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Modelling crop yield using growth parameters and fall armyworm (*Spodoptera frugiperda* J. E. Smith) leaf damage under different NPK regimes for Cameroon Highland Composite (CHC) maize

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Abstract

Fertilization (NKP) is a key driver of maize yield in Cameroon. Nevertheless, inconsistencies remain regarding doses vis-à-vis maize variety especially within the context of the dreaded maize pest fall armyworm (*Spodoptera frugiperda*). We assessed the performance of Cameroon Highland Composite CHC maize varieties at different fertilizer levels, paying attention to fall armyworm leaf damage three decades after release of CHC. A split plot experiment was used with four CHC varieties (CHC201, CHC202, CHC203 and CHC204) as main plots and NPK (20: 10: 10) fertilizer doses (0g, 4g, 8g and 12g per plant) as subplots. Analysis revealed plant growth parameters such as plant height, stem diameter, plant vigour (PV) and leaf area index were not significantly ($P > 0.05$) influenced by interaction effects and variety effects, rather was by different fertilizer dose. However, plant emergence and number of plants at harvest (NPH) were solely influenced ($P < 0.05$) by variety with the highest values observed from CHC202 and CHC203. Fall armyworm (FAW) leaf damage score increased with increasing NPK doses. CHC204 scored 7.5 on 9 at NPK of 12 g/plant. CHC202 had the lowest FAW leaf damage score and the highest fresh weight of 4 t ha⁻¹. The FAW leaf damage only did not significantly affected yield of CHC maize, but a slight detectable effect was observed in the multiple regression with PV and NPH. The three-predictor (PV, NPH and FAW) regression was best fit for predicting CHC yield following the Akaike information criteria.

Keywords: Akaike Information Criteria; Cameroon; fall armyworm; Integrated Pest Management; maize; model; NPK fertilizer; yield

1. Introduction

Maize (*Zea mays* L) is a cereal crop belonging to Poaceae [1]. Maize is the third most important cereal crop in the world next to rice and wheat and has the highest potential among the cereals [2]. Maize serves as the most important nutrient source for people in central and South America, Africa and China [1,2]. Average productivity of maize is 6.7 t/ha in developed countries and 2.4 t/ha in developing countries [3]. It reported that maize is one of the most important cereal crops that allow the food self-sufficiency program of the country, playing a key role in the human diet and animal feed, providing adequate amounts of energy and protein ([4]. Amongst other crops, until the late 1980s maize was regarded by the majority of people in Cameroon as a crop solely for home consumption rather than for cash. During the last three decades, characterized by a drastic drop in the prices of the two main cash crops (coffee and cocoa), maize (*Zea mays*L) has witnessed a steady increase in prices and demand in Cameroon and the world at large [5].

In Cameroon, maize is displayed in tins, buckets and bags by small scale farmers for direct consumption in local markets. Mega buyers such as Societe Camerounaise de Transformation des Cereals (SCTC), Societe Anonyme des Brasseries du Cameroon (SABC), Union Camerounaise des Brasseries (U.C.B), animal feed mills, Societe des Provenderies du Cameroon (S.P.C), Belgocam, Nutricam and larger section of the urban elite has mounted pressure on maize production in Cameroon [5].

Cameroon, like many other African countries under the climate change dispensation is facing a plethora of challenges negatively affecting maize production; access to new and improved varieties, high cost of fertilizer, pests and diseases [6]. In the North West Region of Cameroon as is the case in other parts of the country, maize production is in the hands of small-scale farmers who carry out farming activities with very limited resources and

rudimentary tools such as hoes, machetes, low quality seeds, limited land area, little or no mechanization and inadequate use of fertilizer and pesticides. As a result, realized yield is between 1.5 – 2.6 t ha⁻¹ which is about 50% - 80% lower than optimal yield that can be attained by research-based and evidence-driven technology [7].

Poor soil fertility is among the major factors affecting maize production in Cameroon [4,8]. Organic manure from animal husbandry and farm debris play an important role in supplying this extra nutrients necessary for soil fertility improvement. Nevertheless, many farmers still rely extensively on chemical fertilizers to boost maize yields. Chemical fertilizers are needed to replace nutrient which are removed and lost during cropping in order to maintain positive nutrient balance and increase yield [9]. Nitrogen (N) together with phosphorus (P) are the most limiting macronutrients to maize grain yield in Cameroon and the world [10,11]. Nitrogen availability is very beneficial as it influences the uptake of other nutrient [12] as N-fertilized plants usually have larger roots systems, which enhances the capture of other nutrients [13]. Due to high N mobility, its demand and use is continuously increasing as it is subjected to high loss from the soil-plant system [14,15]. Thus, standardize amounts of fertilizers required for optimum growth and yield is important indifferent agroecological zones.

For most tropical countries, 120kg N/ha + 40kg P/ha is highly recommended for optimal harvest [12]. However, most N products sold that are readily available to farmers in Cameroon are sold as compound fertilizers, Nitrogen, Phosphorus, Potassium (NPK) in different rations such 20:15:14, 10:10:10 and 25:25:40. Therefore, it is important to determine optimal NPK doses for maize.

In addition to optimal NPK dose for maize production, maize improvement programs aim at selecting high-yielding cultivars, which are, in general, very demanding in terms of soil fertility and plant protection. Cameroon Highland Composite (CHC), CHC201, CHC202, CHC203 and CHC204 maize varieties were developed in 1994 by IRAD (Institute of Agricultural Research for Development) Bambui to adapt to different agroecological conditions [16]. Cameroon Highland Composite is especially adapted for use by Cameroon farmers and seed producers in highland zones. The CHC maize varieties are open-pollinated varieties that are best suited for use by small-scale farmers who can select seeds from previous harvest for three cycles before buying new seeds, thereby ensuring seed availability and reducing cost of production [16].

Since 2015 when fall armyworm (FAW) *Spodoptera frugiperda* J. E. Smith (Lepidoptera: Noctuidae) was first reported in Cameroon [17], very little is known about its effect on the CHCs maize vis-à-vis plant nutrient status. The FAW larvae damages maize crops by defoliation on vegetative parts and direct damage on reproductive parts [18]. In intense defoliation, the plant may be left ragged or have a torn-up appearance [19]. The appearance of maize leaf after FAW infestation and damage have been well studied and characterized on a nine-point scale by [20] based on larvae damage severity. Early FAW infestation can result in grain loss of about 58% - 100% while late infestation (late whorl stage) can result in 5% - 20.0% grain loss ([19,21].

Three decades since the release of the CHC maize and almost 10 years since the first report of FAW in Cameroon, no comprehensive studies have been done to assess the susceptibility of CHC maize to FAW in relation to soil fertility. Thus, the aim of this study was to understand the effect of NPK fertilizer on growth, yield and defoliation by FAW on

CHC varieties used by small scale farmers in the North West and West Region of Cameroon. Furthermore, to develop predictive models for maize yield based on *in situ* data of FAW infestation and some growth parameters. We used Akaike information criteria (AIC) for model selection, where the model with the smallest AIC value was considered the best [22]. The AIC is the most common criteria for model selection in ecological literature [23].

2. Materials and Methods

2.1 Experimental site

This experiment was conducted in Bali Nyonga, a village located in Bali sub- Division, North West Region of Cameroon. Bali lies west of Bamenda, the Capital City of North West Region and it has a population of about 500,000 people (2014 estimates). The geographical coordinates of Bali are 5°53' 0" North, 10° 0' East with a humid tropical climate. Annual rainfall ranges between 1800 mm to 2500 mm with average temperatures between 17.0 °C and 27.0°C. The average humidity was 72.2%. The principal economic activity of the inhabitants was agriculture. The main crops grown included maize, beans, potatoes and vegetables. This research was conducted in 2024 from March to July. Site selection and soil preparation took place in March; planting in late March harvesting took place in July.

2.2 Experimental design, field layout and cultural practices

The CHC maize were supplied by the Institute of Agricultural Research for Development (IRAD) Bambui. IRAD Bambui is a state-owned research facility located in the North West

Region of Cameroon, charged with the responsibility to oversee research on annual and perennial crops in the North West and West regions (Western Highlands) of Cameroon. A Split plot experimental design was used with CHC varieties (CHC201, CHC202, CHC203 and CHC204) as main plots and fertilizer doses as subplots (0g, 4g, 8g and 12g per plant). The fertilizer used was a commercial NPK composite in ratio of 20:10:10. There were four replications of the main plots, each with a surface area of 36m². Each main plot was divided into subplots (raised beds: 3m x 2m x 0.4m) separated by 1cm gap. These dimensions were optimized from farmer's recommendation. The main plots were separated by a 1.5m alley. Three seeds of CHC variety were sown per hole on raised beds. Each subplot had 24 maize stands which were separated by 35 cm inter row and 35 cm intra row. Maize seeds were sown on the 25th on March 2024 after two consecutive heavy rain falls. Upon emergence, the maize stands were thinned to 2 plants. Two fertilizer applications were made in the experiment; two weeks and five weeks after emergence. The fertilizer was applied in a ring manner around and at 5 cm away from the plants. Hand weeding was done *ad libidum*. The entire study relied on rain fed irrigation.

2.3 Data collection

Data was collected during the vegetative stage and at harvest. Data was collected on agronomic parameters (plant emergence, plant height, stem diameter, leaf area index, plant vigour and number of plants at harvest), yield (weight of harvested maize) and FAW infestation.

2.3.1 Plant emergence

The number of plants that emerged was counted from the 6th to 10th day after planting (DAP) and the total emergence (%) was calculated using equation 1.

$$TE = \left[\sum_t^n \left(\frac{E_t}{S} \right) \right] \times 100 \quad (1)$$

Where TE – total number of plants that emerged, E – number of plants that emerged on the day/time t, S – total number of seeds planted and n – number of days for which plant emergence was monitored.

2.3.2 Plant height (cm)

Plant height was measured from ground level to the collar of the upper leaf with developed leaf sheath using a meter rule 8 weeks after sowing. Ten plants from the center rows per bed were sampled and their heights measured. The mean obtained was reported per sample.

2.3.3 Stem diameter (cm)

The stem diameter (cm) was measured at tasseling (2.5 months after planting). The circumference (c) was measured at 2/3 the plant height and diameter (d) was calculated as follows (equation 2):

$$d = \frac{c}{\pi} \quad (2)$$

where $\pi \approx 3.14$. Sampling for the stem diameter was done in the same manner as that of plant height.

2.3.4 Leaf Area Index (LAI)

The plant was divided into three equal quadrants along the plant length and a mature leaf in the middle quadrant was used to obtain LAI (equation 3).

$$\text{LAI} = L \times W \times k \quad (3)$$

where L= Length of leaf, W = Width of leaf, and k is a constant ≈ 0.75 [24]. Sampling for the LAI was done in the same manner as that of plant height.

2.3.5 Plant vigour (PV)

Plant vigour was estimated using a three coded scale standard: Poor (1), Average (3) and Good (5). Plant vigour measurements were made 8 weeks after planting. Sampling for plant vigour was done in the same manner as that of plant height.

2.3.6 Number of plants at harvest (NPH)

The number of plants harvested per bed was counted and considered as a sample.

2.3.7 Weight of harvested cobs

The weight of the cobs harvested was measured using a scale balance at harvest (25th of July, 2024). The weight of cobs harvested is reported as ton ha^{-1} by converting the subplot area to hectare.

2.4.8 Fall armyworm (FAW) damage

The assessments of leaf damage by FAW were conducted by trained technicians who master the Davis and Williams [20] scale. The technicians were unaware of the treatments hence avoiding experimental bias. The Davis and Williams scale a nine-point scale which scores leaf damage from 1 to 9, with 1 representing no damage and 9 being the most severe damage rating (Figure 1). The plant was divided into three strata: lower, middle and upper strata. Leaf damage was scored for two randomly chosen leaves per

stratum, given a total of six leaves per plant. Sampling of the plants was done in the same manner as that of plant height.



Fig. 1 Davis and Williams scale for maize leaf damage by Fall armyworm *Spodoptera frugiperda*

2.4 Data analysis

Data collected were keyed unto an excel sheet for coding and analysis. Data were analyzed using SPSS (ver. 23). A full factorial analysis of variance (ANOVA) was used ascertain the interaction and main factor effects on the measured parameters. Where means were significantly different, they were separated using Duncan's Multiple Range Test (DMRT) *posthoc test* at alpha (α) level of 0.05. Where the blocking effect was not statistically significant, the ANOVA was redone with the blocking effect removed in order to increase the degree of freedom of the error term, thus increasing the reliability of the analysis [25]

2.5 Model development

Seven models were developed to predict yield of the CHC maize. The parameters used in the models were plant vigour, number of plants harvested and FAW damage rates. Using path analysis, Achiri et al. [26] had demonstrated that plant vigour and number of plants harvested scored the highest values as direct first-ordered and second-ordered predictors of weight of harvested CHC maize. Using linear regression models with weight of harvested maize as response variable, 3 monomial models with Plant vigour, Number of plants harvested, FAW damage as independent predictors were established. Three binomial models with plant vigour + number of plants harvested, plant vigour + FAW, and number of plants harvested + FAW as predicted were established. One polynomial model with plant vigour + number of plants harvested + FAW as predictors was established.

2.6 Statistical evaluation of model's predictive performance

For each model, the Adjusted coefficient of determination (Adj. R^2), and an Akaike Information Criteria (AIC) were calculated (equation 4 and 5, respectively).

$$\text{Adj } R^2 = 1 - \frac{\left[\frac{\text{RSS}}{n} - (\theta + 1) \right]}{\frac{\text{SS}}{n} - 1} \quad (4)$$

$$\text{AIC} = n \ln \left(\frac{\text{RSS}}{n} \right) + 2\theta \quad (5)$$

where, RSS is residual sum of square, n is the number of samples, θ is the number of parameters, SS is the total sum of squares. Adj. R^2 and AIC are usually used to

statistically compare the performance and accuracy of models [22,27-31]. Due to the relatively small sample size and a high number of parameters in the polynomial model, the AIC was corrected (AICc) for sample size using equation 6.

$$AICc = n \ln \left(\frac{RSS}{n} \right) + 2\theta + \frac{2\theta(\theta + 1)}{(n - \theta - 1)} \quad (6)$$

where, RSS is residual sum of square, n is the number of samples, and θ is the number of parameters. In order to select the best model, Delta (Δ) scores of AIC was calculated (equation 7).

$$\Delta_i = AICc_i - AICc_{\text{smallest}} \quad (7)$$

3. Results

3.1 Plant emergence

Analysis revealed that emergence of Cameroon Highland Composite maize was not affected by an interaction of variety and fertilizer doses ($F = 0.940$, $df = 9, 48$, $P = 0.50$). Fertilizer doses did not also influence the emergence ($F = 0.859$, $df = 3, 48$, $P = 0.469$). However, the emergence was significantly influenced by variety ($F = 12.137$, $df = 3, 48$, $P = 0.0001$) (Fig.2). For the CHC planted under zero fertilizer application, CHC202 had the highest emergence (90.63%), followed by CHC2023 at 66.67%. The pattern was similar across the other fertilizer doses at CHC202 dominated the others for emergence.

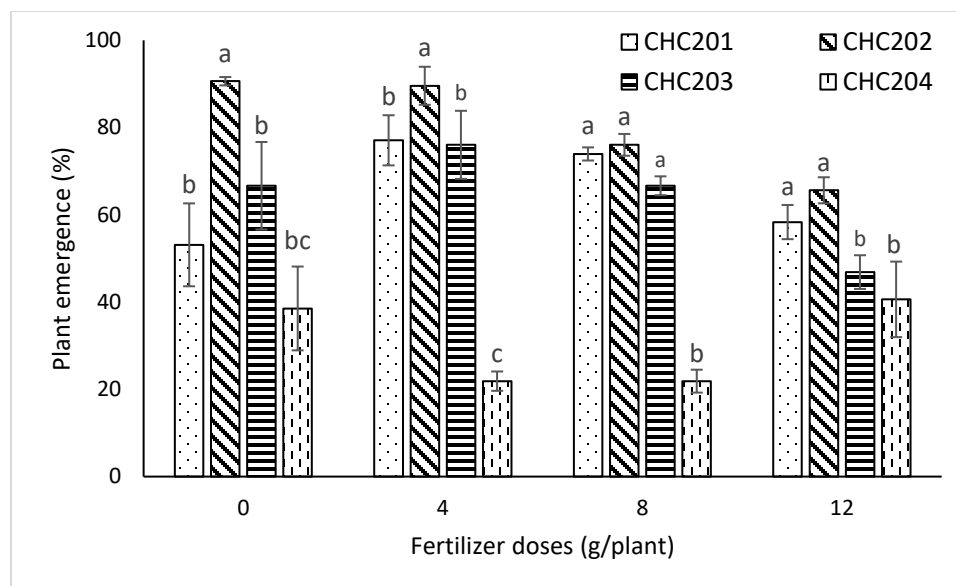


Fig. 2 Effect of NPK fertilizer doses on emergence of some Cameroon Highland Composite (CHC) maize. Mean bars within a dose of fertilizer with the same letters are not significantly different (DMRT, $P < 0.05$).

3.2 Plant height

The plant height for CHC maize did not vary based on the interaction between fertilizer and variety ($F = 0.509$, $df = 9, 48$, $P = 0.860$), as well as variety ($F = 1.393$, $df = 3, 48$, $P = 0.256$). However, plant height was significantly influenced by the fertilizer doses ($F = 10.288$, $df = 3, 48$, $P = 0.0001$) (Table 1). For CHC201 maize, the plant height increased with increased NPK doses. The plant height was 216.75cm, 201.89cm, 174.55cm and 154.65cm from 12 g/plant, 8 g/plant, 4 g/plant and 0 g/plant, respectively (Table 1). The same pattern was observed from CHC202, CHC203 and CHC204. Overall, the highest plant height was 225.80cm, observed from CHC202 maize treated with 8 g/plant, followed by 219.60cm from CHC202 maize treated with 8 g/plant (Table 2). The smallest plant heights were recorded from plants treated with 0 g of NPK.

Table 1. Effect of NPK fertilizer doses on plant height (cm) of some Cameroon Highland Composite (CHC) maize

Fertilizer (g/plant)	Maize plant height (cm)			
	CHC201	CHC202	CHC203	CHC204
0	154.65 ± 14.76Ac	157.90 ± 14.99Ab	159.20 ± 10.13Ab	165.00 ± 22.85Ab
4	174.55 ± 29.28Abc	212.10 ± 25.81Aa	199.40 ± 32.81Aa	176.17 ± 12.51Ab
8	201.89 ± 29.01Aab	219.60 ± 19.76Aa	199.10 ± 33.03Aa	191.85 ± 13.50Aa
12	216.75 ± 18.13Aa	225.80 ± 10.72aA	200.84 ± 24.36Aa	206.71 ± 21.06Aa

Means along a row with the same uppercase letter are not significantly different and means a column with the same lowercase letters are not significantly different (DMRT, $P < 0.05$).

3.3 Stem diameter and Plant vigour

Interaction of fertilizer and variety did not significantly influence stem diameter ($F = 1.159$, $df = 9, 48$, $P = 0.343$) likewise variety ($F = 0.755$, $df = 3, 48$, $P = 0.525$) (Table 2). Stem diameter varied significantly according fertilizer doses ($F = 4.765$, $df = 3, 48$, $P = 0.005$). The stem diameter increased with increasing doses of NPK fertilizer with the highest value at 3.36cm, recorded from CHC201 treated with 12 g/plant. This was followed by 2.35cm from CHC203 maize treated with 12 g/plant and 8 g/plant. At 0 g/plant of NPK, CHC202 and CHC203 had the lowest stem diameter at 1.80cm and 1.92cm, respectively (Table 2).

The plant vigour did not vary significantly based on interaction effect between fertilizer and variety ($F = 0.765$, $df = 9, 48$, $P = 0.649$). Also, the variety had no significant effect on plant vigour ($F = 0.993$, $df = 3, 48$, $P = 0.404$). However, fertilizer dose significantly influenced the plant vigour ($F = 38.916$, $df = 3, 48$, $P = 0.0001$) (Table 2). The plant vigour increased with increased dose rates for all CHC maize. The highest values for plant vigour

were 4.20 and 4.03 from CHC202 and CHC201, respectively, treated with 12g/plant (Table 2). Other close values included 3.90 and 3.85 from CHC204 and CHC202, respectively, treated with 8 g/plant. CHC maize with zero NKP application produced the smallest plant vigour: 1.2, 1.5, 1.94 and 2.0 from CHC202, CHC2023, CHC201 and CHC204, respectively (Table 2).

Table 2. Effect of NPK fertilizer on Stem diameter (cm) and Plant vigour of CHC maize

Fertilizer (g/plant)	Stem diameter (cm)				Plant vigour			
	CHC201	CHC202	CHC203	CHC204	CHC201	CHC202	CHC203	CHC204
0	1.94 ± 0.43Ab	1.80 ± 0.26Ab	1.92 ± 0.18Ab	1.95 ± 0.40Ab	1.94±0.43Ac	1.20 ±0.40Ad	1.50±1.0Ab	2.0±0.16Ac
4	2.20 ± 0.49Ab	2.25 ± 0.09Aa	2.29 ± 0.13Aa	2.25 ± 0.09Aab	2.60±0.46Ab	2.60 ± 0.65Ac	3.40±1.18Aa	3.0±0.33Ab
8	2.26 ± 0.49Ab	2.32 ± 0.11Aa	2.35 ± 0.06Aa	2.67 ± 0.16Aa	3.50±0.50Aa	3.38 ±0.33Ab	3.85±0.66Aa	3.90±0.68Aa
12	3.36 ± 0.72Aa	2.33 ± 0.40Aa	2.35 ± 0.40Aa	2.32 ± 0.51Aab	4.03±0.39Aa	4.20 ± 0.33Aa	3.75±0.53Aa	3.73±1.63Aa

Means along a row with the same uppercase letter are not significantly different and means a column with the same lowercase letters are not significantly different (DMRT, $P < 0.05$).

3.4 Leaf area index

The leaf area index (LAI) was not significantly affected by interaction effect between fertilizer doses and CHC varieties ($F = 0.516$, $df = 9, 48$, $P = 0.856$). The fertilizer doses significantly influenced the LAI ($F = 52.426$, $df = 3, 49$, $P = 0.0001$). Overall, the LAI increased with increasing doses of NPK fertilizer per plant (Fig. 3). Also, the LAI varied significantly according to CHC maize varieties (Fig. 2). The LAI ranged from 673.13 to 260.72, from CHC203 treated with 12 g/plant of NPK, and CHC201 treated with 0 g/plant of NPK respectively (Fig. 3).

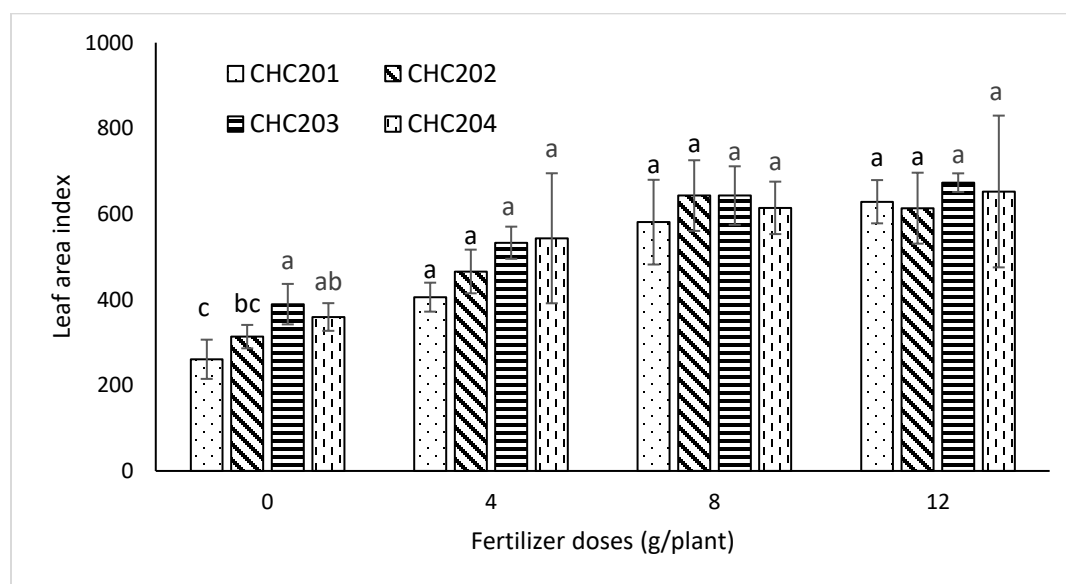


Fig. 3 Effect of NPK fertilizer doses on leaf surface area of some Cameroon Highland Composite (CHC) maize. Mean bars within a dose of fertilizer with the same letters are not significantly different (DMRT, $P < 0.05$).

3.5 Number of plants harvested

The number of plants harvested per plot was not statistically influenced by the interaction between fertilizer doses and CHC maize varieties ($F = 0.413$, $df = 9, 48$, $P = 0.922$). In addition, fertilizer doses did not influence the number of plants at harvest ($F = 0.371$, $df = 3, 48$, $P = 0.775$). Number of plants harvested was significantly affected by the varieties of CHC maize ($F = 10.215$, $3, 48$, $P = 0.0001$). The number of plants harvested per plot ranged from 5 to 10 (Table 3). In particular, the number of plants harvested per plot was 5 or 6 from CHC204. The value was either 9 or 10 for CHC203. From CHC202, the value ranged from 8 to 10, and 8 or 9 for CHC201 (Table 3).

Table 3. Effect of NPK fertilizer doses on number of plants harvested of some Cameroon Highland Composite (CHC) maize

Fertilizer (g/plant)	Number of plants harvested			
	CHC201	CHC202	CHC203	CHC204
0	8.0 ± 1.29Aa	8.0 ± 3.20Aa	9.0 ± 1.26Aa	6.0 ± 4.65Ba
4	9.0 ± 0.82Aa	9 ± 2.50Aa	10.0 ± 3.11Aa	5.0 ± 1.26Ba
8	9.0 ± 1.26Aa	10.0 ± 0.81Aa	9.0 ± 0.82Aa	5.0 ± 2.50Ba
12	8.0 ± 1.14Aa	10.0 ± 1.73Aa	9.0 ± 1.37Aa	6.0 ± 2.94Ba

Means along a row with the same uppercase letter are not significantly different and means a column with the same lowercase letters are not significantly different (DMRT, $P < 0.05$).

3.6 Weight of maize harvested

The fresh weight of CHC maize (ton/ha) treated with different doses of NPK is presented in figure 4. The interaction effect between fertilizer doses and CHC maize variety was not statistically significant ($F = 0.709$, $df = 9, 48$, $P = 0.697$). However, the fresh weight of maize harvested per plot varied significantly according to fertilizer ($F = 22.213$, $df = 3, 48$, $P = 0.0001$) and CHC maize varieties ($F = 9.887$, $df = 3, 48$, $P = 0.0001$). The highest maize fresh weight was 4 ton/ha from CHC202 treated with 12 g/plant of NPK (Fig. 4). This was closely followed by 3.50 ton/ha from CHC202 treated with 8 g/plant of NPK. The smallest maize fresh weight was 1.12 ton/ha from CHC201 treated with 0 g/plant of NPK. This was closely followed by 1.25 ton/ha from CHC204 treated with 4 g/plant of NPK (Figure 4).

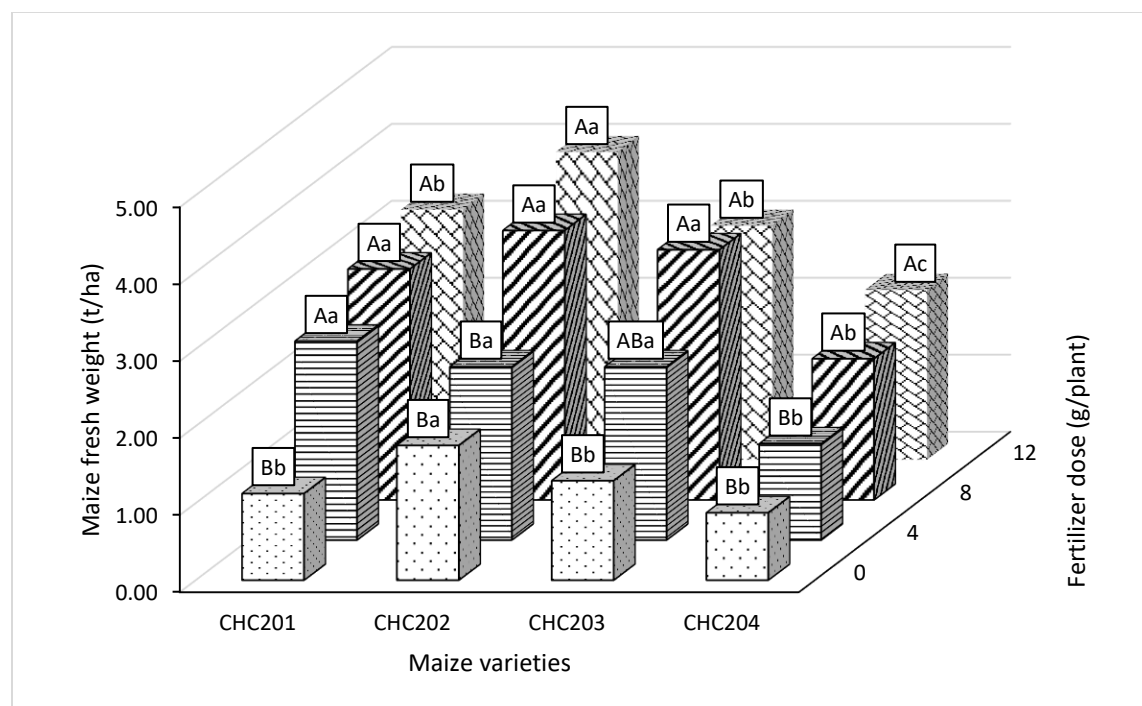


Fig. 4 Effect of NPK fertilizer doses on fresh weight of some Cameroon Highland Composite (CHC) maize. Means along a variety with the same uppercase letter are not

significantly different and means bars along a fertilizer dose with the same lowercase letters are not significantly different (DMRT, $P < 0.05$).

3.7 Fall armyworm leaf damage of CHC maize at different NPK doses

The score of FAW leaf damage on CHC maize treated with different doses of NPK reveals that interaction effects significantly influenced FAW leaf damage ($F = 2.790$, $df = 9, 48$, $P = 0.010$) (Table 4). The highest values of FAW leaf damage were observed on CHC204 maize ranging from 3.75 to 7.50. The 7.50 was recorded from CHC204 treated with 12 g/plant of NPK. It was also observed that CHC202 maize had lowest FAW leaf damage score values ranging from 1.25 to 2.25, from 0 g/plant to 12 g/plant of NPK, respectively. For all CHC maize varieties, those treated with 0 g/plant of NPK produced the lowest score of FAW leaf damage, while those treated with 12 g/plant of NPK had the highest scores of FAW leaf damage (Table 4).

Table 4. Fall armyworm infestation of some Cameroon Highland Composite (CHC) maize at different doses of NPK

Fertilizer (g/plant)	FAW leaf damage score			
	CHC201	CHC202	CHC203	CHC204
0	2.25 ± 0.50ABb	1.25 ± 0.50Bc	1.75 ± 0.50Bbc	3.75 ± 1.0Ab
4	2.25 ± 0.50Bb	1.50 ± 0.58Bbc	2.75 ± 0.96Bbc	4.25 ± 0.50Ab
8	2.75 ± 0.50BCb	1.75 ± 0.50Cab	3.50 ± 0.57ABab	4.75 ± 0.96Ab
12	5.50 ± 1.0Ba	2.25 ± 0.50Ca	5.25 ± 1.50Ba	7.50 ± 0.57Aa

Means along a row with the same uppercase letter are not significantly different and means a column with the same lowercase letters are not significantly different (DMRT, $P < 0.05$). Scores are evaluated from Davis and Williams [20] scale.

3.8 Model development and validation

Three predictors were built into regression models to predict CHC maize yield. All models except the monomial with FAW as the only predictor was not statistically significant ($y = 1.36 + 0.014f$, $Adj R^2 = 0.15$, $F = 0.088$, $P = 0.766$) with an Akaike Information Criterion value of 140.34 (Table 5). As the number of predictors in the models increased, the AIC value decreased. The lowest AIC value was 72.074 obtained from the polynomial model ($y = 0.306p + 0.162h - 0.008f$, $Adj R^2 = 0.665$, $F = 42.597$, $P = 0.0001$) (Table 5). This was followed by 83.281 and 94.881 from the binomial models between plant vigour and number of plants harvested ($y = 0.301p + 0.163h - 0.781$, $Adj R^2 = 0.670$, $F = 64.87$, $P = 0.0001$), and plant vigour and FAW ($y = 0.606 + 0.364p - 0.088f$, $Adj R^2 = 0.312$, $F = 15.316$, $P = 0.0001$), respectively (Table 5).

Two models were selected as best fit models (Figure 5) because they had lowest AIC values. The maximum likelihood estimates of the model coefficients (β) of each parameter is presented. The plant vigour ($\beta = 0.306$ for best model, and 0.301 for second best model) was the strongest predictor of maize yield compared to number of plants harvested and fall army worm infestation.

Table 5. Regression statistics for maize weight (y) produced by different predictors and statistical classification criteria for linear regression models: 3 monomial, 3 binomial and 1 polynomial regression models

Predictor	Regression characteristics						Statistical information		
	n	Regression equation	R^2	Adj R^2	F	P	AIC	AICc	$\Delta AICc$
PV (p)	64	$y = 0.192 + 0.305p$	0.288	0.276	25.04	0.0001	112.713	127.91	40.639
NPH (h)	64	$y = 0.104 + 0.165h$	0.401	0.392	41.57	0.0001	113.408	120.69	41.334
FAW (f)	64	$y = 1.36 + 0.014f$	0.001	0.015	0.089	0.766	140.34	143.67	68.266
PV and NPH	64	$y = 0.301p + 0.163h - 0.781$	0.680	0.670	64.87	0.0001	83.281	134.47	11.207
PV and FAW	64	$y = 0.606 + 0.364p - 0.088f$	0.334	0.312	15.316	0.001	94.881	129.092	22.807
NPH and FAW	64	$9.182h + 0.086f - 0.314$	0.452	0.434	25.133	0.0001	114.933	134.468	42.859
PV, NPH and FAW	64	$y = 0.306p + 0.162h - 0.008f - 0.758$	0.680	0.665	42.597	0.0001	72.074	170.740	0

PV – plant vigour, NPH – number of plants harvested, FAW – fall armyworm, n – number of samples, Adj R^2 – Adjusted R square, AIC – Akaike's Information Criterion, AICc – corrected Akaike's Information Criterion, ΔAIC – AIC delta scores (relative difference between the best model). The values in bold indicate better model performance with regard to the applied statistical criterion used.

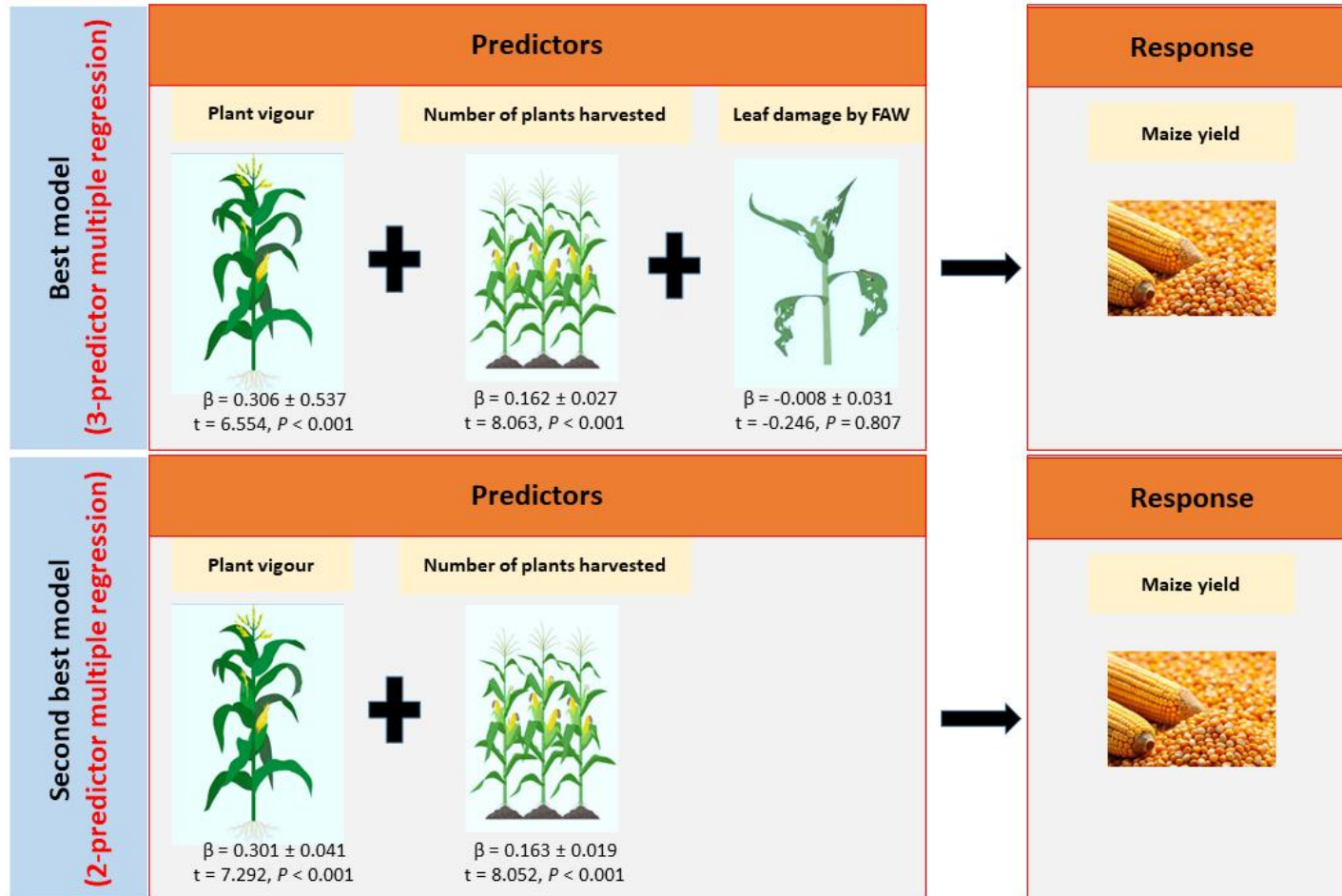


Fig. 5 Maximum-likelihood estimates of model coefficients of each parameter in the best model (3-predictor model) and second best model (2-predictor model), with their t -statistic and p -values

4. Discussion

It was observed that NPK doses did not influence the plant emergence of CHC but variety did with CHC202 having the highest plant emergence. In a similar study, Peram et al. [32] reported that NPK did not affect maize emergence percentage, rather it affected the germination rate. This suggest that the ability of the CHC maize plant to germinate and emerge is varietal dependent i.e genetic issue rather than agronomic practices such as NPK doses. Working with CHC202 only, Achiri et al. [8] concluded that NPK did influence plant emergence. They also observed that NPK doses was inversely proportional to emergence, an observation also reported by Selassie [33]. For all NPK doses, CHC202 had the highest plant emergence, suggesting that CHC202 was superior to the others based on plant emergence.

The plant height, stem diameter, plant vigour and LAI were largely dependent on fertilizer doses. It is widely reported that NPK doses has an effect on growth parameters [8,32,34,35]. The plant height increased with increased doses of NPK for all CHC maize as well as the stem diameter. Law-Ogbomo and Law-Ogbomo [36] suggest that increase height and increase maize plant diameter due to increase NPK doses is an expression of retention of considerable amount of assimilates in the stem. Similar observations on maize plant height and stem diameter were reported by Sallah et al. [37] and Brady and Well [38]. Similar to stem diameter and plant vigour, the LAI increased with increased doses of NPK. The highest LAI were recorded from 12 g/plant of NPK treatments. The LAI in the present study is consistent with that of Olowboko et al. [39] who reported that significantly higher LAI with increasing NPK doses. This high LAI of maize with increasing NPK doses is due to high nitrogen content in NPK promotes leaf area and maintain functional leaves

during vegetative growth [40]. The implication for plants with high LAI is that they are likely to optimally absorb nutrient relevant to improve yield [35].

As far as the number of plants harvested is involved, only the CHC maize variety factor had a significant influence. This trend is similar to that of plant emergence, which solely dependent on variety than fertilizer doses. Achiri et al. [8] did not also observe any effect of fertilizer doses on number of CHC202 plants harvested per plot. High numbers of plants per plot were harvested and recorded from CHC202 and CHC203. Only CHC202 and CHC203 plants had more than 50% of their plants harvested. This variation in the number of plants harvested maybe closely related to the yield. The total fresh weight of maize harvested increased with increased NPK doses. Many studies have documented that increased NPK doses can increase maize yield [8,11,41], suggesting good nutritional requirement of NPK is relevant for maize yield. In addition, it was observed that CHC202 maize outperformed the others for corresponding NPK doses. In fact, CHC202 maize at 12 g/plant of NPK produced 4.0 t ha⁻¹ of maize fresh weight, significantly higher than all other yield observed. After drying, we can be optimistic that this 4.0 t ha⁻¹ obtained from CHC202 at 12 g/plant of NPK will be equal to, if not more than 1.5 5- 2.6 t ha⁻¹ produced by traditional farmers in Cameroon [7]. This observation suggests that CHC202 is most adopted in the western highland region of Cameroon, even though not much is known about their status regarding fall armyworm defoliation.

The FAW leaf damage increased with increased fertilizer doses. For all CHC maize varieties, the leaf damage by FAW doubled from plants treated with 4 g/plants to plants treated with 12 g/plants. The FAW is known as the major pest of maize causing damage to both vegetative and reproductive parts causing severe yield depression [42]. Wang et

al. [43] had demonstrated that increased N availability in maize leads to increased preference by lepidopteran pests. The finding of the current study is in sync with that of Wang et al. [43] and Mason et al. [44]. Mason et al. [44] hypothesized that nutrient availability to maize may alter the plant resistance expression to insect herbivory. They later concluded that fertilization alter larval performance and lower fertilization hindered larval growth, which explains the observation in the current study by smaller feeding leaf area (i.e low lead damage score). In a related study in Ghana, Quandahor et al. [45] studied the effects of different rates of fertilizer (No N-fertilizer, N-fertilizer at 40 kg·ha⁻¹, N-fertilizer at 60 kg·ha⁻¹, N-fertilizer at 80 kg·ha⁻¹, N-fertilizer at 100 kg·ha⁻¹), and two levels of pesticides application (Emastar 125 EC, Pesticide-free plot), and concluded that at 100 kg/ha fertilizer rate with or without insecticides spray gave the highest number of egg mass, larvae, and mean crop damage of FAW while the least occurred on 40 kg/ha treatment.

Overall, the CHC204 maize showed extensive leaf damage by FAW with leaf damage score of 7.5 for plants treated with 12 g/plant of NPK, thus characterizing it as ‘susceptible’ [20]. All the FAW leaf damage score for CHC202 were low even at 12 g/plant of NPK (i.e < 3), unlike the others with higher scores. This may imply that CHC202 is naturally more resistant to FAW attack. The mechanism of such resistance is unclear at this time even though it is clear that plant with good growth and biomass are more prone to insect attacked than plants with poor growth and having less biomass [46], thus opening more research avenue. With such low effect of FAW on CHC202, it is not farfetched to suggest that CHC202 maize plants will produce higher yield than the others as in the case in the current study.

Initial report by Achiri et al. [26] demonstrated that plant vigour and number of plants at harvest are key first and second predictor variables of CHC maize yield in a Path analysis. In light of the leaf damage by FAW, it became imperative to assess some CHC maize yield predictive models with FAW leaf damage as a predictor. The results suggest that only the model with FAW as the sole predictor of CHC yield was not statistically significant. This a novel finding about the CHC maize, suggesting that FAW leaf damage of CHC maize is not a key determinant of yield, even though other studies suggest FAW leaf damage can considerably reduce yield of some maize varieties [42,47]. The current finding is in accordance with that of Tanyi et al. [48] who did not conclude that FAW leaf damage could predict yield of some maize hybrids (PAN-12, PAN-53 and CMS-8704) and a local landrace. The polynomial model with three predictors (plant vigour, number of plants at harvest and FAW leaf damage) had the best fit based the lowest value of the Akaike Information Criteria [27]. Here we noticed that with a binomial model of plant vigour and number of plants at harvest as predictors, the AIC value was low (83.281), but was even lower (72.074) when FAW leaf damage was added in the model, suggesting that FAW leaf damage on CHC had little effect on yield of CHC maize, with just a slight detectable impact when other predictors are considered in the model. Similar conclusions have been reached by others [49].

5. Conclusions

This study revealed that CHC maize varieties did not vary in growth parameters, however the variations observed were due to NPK doses. Overall, it was shown that CHC202 maize outperformed the other CHC maize at 12 g/plant of NPK. In addition, the lowest FAW leaf damage scores were reported from CHC202 maize. It was also learned that

FAW leaf damage alone could not predict yield of CHC maize, however slight effect could be detected for FAW leaf damage in a polynomial model with plant vigour and number of plants at harvested as predictors. The polynomial model with the lowest AIC value is best fit model for predicting CHC yield and should therefore be incorporated in the development of decision-support tools for integrated pest management of FAW and prediction of CHC maize yield. CHC202 is recommended for high yield and low FAW leaf damage.

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