applied corroborating results by Sétamou et al. (1993), and Jiang and Schulthess (2005) from fertilizer trials, and by Chabi-Olaye et al. (2005b) from trials where a maize crop was rotated with leguminous cover or grain crops.

In the current study, application of K had no effect on borers. Life table studies by Denké et al. (2000), working with the noctuid *Sesamia calamistis* Hampson and *E. saccharina,* showed that K mainly affected fecundity of borers and to a much lesser extend survival of immatures, suggesting that the effect of K would be on the next generation mainly. An increase in plant N significantly increased survival of borers, corroborating results by Sétamou et al. (1993), Chabi-Olaye et al. (2006b), Mgoo et al. (2006), and Wale et al. (2006). As shown by Chabi-Olaye et al. (2005c), the effect of N on *B. fusca* infestations decreased with age of the plant until tasseling, when no difference in borer numbers was found between fertilized and nonfertilized plots. This suggests higher disappearance rates of larvae in plots with higher N content. Differences in disappearance might have been due to both increased plant-induced mortality and density dependent migration of larvae on plants with high leaf and stem N (Chabi-Olaye et al., 2005b). Also, as maize plants grow older, N is increasingly translocated from stems and leaves to grains (Bonato et al. 1999); thus, the effect of stem nitrogen on development and survival of borers feeding in the stem decreased with age of the plant and, thus, after 56 DAP the differences in pest densities were not significant anymore. Still, the present experimental setup does not allow for determining whether the differences in pest densities at an early plant growth stage were due to differences in mortality or migration. However, a laboratory experiment by Jiang and Schulthess (2005), on the survivorship of *Chilo partellus* (Swinhoe) (Lepidoptera; Crambidae) larvae in plants subjected to different N fertilizer levels showed that the percentage of larvae surviving the first 2 wk increased significantly with the N dosage applied. In addition, the probability of a dispersing

Table 5. Effects of N and K fertilizer combination on the yield losses caused by *B. fusca* to maize

Yr	Fertilizer dose[a]	Long rainy season: Yield (mg ha^{-1}) IFP	Long rainy season: Yield (mg ha^{-1}) ITP	Long rainy season: % yield loss	Short rainy season: Yield (mg ha^{-1}) IFP	Short rainy season: Yield (mg ha^{-1}) ITP	Short rainy season: % yield loss
2003	N_0K_0	1.303	1.693	23.0	0.910	1.640	44.5
	N_0K_{80}	1.487	1.787	16.8	1.043	1.720	39.3
	N_0K_{160}	1.573	1.817	13.4	1.077	1.733	37.9
	$N_{60}K_0$	3.830	3.963	3.4	3.447	3.753	8.2
	$N_{60}K_{80}$	3.900	4.010	2.7	3.457	3.763	8.1
	$N_{60}K_{160}$	3.937	4.047	2.7	3.507	3.763	6.8
	$N_{120}K_0$	4.460	4.520	1.3	4.133	4.240	4.9
	$N_{120}K_{80}$	4.507	4.587	1.7	4.207	4.253	1.1
	$N_{120}K_{160}$	4.490	4.577	1.9	4.217	4.247	0.7
	F value	461.36			721.44		
	LSD	0.174			0.138		
	df (i, j)	(17, 36)			(17, 36)		
2004	N_0K_0	1.223	1.767	30.8	0.960	1.620	40.7
	N_0K_{80}	1.300	1.817	28.4	1.003	1.717	41.6
	N_0K_{160}	1.323	1.840	28.1	1.013	1.727	41.3
	$N_{60}K_0$	3.637	3.703	1.8	3.340	3.447	3.1
	$N_{60}K_{80}$	3.680	3.763	2.2	3.383	3.470	2.5
	$N_{60}K_{160}$	3.810	3.833	0.6	3.390	3.513	3.5
	$N_{120}K_0$	4.390	4.443	1.2	3.767	3.917	3.8
	$N_{120}K_{80}$	4.410	4.467	1.3	3.833	3.933	2.5
	$N_{120}K_{160}$	4.413	4.523	2.4	3.850	3.967	2.9
	F value[b]	296.81			184.38		
	LSD	0.213			0.244		
	df (i, j)	(17, 36)			(17, 36)		

[a] For each variable, the 18 treatments are presented in two different groups (IFP and ITP) to allow comparison between IFP and ITP plots. % yield loss = 100 × (ITP − IFP)/ITP.
[b] For each variable, *P* value of *F* was equal to 0.0001.

larva to land on a plant of the same fertilizer treatment is high which would compound the effect of mortality and migration.

Horst and Härdter (1994), investigating the causal factors contributing to the differences in production between maize in rotation with cowpea, *Vigna unguiculata* (L.) Walp., and sequential cropping of maize, found that N was the most important factor explaining yield differences between the two cropping systems. In the current study, maize yield losses decreased with an increase in N in spite of higher pest loads and tunnel damage, again confirming results by Sétamou et al. (1995) and Mgoo et al. (2006) who hypothesized that an increased nutritional status of the plants enhanced both borer survival and fitness, and plant vigor, but with a net benefit for the plant.

Table 6. Economic analysis of maize production systems by using mineral fertilizer and insecticide application in the humid forest of Cameroon (yield data pooled across four seasons)

Fertilizer dose	Yield (kg/ha)	Total gross benefit	Cost of inputs	Net benefit	Rate of return
IFP					
N_0K_0	1.0990	305.2778	182.3793	122.8984	N.A.[a]
N_0K_{80}	1.2083	335.6250	266.8763	68.7487	−0.20
N_0K_{160}	1.2465	346.2500	335.2981	10.9519	−0.33
$N_{60}K_0$	3.5635	989.8611	248.6516	741.2095	2.49
$N_{60}K_{80}$	3.6050	1001.3889	333.1486	668.2403	1.64
$N_{60}K_{160}$	3.6610	1016.9444	401.5704	615.3740	1.23
$N_{120}K_0$	4.1875	1163.1944	309.5656	853.6289	2.36
$N_{120}K_{80}$	4.2393	1177.5694	394.0625	783.5069	1.68
$N_{120}K_{160}$	4.2425	1178.4722	462.4843	715.9879	1.28
ITP					
N_0K_0	1.6800	466.6667	258.2538	208.4128	0.33
N_0K_{80}	1.7603	488.9583	342.7508	146.2076	0.07
N_0K_{160}	1.7793	494.2361	411.1726	83.0635	−0.10
$N_{60}K_0$	3.7165	1032.3611	324.5261	707.8350	1.80
$N_{60}K_{80}$	3.7515	1042.0833	409.0231	633.0603	1.25
$N_{60}K_{160}$	3.7890	1052.5000	477.4449	575.0551	0.95
$N_{120}K_0$	4.2800	1188.8889	385.4400	803.4488	1.77
$N_{120}K_{80}$	4.3100	1197.2222	469.9370	727.2852	1.29
$N_{120}K_{160}$	4.3285	1202.3611	538.3588	664.0023	1.01

[a] N.A., not applicable.

Also, percentage of dead-hearts tended to decrease with N, but the plant losses were generally low. As shown by Harris (1962), if soil fertility is not a limiting factor and stand loss is not too high, adequate compensation for loss of stand may be achieved in maize.

Overall, application of K would not benefit the farmers under the prevailing soil conditions because it increased inputs costs by >34%, and, thus, reduced profits. By contrast, N fertilizer gave returns to investment much higher than the cost of capital at current inputs prices. Thus, N could be a strong component of maize integrated pest management (IPM). However, our findings showed that dosages higher than 60 kg N ha^{-1} are not profitable as their marginal rate of returns were lower compared with that of 60 kg N ha^{-1}. Also, if N fertilizer is applied at rates greater than required for maximum yield, plant biomass and long-term soil organic C increase (Raun et al. 1998), but nitrogen use efficiency decreases. Increasing soil organic C, when high N rates are used, could lead to increase in N losses via denitrification (Aulakh et al. 1984). The best solution for reducing N fertilizer needs lies in finding more efficient ways to fertilize crops (Michael et al. 1960, Marschner 2002). Organic farming methods that include legume cultivation and crop rotation are highly efficient (Chabi-Olaye et al. 2005b). In the current study, a higher efficiency was achieved by splitting higher doses of N fertilizer and applying the last dosage at tasseling. Thus, highest grain yields were obtained with 120 kg N ha^{-1}.

The present findings confirm reports by Sétamou et al. (1995), Chabi-Olaye et al. (2005b), and Mgoo et al. (2006) that an increased nutritional status of the plants enhanced both borer fitness and plant vigor, but with a net benefit for the plants. Thus maintaining soil fertility or applying practices that increase N use efficiency in maize production are important components of IPM of *B. fusca.* Furthermore, as also shown by Mgoo et al. (2006), the benefits from insecticide treatments decreased with increasing fertilizer dosage, suggesting that using insecticides is not profitable under high fertility conditions.

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