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Biological and physical constraints on maize production in the Humid Forest and Western Highlands of Cameroon

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Abstract

The aim was to identify biological and physical factors responsible for reducing maize yield in Cameroon. Two surveys were conducted in 137 fields in two agroecological zones in 1995–1997. In the Humid Forest (HF), *Bipolaris maydis, Stenocarpella macrospora, Puccinia polysora, Rhizoctonia solani* and soil fertility were factors that reduced maize production in 1995 and 1996. In the Western Highlands (WHL), *Cercospora zeae-maydis*, and the interaction between soil fertility and maize variety were the most important constraints to maize production in 1996. In 1997, *C. zeae-maydis, S. macrospora*, physiological spot and stem borer damage (*Busseola fusca*) were negatively related to ear weight. The combination of these biological factors (diseases and insects), and the physical parameter of soil fertility were responsible for reducing maize yield in these selected benchmarks of Cameroon. Maximum potential yield reductions were estimated at 68% due to *B. maydis* and 46% due to *S. macrospora,* respectively, in the HF in 1995. In 1996, maximum potential yield reductions in the HF were estimated at 34%, 41% and 30% due to *S. macrospora*, *P. polysora* and *R. solani,* respectively. In the WHL, *C. zeae-maydis* had the potential to cause a yield reduction of 79% in 1996. In the WHL in 1997, the interaction between *C. zeae-maydis* and *B. fusca*, stem diseases and the physiological spot caused potential reductions of 52%, 34% and 39%, respectively.

Introduction

Maize (*Zea mays* L.) production has become a lucrative activity in Cameroon since the devaluation of the 'Communauté Financiere Africaine' (CFA) currency. The demand for maize from the feed industry, breweries, small livestock producers, and local consumers has increased markedly. The hardship due to the poor economic situation has prompted civil servants, and many unemployed youths into agricultural activities, with maize as the commodity of interest. This crop is cultivated in all five ecological zones of the country varying from Humid Forest (HF) to Soudano–Sahelian zones. In the Western Highlands (WHL) zone, maize production is intensive because of the dense population (230 inhabitants/km^2), which is increasing at a rate of 3.2% annually, resulting in dwindling farm size (Ayuk-Takem, 1996; Ayuk-Takem et al., 1982). In these areas, continuous cropping without a fallow period results in a decline in soil fertility and disease inoculum build-up. The area under maize cultivation increased from 320,000 ha in 1991 to 700,000 ha in 1997 (MINAGRI, 1996; NCRE, 1994; Ngoko, 1994). The average yield (1.8 t/ha) has remained constant for many years, although production has increased from 500,000 MT in 1991 to over 800,000 MT in

1997 (Ayuk-Takem, 1996; Ayuk-Takem et al., 1982; MINAGRI, 1996). Production could be higher if factors such as soil infertility, poor managerial skills, the high costs of supplies, environmental stresses, pests and diseases were not constraining the potential yield of improved varieties (COCA, CHC201, CHH105; NCRE, 1994).

Losses reported due to pests and diseases range from 20% to 50% (Cardwell et al., 1997). Several maize diseases have been reported in the country though the findings did not relate the prevalence of diseases to yield loss (Ngoko, 1994; Timti, 1980). However, losses up to 90% were reported by the extension service in some fields in Bali and other parts of the country due to grey leaf spot (*Cercospora zeae-maydis* Tehon and Daniels) in the 1995–1996 cropping season (MINAGRI, 1996). Timti (1980) reported that foliar diseases were responsible for the reduction of maize production though the loss was not measured. Cardwell et al. (1997) demonstrated ca. 600 kg/ha yield loss attributed to the combined effect of foliar and stem diseases, and insect damage. Detailed information on the relationships between pests, diseases and abiotic factors and yield are not known in much of Cameroon.

The objectives of this study were to identify and quantify the biological and physical constraints affecting maize yield in two ecological zones of Cameroon.

Materials and methods

Field surveys

Two field surveys were conducted in four villages (Kometou, Ngat, Etoud and Mvoutessi) in the HF in 1995 and in three villages (Kometou, Ngat and Etoud) in 1996. In 1996 and 1997, two surveys were conducted in three villages (Bamunka, Bali and Njinikom) of the WHL. In all surveys, from nine to twelve farmers per village (137 farms total) were interviewed and their fields visited. A plant pathologist and an entomologist carried out the surveys.

On each farm, 15 plants were chosen at random and assessed for growth and damage variables. The crops were mostly between the grain fill and maturity growth stages. In all fields, data were recorded on: cropping system; organic matter (1–3 with 1 = low, 3 = high); soil texture (1–3 scale: 1 = sandy and 3 = clay); soil fertility (on a 1–3 scale: 1 = poor soil with weak plants and 3 = rich soil with vigorous plants); weediness (1–3 scale: 1 = clean and 3 = very weedy field); crop stage on a 1–9 scale: (1 = emergence, 5 = silking, 7 = milk stage and 8 = hard dough and 9 = physiological maturity); variety used (local = 0 and improved = 1); weight of cobs without husk; ear length and width; and percentage grain fill on a 0–100% scale (0 = cob without grain, 100 = cob full of grain to the tip).

The most important diseases were identified and assessed for severity on a 0–4 scale: (0 = no symptoms and 4 = severe plant damage due to presence of the pathogen); stem infections on a 0–4 scale: (0 = no symptoms and 4 = >90% of the stem damaged by fungi; and the percent of total leaf area infected (LAI) with diseases calculated according to James (1971). Identity of the highland blight (*Exserohilum turcicum* (Passerini) Leonard and Suggs) and lowland blight (*Bipolaris maydis* (Nisikado and Miyake) Shoemaker) were confirmed by incubating leaf samples on PDA (Shurtleff, 1986). Diplodia leaf spot (*Stenocarpella macrospora* (Earle) Sutton = *Diplodia macrospora* Earle), common smut (*Ustilago maydis* DC), head smut (*Sporisorium reilianum* (Kühn) Langdon and Fullerton = *Sphacelotheca reiliana* (Kühn) Clint), Phaeosphaeria leaf spot (*Phaeosphaeria maydis* (P. Henn) Rane, Payak and Renfro), highland rust (*Puccinia sorghi* Schw.), lowland rust (*Puccinia polysora* Underw.), brown spot (*Physoderma maydis* Miyabe) and sheath blight (*Rhizoctonia solani* Kühn) were identified based on symptoms (Shurtleff, 1986). Grey leaf spot was identified according to Latterell and Rossi (1983).

Stem borer damage was assessed only in 1997. The predominant taxon, *Busseola fusca* Fuller (Lepidoptera: Noctuidae) was identified according to Van Rensburg et al. (1987). No other pest damage was apparent or considered. Tunnel length (cm) was measured and the number of holes and internodes bored on the stem were counted. Other borer species were noted and only stem borer damage was assessed.

Statistical analysis

Analysis was performed using SAS 6.12 for Windows. Means of each variable were computed by field. Pearson correlation analysis was used to investigate any significant interactions among variables. Backward linear regression was performed using the variables that were significantly related in the correlation analysis. Ear weight (in all years and zones) and arcsine transformed percentage grain fill (in the WHL in 1996 and 1997) were used respectively as the dependant variables and physical and biological factors as the independent variables. Factors that were removed by the regression equation were not used for the analysis of the results though they were recorded.

Maximum potential yield (Y_{max}) was calculated using the maxima of significant positive variables while holding disease variables at their minima. Regional mean yields (Y_{mean}) were estimated using field means of significant positive variables in the regression equation per ecological zone and per year (Table 1). Yield when a pathogen or pest was present (Y_P) was calculated using pathogen (P) set to the maximal value while, all other factors are held at the mean levels, or, in the case of other constraints, held at the minimal levels. Reduction in yield relative to the maximum potential ear weight per disease causal agent was calculated per disease (or pest) by the formula $Y_{LP} = [1 - (Y_P/Y_{max})]100$ (modified from Cardwell et al., 1997). Data were analyzed separately for each year and each zone. Similar formulae were used to determine the effects of variables on percentage grain fill.

Results

Humid Forest 1995

Pearson correlation analysis (data not shown) showed that several biotic and abiotic factors were significantly related. Stem diameter and *B. maydis* infection were negatively related to *E. turcicum* ($P = 0.0001$ for both). *Bipolaris maydis* and *P. polysora* were strongly negatively related ($P = 0.0001$) while *S. macrospora* was inversely related to *R. solani* ($P = 0.04$), but positively related to stem diameter ($P = 0.001$). Increased organic matter content of the soil had a negative effect on *E. turcicum* ($P = 0.005$) and *R. solani* ($P = 0.004$), and increased stem diameter ($P = 0.0001$). In all, there were 31 significant interactions among 14 variables on 615 plants. These primary factors and interactions were used as variables in the stepwise backward regression analysis.

Backward regression analysis demonstrated which variables had a significant effect on ear weight in 1995 (Table 1). Ear weight increased with crop growth stage, but there was a crop growth stage by soil

Table 1. Factors affecting ear weight as calculated by a stepwise backward regression analysis, maxima (Max), mean and minima (Min) in the HF zone of Cameroon in 1995 ($R^2 = 0.10$; $P = 0.0001$; $N = 615$)

Variable	Regression coefficient	*t* value	$P > t$	Max	Mean	Min
Intercept	109.3	12.9	0.004			
CSTG	9.1	5.3	0.021	9.0	7.4	6.0
Bm	−56.5	15.4	0.001	4.0	1.4	0.0
CSTG × soil	−2.8	22.7	0.001	27.0	15.9	7.0
Weed × Bm	3.2	11.2	0.000	8.0	2.8	0.0
Sdia × OM	12.5	16.8	0.001	6.0	3.8	1.0
Sdia	−23.8	7.6	0.006	2.5	1.8	1.0
Soil × Bm	4.0	3.0	0.008	12.0	2.8	0.0
Sm	−5.9	2.8	0.084	3.0	0.2	0.0

CSTG = maize crop growth stage (1–9); Bm = *Bipolaris maydis*; CSTG × soil = interaction between the growth stage and the soil rating (texture on a 1–3 scale with increasing clay content); Weed × Bm = weediness (1–3 scale) by *B. maydis* interaction; Sdia × OM = stem diameter by organic matter content (1–3 scale); Sdia = stem diameter (cm); Sm = *Stenocarpella macrospora*.

$$Y_{max} = 109.3 + 9.1\text{CSTG}_{max} - 56.5\text{Bm}_{min} - 2.8(\text{CSTG} \times \text{Soil}_{min}) + 3.2(\text{Weed} \times \text{Bm}_{min}) + 12.5(\text{Sdia} \times \text{OM}_{max}) - 23.7\text{Sdia}_{min} + 4.0(\text{Soil} \times \text{Bm}_{min}) - 5.9\text{Sm}_{min} = 222.8\text{ g/ear},$$

$$Y_{mean} = 109.3 + 9.1\text{CSTG}_{mean} - 56.5\text{Bm}_{mean} - 2.8(\text{CSTG} \times \text{Soil}_{mean}) + 3.2(\text{Weed} \times \text{Bm}_{mean}) + 12.5(\text{Sdia} \times \text{OM}_{mean}) - 23.7\text{Sdia}_{mean} + 4.0(\text{Soil} \times \text{Bm}_{mean}) - 5.9\text{Sm}_{mean} = 156.5\text{ g/ear},$$

$$Y_{Bm} = 109.3 + 9.1\text{CSTG}_{mean} - 56.5\text{Bm}_{max} - 2.8(\text{CSTG} \times \text{Soil}_{mean}) + 3.2(\text{Weed} \times \text{Bm}_{max}) + 12.5(\text{Sdia} \times \text{OM}_{mean}) - 23.7\text{Sdia}_{mean} + 4.0(\text{Soil} \times \text{Bm}_{max}) - 5.9\text{Sm}_{min} = 70.8\text{ g/ear},$$

$$Y_{Sm} = 109.3 + 9.1\text{CSTG}_{mean} - 56.5\text{Bm}_{min} - 2.8(\text{CSTG} \times \text{Soil}_{mean}) + 3.2(\text{Weed} \times \text{Bm}_{min}) + 12.5(\text{Sdia} \times \text{OM}_{mean}) - 23.7\text{Sdia}_{mean} + 4.0(\text{Soil} \times \text{Bm}_{min}) - 5.9\text{Sm}_{max} = 120.2\text{ g/ear},$$

where Y_{max} = maximum yield; Y_{mean} = average yield across visited fields; Y_{Bm} = yield when *Bipolaris maydis* is maximum (using the maximum recorded value); Y_{Sm} = yield when *S. macrospora* is maximum (using the maximum recorded value).

texture interaction during this season that reduced ear weight. Among the pathogens only *B. maydis* ($P = 0.001$) and *S. macrospora* ($P = 0.084$) had significant negative relationships with ear weight. When stem diameter and organic matter content increased together, the ear weight also increased significantly ($P = 0.001$). Otherwise, in these data, increase in stem diameter and ear weight were inversely related. Although *B. maydis* alone caused significant loss in ear weight, there were interactions of *B. maydis* with weediness and soil texture for which ear weight was higher.

Maximum potential yield that can be calculated from Table 1 would be 222.8 g/ear. The mean yield estimate using the significant variables that entered the equation was 156.5 g/ear. At maximum disease expression of *B. maydis*, the ear weight would decrease to 70.8 g/ear, while the maximum level of *S. macrospora* would reduce ear weight to 120.2 g/ear.

Humid Forest 1996

Pearson correlation analysis (data not shown) showed 33 significant interactions among 15 biotic and abiotic factors. *Bipolaris maydis* was negatively correlated with *S. macrospora* ($P = 0.005$) and organic matter content ($P = 0.0001$). *Puccinia polysora* was positively correlated with maize streak virus ($P = 0.0001$). *Bipolaris maydis* and *R. solani* decreased with increasing organic matter and heavier soil texture ($P = 0.01$ for both) and *E. turcicum* was also inversely related to soil organic matter ($P = 0.05$). The significant interactions and principal variables were used in the regression against ear weight (Table 2).

From the regression analysis against ear weight, *P. polysora* ($P = 0.0001$), *R. solani* ($P = 0.031$) and *S. macrospora* ($P = 0.0003$) independently were associated with significantly lower ear weight. Interaction between *E. turcicum* and maize streak virus exerted a

Table 2. Factors affecting ear weight as calculated by a stepwise backward regression analysis, maxima (Max), mean and minima (Min) in the HF zone of Cameroon in 1996 ($R^2 = 0.20$; $P = 0.0001$; $N = 465$)

Variable	Regression coefficient	*t* value	$P > t$	Max	Mean	Min
Intercept	133.3	6.9	0.0001			
CSTG	2.0	0.4	0.055	9.0	7.5	6.0
Pp	−8.4	73.4	0.0001	4.0	0.9	0.0
Et × Bm	7.7	11.6	0.0001	4.0	0.1	0.0
Et × MSV	−13.9	12.2	0.0001	2.0	0.04	0.0
CSTG × Bm	−0.8	39.7	0.0001	32.0	11.6	0.0
CSTG × soil	−0.6	11.5	0.0001	25.5	14.4	6.0
Sm	−5.1	13.4	0.0003	4.0	0.3	0.0
Rs	−3.9	4.6	0.031	3.0	0.2	0.0
Sdia × Fertility	2.2	3.5	0.061	4.0	0.4	1.0

CSTG = crop growth stage; Pp = *Puccinia polysora*; Et = *Exserohilum turcicum*; Bm = *Bipolaris maydis*; Sdia = stem diameter; MSV = maize streak virus; Et × MSV = the interaction between *E. turcicum* and maize streak virus; CSTG × soil = interaction between crop growth stage and soil (texture ranking from 1 to 3 with increasing clay content); Sm = *Stenocarpella macrospora*; Rs = *Rhizoctonia solani*; Sdia × Fertility = Stem diameter by field fertility.

$$Y_{max} = 133.3 + 2.0\mathrm{CSTG}_{max} - 8.4\mathrm{Pp}_{min} + 7.7(\mathrm{Et} \times \mathrm{Bm}_{min}) - 13.9(\mathrm{Et} \times \mathrm{MSV}_{min}) - 0.8(\mathrm{CSTG} \times \mathrm{Bm}_{min}) - 0.6(\mathrm{CSTG} \times \mathrm{Soil}_{min}) - 5.1\mathrm{Sm}_{min} - 3.9\mathrm{Rs}_{min} + 2.2(\mathrm{Sdia} \times \mathrm{Fertility}_{max}) = 183.0\ \mathrm{g/ear},$$

$$Y_{mean} = 133.3 + 2.0\mathrm{CSTG}_{mean} - 8.4\mathrm{Pp}_{mean} + 7.7(\mathrm{Et} \times \mathrm{Bm}_{mean}) - 13.9(\mathrm{Et} \times \mathrm{MSV}_{mean}) - 0.8(\mathrm{CSTG} \times \mathrm{Bm}_{mean}) - 0.6(\mathrm{CSTG} \times \mathrm{Soil}_{mean}) - 5.1\mathrm{Sm}_{mean} - 3.9\mathrm{Rs}_{mean} + 2.2(\mathrm{Sdia} \times \mathrm{Fertility}_{mean}) = 121.6\ \mathrm{g/ear},$$

$$Y_{Sm} = 133.3 + 2.0\mathrm{CSTG}_{mean} - 8.4\mathrm{Pp}_{min} + 7.7(\mathrm{Et} \times \mathrm{Bm}_{min}) - 13.9(\mathrm{Et} \times \mathrm{MSV}_{min}) - 0.8(\mathrm{CSTG} \times \mathrm{Bm}_{min}) - 0.6(\mathrm{CSTG} \times \mathrm{Soil}_{mean}) - 5.1\mathrm{Sm}_{max} - 3.9\mathrm{Rs}_{min} + 2.2(\mathrm{Sdia} \times \mathrm{Fertility}_{mean}) = 120.0\ \mathrm{g/ear},$$

$$Y_{Pp} = 133.3 + 2.0\mathrm{CSTG}_{mean} - 8.4\mathrm{Pp}_{max} + 7.7(\mathrm{Et} \times \mathrm{Bm}_{min}) - 13.9(\mathrm{Et} \times \mathrm{MSV}_{min}) - 0.8(\mathrm{CSTG} \times \mathrm{Bm}_{min}) - 0.6(\mathrm{CSTG} \times \mathrm{Soil}_{mean}) - 5.1\mathrm{Sm}_{min} - 3.9\mathrm{Rs}_{min} + 2.2(\mathrm{Sdia} \times \mathrm{Fertility}_{mean}) = 107.2\ \mathrm{g/ear},$$

$$Y_{Rs} = 133.3 + 2.0\mathrm{CSTG}_{mean} - 8.4\mathrm{Pp}_{min} + 7.7(\mathrm{Et} \times \mathrm{Bm}_{min}) - 13.9(\mathrm{Et} \times \mathrm{MSV}_{min}) - 0.8(\mathrm{CSTG} \times \mathrm{Bm}_{min}) - 0.6(\mathrm{CSTG} \times \mathrm{Soil}_{mean}) - 5.1\mathrm{Sm}_{min} - 3.9\mathrm{Rs}_{max} + 2.2(\mathrm{Sdia} \times \mathrm{Fertility}_{mean}) = 128.7\ \mathrm{g/ear},$$

where Y_{max} = maximum yield; Y_{mean} = average yield across visited fields; Y_{Sm} = yield when *S. macrospora* is maximum (the maximum recorded value); Y_{Pp} = yield when *P. polysora* is maximum (the maximum recorded value); Y_{Rs} = yield when *R. solani* is maximum (the maximum recorded value).

highly significant ($P = 0.0001$) negative effect on ear weight, but a high *E. turcicum* by *B. maydis* interaction had a positive relationship with yield (Table 2). The interaction between stem diameter and soil fertility was positively related to ear weight. The interaction between the crop stage and *B. maydis* had a negative impact on ear weight, indicating the effect of early infection.

Maximum potential yield for this zone in this year can be calculated from the equation in Table 2 to be 183.0 g/ear. The mean yield estimate using the significant variables that entered the equation was 121.6 g/ear. At maximum disease expression of *P. polysora*, the ear weight would decrease to 107.2 g/ear, while the maximum level of *S. macrospora* would reduce ear weight to 120.0 g/ear and *R. solani* to 128.7 g/ear.

Western Highlands 1996

Pearson correlation analysis (data not shown) produced 14 significant interactions among 11 biotic and abiotic factors. In this survey, variety was assessed as local or improved. The improved variety was significantly ($P = 0.0001$) negatively correlated with *E. turcicum* and *C. zeae-maydis*, indicating better resistance than the local variety. *Cercospora zeae-maydis* and *E. turcicum* were significantly related to each other ($P = 0.0001$) and both increased significantly as soil fertility increased ($P = 0.01$ and $P = 0.0001$, respectively). Stem lesions interacted significantly with soil texture ($P = 0.004$), indicating more stem disease in lighter textured soils.

The significant interactions of the correlation matrix and the principal variables were used in the regression against ear weight (Table 3) and against percentage grain fill (Table 4). As expected, crop stage, soil texture and soil fertility were positively correlated with ear weight (Table 3). Likewise, variety by fertility interaction was positively related to ear weight, indicating a strong yield advantage from using both. The interactions between variety and *C. zeae-maydis* and soil fertility and *C. zeae-maydis* were the main factors associated with ear weight loss. Since the correlation between *C. zeae-maydis* and variety was negative, it can be inferred that most yield loss occurred because of the disease on susceptible local cultivars. As *C. zeae-maydis* increased with soil fertility, the negative yield effect of the interaction of these two variables indicates that there is a point at which increased fertility will begin to be counterproductive.

Maximum potential yield for the WHL during this year can be calculated from the equation in Table 3 to be 203.2 g/ear. The mean yield estimate using the significant variables that entered the equation was 99.2 g/ear, while with maximum disease expression of *C. zeae-maydis*, the ear weight would be reduced to 43.6 g/ear.

Table 3. Factors affecting ear weight as calculated by a stepwise backward regression analysis, maxima (Max), mean and minima (Min) in the WHL zone of Cameroon in 1996 ($R^2 = 0.10$; $P = 0.0001$; $N = 435$)

Variable	Regression coefficient	*t* value	$P > t$	Max	Mean	Min
Intercept	−41.1	17.2	0.076			
CSTG	11.8	20.6	0.0001	9.0	6.9	6.0
Fertility	21.3	13.3	0.0003	3.0	2.1	1.0
Var × Fertility	15.8	6.1	0.014	3.0	0.3	0.0
Soil	8.8	5.7	0.017	3.0	2.3	1.0
Var × Cz	−16.6	4.6	0.032	3.0	0.2	0.0
Fertility × Cz	−2.0	3.1	0.081	9.0	4.3	0.0

CSTG = crop growth stage; field fertility; Var = maize variety (0 = local, 1 = improved); Soil = soil texture; Cz = *Cercospora zeae-maydis*; Var × Cz = interaction between variety and *C. zeae-maydis*.

$$Y_{max} = -41.1 + 11.8\mathrm{CSTG}_{max} + 21.3\mathrm{Fertility}_{max} + 15.8(\mathrm{Var} \times \mathrm{Fertility}_{max}) + 8.8\mathrm{Soil}_{max} - 16.6(\mathrm{Var} \times \mathrm{Cz}_{min}) - 2.0(\mathrm{Fertility} \times \mathrm{Cz}_{min}) = 203.2\ \mathrm{g/ear},$$

$$Y_{mean} = -41.1 + 11.8\mathrm{CSTG}_{mean} + 21.3\mathrm{Fertility}_{mean} + 15.8(\mathrm{Var} \times \mathrm{Fertility}_{mean}) + 8.8\mathrm{Soil}_{mean} - 16.6(\mathrm{Var} \times \mathrm{Cz}_{mean}) - 2.0(\mathrm{Fertility} \times \mathrm{Cz}_{mean}) = 99.2\ \mathrm{g/ear},$$

$$Y_{Cz} = -41.1 + 11.8\mathrm{CSTG}_{mean} + 21.3(\mathrm{Fertility}_{mean}) + 15.8(\mathrm{Var} \times \mathrm{Fertility}_{mean}) + 8.8\mathrm{Soil}_{mean} - 16.6(\mathrm{Var} \times \mathrm{Cz}_{max}) - 2.0(\mathrm{Fertility} \times \mathrm{Cz}_{max}) = 43.6\ \mathrm{g/ear},$$

where Y_{max} = maximum yield; Y_{mean} = average yield across visited fields; Y_{Cz} = yield when *C. zea-maydis* is maximum (the maximum recorded value).

Table 4. Factors affecting percentage grain fill (arcsine transformed) as calculated by a step-wise backward regression analysis, maxima (Max), mean and minima (Min) in the WHL zone of Cameroon in 1996 ($R^2 = 0.23$; $P = 0.0001$; $N = 435$)

Variable	Regression coefficient	*t* value	$P > t$	Max	Mean	Min
Intercept	40.1	3.7	0.0003			
CSTG	11.8	0.9	0.3792	9.0	6.9	6.0
Weed	−11.4	1.9	0.0507	2.0	1.6	0.0
Soil	2.8	2.3	0.0222	3.0	2.3	1.0
Fertility	7.1	1.7	0.0886	3.0	2.1	1.0
Var × Cz	−2.3	2.4	0.0183	3.0	0.2	0.0
Soil×Stem disease	−1.6	2.1	0.0375	9.0	2.5	0.0

CSTG = crop growth stage (1–9); Stem disease (0–4 scale); Weeds (0–2 scale); Fertility (1–3 scale); Var = maize variety (0 = local, 1 = improved); Soil = soil (texture ranking from 1 to 3 with increasing clay content); Cz = *Cercospora zeae-maydis*; Var × Cz = interaction between variety and *C. zeae-maydis*.

When the biotic and abiotic variables were regressed against percentage grain fill, a different set of variables entered than for ear weight (Table 4). Weediness of the field, severity of *C. zeae-maydis* on the local variety, and stem disease reduced grain filling. Soil fertility and soil texture (increasing clay content) had a positive effect on grain filling.

Western Highlands 1997

Pearson correlation analysis (data not shown) produced 14 significant interactions among 16 biotic and abiotic variables. In this survey, variety was strongly negatively related to *C. zeae-maydis* and stem borer parameters ($P = 0.0001$ for both), again indicating that the improved varieties were significantly more resistant to these biotic factors. As *C. zeae-maydis* increased, *P. maydis* ($P = 0.05$), *S. macrospora* ($P = 0.04$), and physiological spot ($P = 0.05$) decreased significantly. *Exserohilum turcicum* and *S. macrospora* were also inversely related ($P = 0.05$). *Cercospora zeae-maydis* was significantly correlated with all stem borer damage parameters ($P = 0.0001$), indicating that plants infested with the insect are more susceptible to the pathogen, or vice versa. Fertility and organic matter were significantly correlated in this survey ($P = 0.0001$).

The significant interactions of the correlation matrix and the principal variables were used in the regression against ear weight (Table 5) and against percentage grain fill (Table 6). Once again, crop growth stage and soil fertility by organic matter interaction were positively correlated with ear weight. *Stenocarpella macrospora* was positively related to ear weight, but this pathogen increased with fertility ($P < 0.05$), thus the positive slope may reflect infection on larger plants. The interaction between the number of internodes bored by the stem borer and *C. zeae-maydis* was the main factor associated with ear weight lost. Since the correlation between stem borer variables, *C. zeae-maydis* and variety were negative, it can be inferred that most yield loss occurs because of the damage to susceptible local cultivars. Stem disease and the physiological spot also had a negative effect on ear weight.

Maximum potential yield for the WHL during this year can be calculated from the equation in Table 5 to be 278.9 g/ear. The mean yield estimate using the significant variables that entered the equation was 173.5 g/ear, while with maximum expression of disease caused by *C. zeae-maydis* and internodes bored by *B. fusca*, the ear weight would decrease to 135.0 g/ear.

When grain filling was used as the dependant variable, stem disease and *C. zeae-maydis* on susceptible varieties were seen to reduce grain filling. The improved variety had significantly ($P = 0.009$) better grain filling (Table 6). Actual yield losses due to the combination of factors were 30.0% and 33.6% in the HF in 1995 and 1996, respectively (Table 7). In 1996 in the WHL, *C. zeae-maydis* alone caused a yield reduction of 78.5% of the 51.2% total losses; the combined effects of the same pathogen and *B. fusca*, the stem disease and the physiological spot reduced the yield by 37.7% in 1997 of which *C. zeae-maydis* and *B. fusca* caused a yield reduction of 51.6% (Table 7).

Discussion

The assessment of the biological and physical constraints to maize production in the HF zone of

Table 5. Factors affecting ear weight as calculated by a stepwise backward regression analysis, maxima (Max), mean and minima (Min) in the WHL zone of Cameroon in 1997 ($R^2 = 0.79$; $P = 0.0001$; $N = 540$)

Variable	Regression coefficient	*t* value	$P > t$	Max	Mean	Min
Intercept	−122.6	4.5	0.0422			
CSTG	39.4	28.3	0.0001	8.5	7.8	6.7
Cz × IB	−14.4	62.3	0.0001	6.3	2.5	0.1
Fertility × OM	13.7	9.9	0.0038	5.0	3.0	2.2
Stem disease	−20.1	8.7	0.0063	2.0	0.9	0.0
PSPT	−36.8	7.4	0.0111	1.5	0.1	0.0
Sm	11.4	3.5	0.0721	1.6	0.5	0.0

CSTG = crop growth stage; Fertility = field fertility; OM = organic matter; Cz = *Cercospora zeae-maydis*; IB = square root of number of internodes bored by *Busseola fusca*; PSPT = physiological spot; Sm = *Stenocarpella macrospora*.

$$Y_{max} = -122.6 + 39.4\text{CSTG}_{max} - 14.4(\text{Cz} \times \text{IB}_{min}) + 13.7(\text{Fertility} \times \text{OM}_{max}) - 20.1\text{Stem}_{min} - 36.8\text{PSPT}_{min} + 11.4\text{Sm}_{min} = 278.9 \text{ g/ear},$$
$$Y_{mean} = -122.6 + 39.4\text{CSTG}_{mean} - 14.4(\text{Cz} \times \text{IB}_{mean}) + 13.7(\text{Fertility} \times \text{OM}_{mean}) - 20.1\text{Stem}_{mean} - 36.8\text{PSPT}_{mean} + 11.4\text{Sm}_{mean} = 173.5 \text{ g/ear},$$
$$Y_{Cz\times Ib} = -122.6 + 39.4\text{CSTG}_{mean} - 14.4(\text{Cz} \times \text{IB}_{max}) + 13.7(\text{Fertility} \times \text{OM}_{mean}) - 20.1\text{Stem}_{min} - 36.8\text{PSPT}_{min} + 11.4\text{Sm}_{min} = 135.0 \text{ g/ear},$$
$$Y_{Stem} = -122.6 + 39.4\text{CSTG}_{mean} - 14.4(\text{Cz} \times \text{IB}_{min}) + 13.7(\text{Fertility} \times \text{OM}_{mean}) - 20.1\text{Stem}_{max} - 36.8\text{PSPT}_{min} + 11.4\text{Sm}_{min} = 185.3 \text{ g/ear},$$
$$Y_{Pspt} = -122.6 + 39.4\text{CSTG}_{mean} - 14.4(\text{Cz} \times \text{IB}_{min}) + 13.7(\text{Fertility} \times \text{OM}_{mean}) - 20.1\text{Stem}_{min} - 36.8\text{PSPT}_{max} + 11.4\text{Sm}_{min} = 170.2 \text{ g/ear},$$

where Y_{max} = maximum yield (no borers or diseases and optimum fertility); Y_{mean} = average yield across visited fields; $Y_{Cz\times Ib}$ = yield when *C. zea-madis* and *B. fusca* internodes-bored are interacting (using the maximum recorded values); Y_{Stem} = yield when the stem lesion rating is maximum (the maximum recorded value); Y_{Pspt} = yield when the physiological spot rating is maximum (the maximum recorded value).

Table 6. Factors affecting percentage grain fill (arcsine transformed) as calculated by a stepwise backward regression analysis, maxima (Max), mean and minima (Min) in the WHL zone of Cameroon in 1997 ($R^2 = 0.29$; $P = 0.0102$; $N = 540$)

Variable	Regression coefficient	*t* value	$P > t$	Max	Mean	Min
Intercept	69.3	581.9	0.0001			
Stem disease	−1.6	3.2	0.0843	2.0	0.9	0.0
Var	3.7	7.6	0.0097	1.0	0.5	0.0
Var × Cz	−2.1	10.4	0.0029	4.0	0.6	0.0

Var = local or improved maize variety; Cz = *Cercospora zeae-maydis*.

Cameroon in 1995, revealed that *B. maydis* and *S. macrospora*, and physical factors such as soil texture were the most important factors affecting yield. The main abiotic factor that was measured and that was responsible for the difference between potential yield and actual yield was soil fertility. In general, the reduction of the ear weight was a result of the interaction between factors. The negative effects of the soil fertility are explained by the acidic soils that are more predominant in the HF though not uniformly distributed across the region (Embrechts, 1978; FAO, 1986; Kotto-Same et al., 1997). As was also seen by Cardwell et al. (1997) some significant interactions reveal underlying physiological processes, that is the inverse relationship of ear weight and stem diameter. Ear weight increases with crop maturity, while stem diameter declines.

Contrary to the 1995 observations, diseases that contributed to the reduction of maize production in 1996 in the HF were *S. macrospora*, *R. solani* and *P. polysora*. Although *E. turcicum* was not retained by the regression analysis as an individual factor causing yield loss, its interaction with the organic matter content and maize streak virus was associated with significantly reduced yield ($P = 0.0001$). This is in accordance with Cardwell et al. (1997) who found that individual diseases often have no direct impact

Table 7. Summary of estimated actual and potential ear weight and % reduction due to maize diseases and pests in the HF and WHL of Cameroon, 1995–1997

Ecological zone	Yield (g/ear)	% Reduction*
Humid Forest 95		
Potential yield	222.8	
Actual yield	156.5	30.0
Potential yield at disease maximum		
B. maydis	70.8	68.2
S. macrospora	120.2	46.1
Humid Forest 96		
Potential	183.0	
Actual	121.6	33.6
Potential yield at disease maximum		
S. macrospora	120.0	34.4
P. polysora	107.2	41.4
R. solani	128.7	29.7
Western Highlands 96		
Potential	203.2	
Actual	99.2	51.2
Potential yield at disease maximum		
C. zeae-maydis	43.6	78.5
Western Highlands 97		
Potential	278.9	
Actual	173.5	37.8
Potential yield at disease and pest maxima		
C. zeae-maydis and *B. fusca*	135.0	51.6
Stem disease	185.0	33.7
Physiological spot	170.0	39.1

*Reduction over potential yield.

on ear weight. In the field environment, yield is usually affected by a combination of several factors, some of which can be inversely related. The inverse significant correlation between *S. macrospora*, *E. turcicum* and *B. maydis* suggests that they are not favoured by the same agroecological conditions. Although significant losses were not associated with the presence of *E. turcicum* in the HF, the presence of this pathogen, which is considered to be a cool climate (mid-altitude) pathogen, indicates that the HF zone in Cameroon has variable climatic conditions. Losses from *S. macrospora* averaged about 20% in the HF over the two years. This disease has never been considered as a major problem in the IRAD maize improvement programme. A policy decision needs to be made about investing in screening for resistance to *S. macrospora*. At its most severe, *B. maydis* was estimated to cause up to 70% ear weight loss. It is clear that work needs to be done on host plant resistance to these foliar pathogens. Yield losses from *P. polysora* in the HF were estimated at 41% in 1996. This is contrary to a previous report in which Cardwell et al. (1997) reported no yield loss due to *P. polysora* because the disease rating was positively correlated with yield. This difference could be the result of environmental factors, a breakdown in resistance or a consequence of newly introduced susceptible maize cultivars at the farmers' level by the extension service. Nevertheless, correlating disease symptoms to yield loss can be inaccurate when the pathogen has a physiological effect greater than simple loss of photosynthetic area.

Maize is the primary crop in the WHL and more emphasis is being placed on maize production in the HF for commercial purposes. Therefore, maize pathogens may become more important as production intensifies. Disease factors are important constraints to maize production in both agroecological zones. Although *E. turcicum*, *P. maydis* and maize streak virus were not associated with yield losses in this study, this does not imply that they do not cause yield loss. Research programmes should be aimed at elucidating these disease/yield loss relationships, especially as maize is becoming a cash crop in areas where agricultural practices are still traditional for most farmers. In the HF shifting cultivation and slash-and-burn (Kotto-Same et al., 1997), are among the most common farming practices. In the long term, shifting cultivation contributes to the rapid loss of soil fertility due to leaching of minerals and an accelerated degradation of organic matter (Kotto-Same et al., 1997).

In the WHL, *B. fusca*, *C. zeae-maydis* and stem diseases, and the interaction between maize streak virus and *E. turcicum* were the most important constraints to maize production in both 1996 and 1997. Ward et al. (1999) reported that grey leaf spot caused from 11% to 68% losses in the USA and South Africa, and that it is rapidly becoming a disease of global importance. Although the number of insects collected is not mentioned in this paper, the effect of *B. fusca* is expressed by the interaction between *C. zeae-maydis* and the number of internodes bored. The length of the tunnel and the number of holes bored on the stem, though recorded, were not significant in the regression analysis. The *B. fusca* tunnelling was more extensive in plants growing in fertile soil than in poor sandy soils. These results suggest that *B. fusca* is a major constraint to maize production in the WHL that needs to be addressed. These associations between stems, insects and pathogens may lead to stalk rots and lodging. Cardwell et al. (1997)

noted a positive relationship between soil organic matter and the stem borers *B. fusca* and *Eldana saccharina* Walker (Lepidoptera: Pyralidae) and *B. maydis*.

Severity of *S. macrospora* was positively related to soil fertility. High levels of nitrogen have been shown to increase some leaf diseases of maize (Fajemisin, 1985). Farmers in the WHL used mostly organic fertilizer such as chicken manure, cow manure and/or compost. Chicken manure is known to contain a high level of nitrogen and phosphorous. How the 'organic' fertilization relates to disease incidence and severity is not understood. No relationship was found between the incidence *of S. macrospora*, *E. turcicum*, *B. maydis* and the effects of *B. fusca*. However, Flett and Van Rensburg (1992) found that *B. fusca* increased the incidence of *Fusarium moniliforme* Sheldon ear rot although this did not result in an increase in kernels rotted by *F. moniliforme.* More research is needed to improve the understanding of the relationship between insect infestations and stem rotting fungi. Livestock farmers are using more maize stalks to feed their animals, but there is no information on the effects of the complex of fungi found in Cameroonian maize on the health of livestock. Diplodiosis has been reported in cows fed with stalk and leaves infected by *S. maydis* (Berk.) Sutton (Marasas, 1977).

Although this is based on data from only 72 fields, the results indicated that the combination of biological factors (diseases and insects) and physical parameters (soil fertility and organic matter) are responsible for the significant yield reduction of maize in Cameroon. Although yield reduction caused by some of the diseases was shown, it is probable other maize pathogens also cause some losses (Zadoks and Schein, 1979). Future investigations may highlight the importance of other diseases. On-station trials should be conducted to understand more fully how these factors affect yield, and how they can be ameliorated to enhance maize production in Cameroon. Efforts should be geared towards strategies that increase the levels and/or value of production, which can be directly translated into the improvement of the quality of life of the rural population who rely on subsistence agriculture for survival.

Conclusion

We have shown that pathogens such as *B. maydis*, *P. polysora* and *S. macrospora* and their combined effects were among the factors responsible for yield losses in the HF of Cameroon in 1995 and 1996. In the WHL, *C. zeae-maydis*, *E. turcicum* and *B. fusca* caused yield losses. Potential, actual and individual loss was estimated for each zone according to the period, indicating factors on which control strategies may be applied to increase the yield.

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