The International Journal of Multi-Disciplinary Research
ISSN: 3471-7102

Assessing crop growth indices and yield parameters for maize (Zea mays L.) under irrigated condition in a subtropical environment of Zambia

(Conference ID: CFP/394/2017)

Charles Bwalya Chisanga[1,2]
[1]Ministry of Agriculture and Livestock, Box 70232, Ndola, Zambia
[2]University of Zambia, School of Agricultural Sciences, Department of Soil Science, Lusaka, Zambia
Tel: +260 955 885667; email: cbchisanga@gmail.com
Correspondence: Charles Bwalya Chisanga, Ministry of Agriculture and Livestock, Box 70232, Ndola, Zambia.

Elijah Phiri[2]
[2]University of Zambia, School of Agricultural Sciences, Department of Soil Science, Lusaka, Zambia

Vernon R.N. Chinene[2]
2University of Zambia, School of Agricultural Sciences, Department of Soil Science, Lusaka, Zambia

Abstract— *A study was conducted at Zambia Agriculture Research Institute (ZARI) Central Research Station (latitude=15.550^o S, longitude=28.250^o E, altitude=1200 m), Mount Makulu, Zambia to assess crop physiological growth indices. The field experiment was setup as a split plot design with maize variety and fertilizer rate as main and sub-treatments, respectively during the 2016 irrigated season. The crop growth indices were determined for the maize crop as a function of fertilizer application rate and variety. Fertilizer application significantly influenced the growth indices: grain yield, grain number, biomass, seeds per m-2, cob weight, ear weight, V6 (biomass) and Relative Growth Rate (RGR [R4-R6]). Maize variety also significantly influenced growth indices: husk, V6 (biomass), 100 seed grain weight, RGR (V6-R1), RGR (R4-R6), Leaf Area Ratio (LAR) (V6-R4) and Net Assimilation Rate (NAR) (V6-R4). Among the three maize varieties, ZMS606 had the highest LAR (V6-R4), grain yield (7.17 ton ha^{-1}), husk (0.38 ton ha^{-1}), seed number (2799 m^{-2}) and mean grain number (350 grains cob-1). The biomass and grain yield varied from 7.49 to 11.51 kg ha^{-1} and 5.26 to 7.73 ton ha^{-1}, respectively. In addition, the Net Assimilation Rate was significantly increased by increased N fertilization. These crop indices and yield parameters are useful for validating and calibrating DSSAT Crop simulation model.*

Keywords— *leaf area index; total dry matter; crop growth rate; relative growth rate; biomass*

I. Introduction

Maize (Zea mays L.) is the third most important cereal crop in the world after wheat and rice and is the main staple food for hundred millions of people in developing countries especially in Sub Saharan Africa [1]. In tropical Africa, nearly all the maize grain is used for human consumption, prepared and consumed in many ways. Maize grain is used for three main purposes namely: (I) as a staple food; (II) as livestock and poultry feed; and (III) as a raw material for many industrial products [2]. In Zambia, maize is a staple crop grown by both small scale farmers (80%) and commercial farmers (20%) [3], [4].

Leaf area is influenced by genotype, climate and soil fertility [5]. Leaf area index (LAI) is the product of the total leaf area and the plant population per m2 [1]. Furthermore, LAI is used as an indicator of plant growth and for evaluating assimilation, determining photosynthesis, transpiration rates and dry matter accumulation in plant physiological studies [1], [6]. Some researchers have reported that a leaf area index (LAI) between 3 and 4 may be optimal for achieving maximum yield [5], [7]. The maize plant yields high dry matter and therefore, has a high requirement for nutrients especially nitrogen (N), phosphorus (P) and potassium (K) (Aldrich et al., 1986). Nitrogen is the major nutrient that influence plants yield, and protein concentration and its deficiency reduces maize yield substantially [5]. Nitrogen is a key component to achieving high yield and optimum economic return as it plays a very important role in crop productivity [8], [9]. The deficiency of nitrogen constitutes a major yield limiting factors for maize production [5], [8]. The amount of available soil nitrogen limits yield potential and additions of nitrogenous fertilizers can substantially increase maize yield and total dry matter [5]. Nitrogen fertilization rates affects maize dry matter production by influencing leaf area development, leaf area maintenance, photosynthetic efficiency of the leaf area and accumulation of biomass and dry matter yields [10]–[12].

Plant growth analysis is a quantitative method that is used to describe and interpret the performance of the whole plant system grown under natural, semi-natural or controlled conditions accompanied by a quantitative change in biomass [13], [14]. Growth analysis is a conceptual framework for resolving the nature of genotype x environment interactions on plant growth and development. According to [11], growth analysis is one approach used to analyze plant biomass and dry matter as affected by genetic parameters, soil fertility, water availability, environmental and production technology. Maize needs 450 to 600 mm of water per season, which is mainly acquired from the soil moisture reserves [15]. [16] asserted that the analysis of plant growth is a very important method in quantitative analysis of plant growth and production of grain yield and total dry matter. The rate of plant growth indicates the partitioning of dry matter in plants and this is distinguished chronological per unit area. Crop growth rate is directly related to the amount of RI (radiation intercepted) by the crop [17]. The growth is analyzed by measuring two factors: (i) leaf area; and (ii) dry weight of the organs, and other quantities are calculated based on these two factors.

Growth analysis is the most simple and precise method to evaluate the contribution of different physiological processes in plant development. The physiological growth indices of leaf area index (LAI), total dry matter (TDM), crop growth rate (CGR), leaf area ratio (LAR), leaf weight ratio (LWR), net assimilation rate (NAR) and relative growth rate (RGR) are influenced by cultivar genetic parameters, plant population, climate and soil fertility [18], [19]. Of the parameters typically calculated, the most important is relative growth rate (RGR) [13], [14]. Therefore, the objective of this study was to investigate the effect of nitrogen rates on physiological traits, leaf area index, grain yield and total dry matter for three maize cultivars.

II. 2.0 Materials and Methods

III. *2.1 Weather data*

The weather data (latitude and longitude of the weather station, rainfall, maximum, and minimum temperature, solar radiation) was

ISSN: 3471-7102

obtained from the Zambia Meteorological Department (ZMD) (**Error! Reference source not found.**). The weather data presented in **Error! Reference source not found.** is from May 2016 to November 2016. The Tmin, Tmax, Tmean and precipitation were 14.45°C, 27.67°C, 21.06°C and 77.29 mm, respectively.

IV. *2.1 Description of study area and field experiments*

A field experiments was carried out during in 2016 at Zambia Agriculture Research Institute (ZARI) Central Research Station (latitude=15.550° S, longitude=28.250° E, altitude=1200 m), Mount Makulu under irrigated conditions. The type of soil at the study site is Makeni soil series. This type of soil is well drained, yellowish red to red (2.5-5YR), deep to very deep, clayey soil with high activity clayey, medium base saturation and clayey topsoil. It is classified in Soil Taxonomy as an Ustic Paleustalf [20] and as a Eutric Nitisol [21].

The field experiment was a Randomized Split-plot Design (RSPD) with three replicates, three maize cultivars (ZMS 606, Pioneer hybrids 30G19, and 30B50) and three nitrogen rates (56, 112 and 168 kg N/ha). Two days prior to planting, the site was disked to a depth of about 20 cm and harrowed. The three maize hybrids were planted with basal dressing (N=10,P=20, K=10) on 5th June 2016. All crop management factors were applied uniformly to the entire site. Weeds were controlled by a combination of herbicides and hoeing. Top dressing was applied after 9 weeks/at V9. Individual plot sizes were 6 meters (12 rows) by 5 meters. The plots were separated from each other by a 2 meter distance to prevent cross contamination of treatments between plots. Seeds were sown by hand at 5 cm depth in a flat seedbed in 0.50 meter row spacing and 0.30 meter spacing between plants.

V. *2.2 Soil analysis*

The soil physical and chemical analysis was done using standard methods. The following parameters were analyzed at ZARI. The soil pH in water ranged from 6.58 to 6.80 which were considered within the neutral to optimal range for crop growth. The nitrogen percentage was determined using the Kjeldahl method and the values ranged from 0.01 to 0.10 percent and therefore considered low. Soil organic carbon (OC) was determined using the Walkley and Black method [22]. The OC values ranged from 0.39 to 0.54 and considered to be low while the critical value for OC is 1.58 percent. Bray I and ammonium acetate (NH4OAc) were used to determine exchangeable phosphorus (P) and exchangeable bases (calcium, magnesium and potassium), respectively. The exchangeable bases Ca^{2+}, Mg^{2+} and K^{+} were extracted with 1.0 M neutral NH4OAc extract [22], [23] and determined using a Perkin-Elmer atomic absorption spectrophotometer at wavelength of 422.7 nm and 285 nm respectively. The K^{+} was determined using the Eppendorf flame photometer at wavelengths of 766.5 nm.

VI. *2.2 Plant growth analysis*

Phenological events (emergence, silking, dough stage, physiological maturity), leaf area index (LAI) and biomass were recorded and measured at recommended growth stages V6 (50% of plants with collar of 6th leaf visible), V8 (50% of plants with collar of 8th leaf visible), R1 (50% of plants with some silks visible outside husks), R4 (50% of plants in "dough" stage-endosperm with pasty consistency-often 24-28 days after silking) and R6 (75% of plants with black layer at the base of the seed) [2], [6], [24]–[26]. The maize leaf area was calculated by multiplying the manually measured length and maximum width and multiplied by 0.75 reported as the maize calibration factor [27].

One of the most common staging methods is the leaf collar method [28]. Each leaf stage is defined according to the uppermost leaf whose collar is visible and these are referred to as V (for vegetative) stages [2], [24], [25], [29]. The first leaf is smaller and has a rounded tip. This leaf is counted as leaf 1 when staging by this method. Four plants were staged by counting the number of leaves with visible leaf collars. If a plant has "n" number of visible leaf collars, then it was defined as being at leaf stage Vn. A field is defined as being at a specific leaf stage when at least 50% of the plants are at the given stage or beyond. Leaf fresh weight of each leaf was measured immediately after it was removed from the stalk. The dry plant matter at vegetative and reproductive stages (V6, V8, R1, R4 and R6) was determined by destructive sampling. The leaf and stem samples were oven dried at 70°C for 72 hours. Crop growth rate (CGR), net assimilation rate (NAR), leaf area ratio (LAR) and leaf weight ratio (LWR) were computed according to [5], [30]–[32] as presented below:

Leaf area index (LAI): The Leaf area index was measured according to [33]:

$$Leaf\ area\,(LA)/_{Plant\ (cm^2)} = Leaf_L * Leaf_W * 0.75$$

Leaf area duration, LAD (dyes), was determined by the formula cited by Ahmad et al. (2010) in Hunt (1978).

$$LAD = (LAI_1 + LAI_2) * (T_2 - T_1) * 0.5$$

Crop growth rate (CGR): It was calculated in terms of g cm-2 day-1 using the equation by [30]:

$$CGR = \frac{W_2 - W_1}{(T_2 - T_1)}$$

Net assimilation rate (NAR): Net assimilation rate is defined as the increase of plant material per unit of leaf area per unit of time [32]. NAR can be described by yield (g cm^{-2} day^{-1}) and leaf area per unit land area at several time intervals. It was calculated in terms of g cm^{-2} leaf area day^{-1}:

$$NAR = \frac{W_2 - W_1}{T_2 - T_1} x \frac{lnLA_2 - lnLA_1}{LA_2 - LA_1}$$

Relative growth rate (RGR): The RGR of a plant is the product of leaf area ratio (LAR; leaf area per unit total plant biomass) and net assimilation rate (NAR; dry matter gain per unit leaf area per unit time). It was calculated in terms of g g^{-1} day^{-1}:

$$RGR = \frac{lnW_2 - lnW_1}{T_2 - T_1}$$

Leaf area ratio (LAR): It was calculated in terms of cm^2 g^{-1}:

$$LAR = \frac{\frac{LA_1}{W_1} + \frac{LA_2}{W_2}}{2}$$

The symbols used in the equations above are as follows:

W1: total biomass measured at the first sampling

LA1: leaf area measured at the first sampling

W2: total biomass measured at the second sampling

LA2: leaf area measured at the second sampling

T1: first sampling time

LW1: leaf biomass measured at the first sampling

T2: second sampling time

LW2: leaf biomass measured at the second sampling

GA: ground area

ln: Natural logarithm

VII. *2.3 Statistical analysis*

Yield and yield components, LAI, leaf area (LA), total dry matter (TDM), Crop Growth Rate (CGR), Relative Growth Rate (RGR), Leaf Area Ratio (LAR), Net Assimilation Rate (NAR) and Leaf Area Duration (LAD) were subjected to analysis of variance (ANOVA) using the agricolae [35] package in R Programming software. Pertinent means were separated by means of Fisher-LSD (Least Significant Difference) Test at $p<0.05$ when the F-values were significant.

VIII. 3.0 Results and Discussion

IX. *3.1 Crop growth rate (CGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR), Leaf Area Ratio (LAR)*

Growth analysis for the three cultivars was computed as affected by variety and nitrogen fertilizer effects and interaction as presented in **Error! Reference source not found.**. The purpose of calculating growth indices is to describe how plant species response to a given environmental situation. Relative Growth Rate (RGR) was significantly affected by N rate from R4 (dough stage) - R6 (maturity) **Error! Reference source not found.**. The RGR was significantly affected by variety from R1 (silking) to R4 (dough stage) as presented in **Error! Reference source not found.** and **Error! Reference source not found.**a. Crop Growth Rate (CGR) was non-significant at all treatment levels and the finding of this research is not supported by [34] who observed variation in CGRs of different maize cultivars. The maize cultivars exhibited significantly differences in RGR (V6-R1), RGR (R4-R6 [maturity]), LAR (V6-R4) (**Error! Reference source not found.**b) and NAR (V6-R4) (**Error! Reference source not found.**c) at $p<0.05$. The mean RGR from V6 to R1 (silking) were 5.18, 5.13 and 4.79 for P30G19, P30B50 and ZMS606, respectively. Pooled mean RGR for N1, N2 and N3 were 5.127 g g^{-1} day^{-1}, 4.984 g g^{-1} day^{-1} and 4.982 g g^{-1} day^{-1}, respectively. The mean RGR was significantly affected by the N rate as presented in **Error! Reference source not found.**. Pooled data indicated that N3, N2 and N1 were 4.60 g g^{-1} day^{-1}, 4.59 g g^{-1} day^{-1} and 4.39 g g^{-1} day^{-1}, respectively. Results also showed non-significantly interaction between variety and N rate under RGR at $p<0.05$. The results as presented in **Error! Reference source not found.** shows that the interaction between variety and N rate had significant effects on the mean RGR from V6 to R1 (silking stage), while N rate had non-significant effects on RGR (V6-R1; R1-R4). [36] reported that CGR and RGR are the most important traits in plant growth analysis and plant growth analysis was reported as a suitable method for studying the response of plants to different environmental conditions.

Net Assimilation Rate (NAR) was significantly affected by the N rates and P30G19 had the highest NAR of 2.10 x 10^{-3} g cm^{-1} day^{-1} followed by P30B50 (2.00 x 10^{-3} g cm^{-1} day^{-1}) and ZMS606 (1.99 x 10^{-3} g cm^{-1} day^{-1}) (see **Error! Reference source not found.**c). Pooled for N rate indicated that N1 (2.35 x 10^{-3} g cm^{-1} day^{-1}) had the highest NAR followed by N2 (1.91 x 10^{-3} g cm^{-1} day^{-1}) and N3 (1.83 x 10^{-3} g cm^{-1} day^{-1}). The cultivars with highest N rate were more sensitive in this regard and this finding is supported by [37]. Soil moisture stress after silking notably decreased the net assimilation rate (NAR) among the maize cultivars during their growth period. The LAR was significantly affected by N rate at $p<0.05$. The mean LARs was 46.21 cm2 g^{-1}, 41.27 cm^2 g^{-1} and 32.05 cm^2 g^{-1} for ZMS606, P30B50 and P30G19, respectively. ZMS606 cultivar with higher value for LAR from V6 to dough stage gave higher grain (7171.6 kg ha^{-1}), and biomass (9839.3 kg ha^{-1}) yield, seeds per square meter (2798.7) and grain number per cob (349.8) followed by P30B50 and P30G19 as presented in **Error! Reference source not found.**, **Error! Reference source not found.**, and **Error! Reference source not found.** and similar results were reported by [31]. The results of this study are Pooled data for LAR using N rate showed that N2 (43.98 cm^2 g^{-1}) had the highest followed by N3 (38.33 cm^2 g^{-1}) and N2 (37.22 cm^2 g^{-1}) (see **Error! Reference source not found.**c). According to [32], NAR represents the plant's net photosynthetic effectiveness in capturing light, assimilating CO2 and storing photoassimilate. Variation in NAR can derive from differences in canopy architecture and light interception, photosynthetic activity of leaves, respiration, and transport of photoassimilate and storage capacity of sinks. Leaf area being an important driving variable for plant growth and the proportion of plant biomass had an important bearing on RGR. There were no interaction effects at all treatment levels for the RGR (R1-R4), LAR (V6-R4) and NAR (V6-R4), respectively.

X. 3.2 Leaf area (LA) and leaf area index (LAI)

The data for the mean leaf area and leaf area index are presented in **Error! Reference source not found.** and **Error! Reference source not found.**. Leaf area index, an important photosynthetic character and leaf area were non-significantly affected by N rates at all treatment ($p<0.05$). Although leaf area index is a factor that plays an important role in plant production for both quantitative and qualitative traits as reported by [1] it was not significantly affected by N rate. The cultivar with the highest LAI using pooled data was recorded under P30G19 (3.66) followed by P30B50 (3.41) and lastly ZMS606 (3.05). Pooled data showed that the highest LAI was recorded at N2 (3.70) followed by N3 (3.38) and N1 (3.05). The results of this study are not in agreement with [5] who reported that leaf area is influenced by genotype, climate and soil fertility. [34] reported that LAI of the crop at a particular stage of growth indicates the size of assimilatory system that ultimately contributes towards dry matter accumulation and partitioning.

XI. *3.6 Total dry matter (TDM)*

XII. *3.6.1 Grain yield, biomass, cob, husk and ear weight*

The relationships between nitrogen rate (kg ha^{-1}) and yield and yield components (kg ha^{-1}) were evaluated under irrigated conditions for 2016. Grain yield is the main target of maize production. The grain yield and husk weight were significantly affected by nitrogen rate and variety, respectively as presented in **Error! Reference source not found.**e, **Error! Reference source not found.**f and **Error! Reference source not found.**g. The highest husk weight was observed under ZMS606 (383.94 kg ha^{-1}) followed by P30G19 (301.56 kg ha^{-1}) and P30B50 (267.27 kg ha^{-1}). Pooled data for husk weight showed that N1 (375.48 kg ha^{-1}) had the highest followed by N2 (289.70 kg ha^{-1}) and N3 (287.59 kg ha^{-1}), respectively as presented in **Error! Reference source not found.**k. Grain weight (**Error! Reference source not found.**d), final biomass (**Error! Reference source not found.**e), cob weight, ear weight (**Error! Reference source not found.**f and **Error! Reference source not found.**g) and biomass at V6 (**Error! Reference source not found.**h, **Error! Reference source not found.**i and **Error! Reference source not found.**) were significantly affected by the N rate. [38], [39] reported that yield and yield component of maize were increased by increasing the rate of applied nitrogen and his results agree with the findings of this study. The vegetative growth stage (V6) was influenced by both cultivar and N rate as presented in **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.**h and **Error! Reference source not found.**i. This indicated photosynthetic capacity in maize increased with higher levels of N fertilizer rate [40]. The R2 (0.80) values between the grain yield and N for the pooled data were 5656.87, 7114.69, 7137.11 kg N ha^{-1}, respectively indicated an increase in grain yield with increasing N rate. The pooled data for grain yields were 6620.09, 6117.01 and 7171.57 kg ha^{-1} for P30B50, P30G19 and ZMS606, respectively. The ZMS606 cultivar yielded more grain compared to the two Pioneer cultivars.

The nitrogen rate had influence on accumulation of biomass and dry matter yields and [11], [41] agrees with the findings of this study. However, [42] observed that nitrogen deficiency or excess could result in reduced maize yields. Therefore, variations in the rate of nitrogen application can strongly influence yield and yield components sequentially as observed by [43]. Furthermore, the study results are in agreement with the finding of [44] and [45] who reported that increased grain yield was affected with higher rates of nitrogen application. Other researchers such as [46] and [9] have also reported increase in grain yield of maize with increase in N rate. [38] stated that applying 160 Kg N Fed-1 significantly increased ear characters and grain yield of maize. On the other hand, [40] asserted that leaf growth, leaf appearance and photosynthetic capacity in maize increases with higher levels of N fertilizer.

The coefficient of variation for final grain and biomass were 15.31 and 13.38%, respectively which are above 12% considered by [47] to be inefficient. The CV results for the final grain and biomass do not agree with the findings of [2], [47].

XIII. *3.6.2 Grain number per hectare, seed number per square meter and 100 seed weight*

Grain number per hectare and seed number per square meter were highly significantly affected by the N rate (**Error! Reference source not found.**). The number of seeds per square meter increased with higher N rate. The mean grain number for the varieties ranged from 349.8 to 281.9. The mean maximum number of grains per ear (337.4) was recorded at the highest nitrogen rate (168 kg N ha^{-1}) and mean minimum (266.6) was recorded at N application rate of 52 kg N ha^{-1} (**Error! Reference source not found.**). ZMS606 recorded the highest mean grain number of 349.8 followed by P30G19 (292.6) and P30B50 (281.9) as presented in **Error! Reference source not found.**j. On the other hand, the number of grains per ear increased with increasing rate of nitrogen. [48] agree with the findings of this study who reported that the grain number increased with increasing nitrogen rates. Increase in grains per ear at higher nitrogen rates is due to the lower competition for nutrient and this allows the plants to accumulate more total dry matter with higher capacity to convert more photosynthesis into sink resulting in more grains per ear [48]. This is also in agreement with [9] who concluded that grain number per ear was maximum at the highest nitrogen level. The R^2 (0.82) values between the grain number and N for the pooled data (281.87 (P30B50), 292.64 (P30G19), 349.83 (ZMS606), respectively) indicated a strong increase in grain number with increasing N rate. [49] also reported that the differences in grain weight could be due differences nitrogen application rates. This was attributed to variation in the response of maize cultivars' nutrition.

The seed number per square number was significantly influenced by the N rate at $p<0.05$. Pooled data indicated that the highest seed number per square meter (2699) was observed at the highest nitrogen application rate. Seed number per square meter at N1 and N2 were 2133 and 2563, respectively. The seed number per square meter for ZMS606, P30G19 and P30B50 were 2799, 2341 and 2255, respectively. The highest seed number per square meter was observed under ZMS606 (2799) and 168 kg N ha^{-1} (**Error! Reference source not found.**m). The mean 100 seed grain varied significantly ($P<0.05$) among the maize cultivars. The mean 100 seed weight for the three varieties ranged from 22.2 to 37.2. The mean maximum 100 seed weight was recorded under P30B50 (31.39 g), P30G19 (29.3 g) and lastly ZMS606 (27.53 g) (see **Error! Reference source not found.**l). Differences in the 100 seed weight has also been reported by [34]. The differences in 100 seed weight may result from differences in the initial size of the spikelets, in growth rates during the exponential and linear phases of grain filling duration of those phases. Soil moisture stress after silking notably decreased pooled values for 100 seed weight with increasing N rate (N1 [29.04 g], N2 [30.26 g] and N3[28.96 g]). [34] showed that initial grain weight after pollination was a key factor in the early growth of the kernels. The N rate was non-significant at $p<0.05$ at all treatment levels and there was no interaction between the variety and N rate.

XIV. *3.6.3 Harvest index, stover, stem, veg, and leaf at vegetative and reproductive stage*

The harvest index (HI), stover weight, stem weight, vegetative weight, leaf weight, biomass at anthesis (silking) and dough stage, leaf area index at vegetative (V6) and reproductive (anthesis and dough) stages of the three maize cultivars were not significantly affected by nitrogen application rate at $p<0.05$ and there was no interaction between treatments at all levels. The HI is defined as the physiological efficiency and ability of a crop to convert the total dry matter into economic yield. Nitrogen rates showed no significant difference for HI of the three maize varieties. The results of this study are in agreement with [38] who also observed that N application rate did not affect HI.

XV. *3.6.4 Effect of soil water content on total dry matter and grain yield*

The biomass and grain yield varied from 7493.95 - 11507.71 kg ha^{-1} and 5265.19 - 7731.56 kg ha^{-1}, respectively for all the cultivars. As the season progress less irrigation water was being applied from three times per week to one (**Error! Reference source not found.**). Water stress in maize increased with reducing irrigation water and this contributed to biomass and grain yield reduction as the season progressed. This is supported by [50] who reported that adequate soil water availability led to both a better uptake and use of the N thus increasing crop biomass and yield. Stress as a result of water deficiency from silking to maturity stage affected the ultimate size and yield of ears and it is supported by [15]. Adverse conditions such as water stress and nitrogen deficiency delay plant growth and slow silk development [43], [44]. Nitrogen is most yield limiting nutrient and its fertilization plays a significant role in improving soil fertility [44].

XVI.4 CONCLUSION

The results showed that application of different nitrogen rate influenced the physiological growth indices, yield and yield component differently for the ZMS606, P30G19 and P30B50 maize cultivars. The RGR significantly affected the maize cultivar differently based on the N rate. Net Assimilation Rate (NAR) was significantly affected by the N rates and P30G19 had the highest NAR of 2.10 x 10^{-3} g cm^{-1} day^{-1} followed by P30B50 (2.00 x 10^{-3} g cm^{-1} day^{-1}) and ZMS606 (1.99 x 10^{-3} g cm^{-1} day^{-1}). ZMS606 cultivar with higher value for LAR from V6 to dough stage gave higher grain yield followed by P30B50 and P30G19. The ZMS606 cultivar gave the highest grain yield and grain number for the pooled data followed by P30G19 and P30B50, respectively. Therefore, careful estimation of nitrogen fertilizer rates could increases optimal yield and growth rate under sustainable agriculture. This study has revealed that 168 kg N ha-1 gave the highest grain and biomass yield for the cultivars. Practically, the findings may suggest that farmers and researchers should carry out physical and chemical analysis of soils before determining the optimum amounts of fertilizers to be applied. ZMS606 with the highest values for RGR (R1-R4; R4-R6) and LAR (46.21) had the highest grain yield (7171.6 kg ha-1), seed number per square meter (2798.7) and grain number per cob (349.8) indicating that genotypic superiority for grain yield was particularly related to differences in the traits and dependent on the inherent genetic potential of the varieties themselves.

Acknowledgment

The researchers wish to thank the Agricultural Productivity Program for Southern Africa (APPSA) for financing the publication of this paper.

References

[1] J.-C. L. Lukeba, R. K. Vumilia, K. C. K. Nkongolo, M. L. Mwabila, and M. Tsumbu, “Growth and Leaf Area Index Simulation in Maize (Zea mays L.) under Small-Scale Farm Conditions in a Sub-Saharan African Region,” *Am. J. Plant Sci.*, vol. 4, pp. 575–583, 2013.

[2] C. B. Chisanga, “Evaluation of the Ceres-Maize Model in Simulating Maize (Zea Mays L.) Growth , Development and Yield At Different Planting Dates and Nitrogen Rates in a Subtropical Environment of Zambia,” MSc thesis, University of Zambia, 2014.

[3] B. P. Mulenga and A. Wineman, “Climate Trends and Farmers’ Perceptions of Climate Change in Zambia,” 2014.

[4] ZDA, *Agriculture, Livestock and Fisheries Sector Profile 2011*. Lusaka: Zambia Development Agency (ZDA), 2011.

[5] S. A. Valadabadi and H. A. Farahani, “Effects of planting density and pattern on physiological growth indices in maize (Zea mays L.) under nitrogenous fertilizer application,” *J. Agric. Ext. Rural Dev.*, vol. 2, no. 3, pp. 40–47, 2010.

[6] G. Hoogenboom, P. W. Wilkens, and G. Y. Tsuji, *DSSAT v3, volume 4*, vol. 4. Honolulu, Hawaii: University of Hawaii, 1999.

[7] J. L. Lindquist, D. A. Mortensen, and B. E. Johnson, “Mechanisms of Corn Tolerance and Velvetleaf Suppressive Ability,” *Agron. J.*, vol. 90, no. 6, p. 787, 1998.

[8] M. K. Bahadar, P. Shah, N. Maula, and S. Arifullah, “Nitrogen levels and its time of application influence leaf area, height and biomass of maize planted at low and high density,” *Pak. J. Bot*, vol. 41, no. 2, pp. 761–768, 2009.

[9] M. S. Zeidan, A. Amany, and M. F. Bahr

El-Kramany, “Effect of N fertilizer and plant density on yield and quality of maize in sandy soil,” *Res. J. Agric. Biol. Sci.*, vol. 2, no. 4, pp. 156–161, 2006.
[10] R. C. Muchow, “Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semi-arid tropical environment III. Grain yield and nitrogen accumulation,” *Field Crops Research*, vol. 18, no. 1. pp. 31–43, 1988.
[11] S. Fetahu, S. Aliu, I. Rusinovci, F. Elezi, K. Bislimi, A. Behiluli, and Q. Shabani, “Variation of physiological growth indices, biomass and dry matter yield in some maize hybrids,” *Albanian J. Agric. Sci.*, vol. 2014, p. 69, 2014.
[12] P. Shah, A. Khan, H. ur Rahman, and Z. Shah, “Plant density and nitrogen effects on growth dynamics, light interception and yield of maize,” *Arch. Agron. Soil Sci.*, vol. 54, no. 4, pp. 401–411, Aug. 2008.
[13] W. A. Hoffmann and H. Poorter, “Avoiding bias in calculations of relative growth rate,” *Ann. Bot.*, vol. 90, no. 1, pp. 37–42, 2002.
[14] R. Hunt, D. R. Causton, B. Shipley, and A. P. Askew, “A modern tool for classical plant growth analysis,” *Ann. Bot.*, vol. 90, no. 4, pp. 485–488, 2002.
[15] J. du Plessis, “Maize production,” *Resour. Cent. Dir. Agric. Inf. Serv.*, pp. 1–38, 2003.
[16] S. Eliaspour, F. Shirzadi, F. Zandian, and A. Gholami, “The effect of plant date and density on the growth index of maize variety (ksc704) in tropical region of Kermanshah Province,” *Int. J. Agron. Agric. Res.*, vol. 5, no. 6, pp. 2223–7054, 2014.
[17] J. T. Edwards, L. C. Purcell, and E. D. Vories, “Light Interception and Yield Potential of Short-Season Maize (Zea mays L.) Hybrids in the Midsouth,” *Agron. J.*, vol. 97, pp. 225–234, 2005.
[18] R. S. Sharifi, Y. Raei, and W. Weisany, “Study of physiological growth indices in maize (Zea mays L.) hybrids under different plant densities,” *Int. J. Biosci*, vol. 5, no. 3, pp. 100–109, 2014.
[19] S. Hokmalipour and M. H. Darbandi, “Physiological Growth Indices in Corn (Zea mays L.) Cultivars as Affected by Nitrogen Fertilizer Levels,” *World Appl. Sci. J.*, vol. 15, no. 12, pp. 1800–1805, 2011.
[20] USDA, “Keys to Soil Taxonomy, Tenth Edition,” 2006.
[21] FAO, *World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106*. Rome, Italy: FAO, 2015.
[22] J. H. Sato, C. C. de Figueiredo, R. L. Marchão, B. E. Madari, L. E. C. Benedito, J. G. Busato, and D. M. de Souza, “Methods of soil organic carbon determination in Brazilian savannah soils,” *Sci. Agric.*, vol. 71, no. 4, pp. 302–308, Aug. 2014.
[23] X. Wang, J. Wang, and J. Zhang, “Comparisons of three methods for organic and inorganic carbon in calcareous soils of northwestern China.,” *PLoS One*, vol. 7, no. 8, p. e44334, 2012.
[24] R. L. Nielsen, “Determining Corn Leaf Stages,” *Corny News Network*, 2014. [Online]. Available: http://www.kingcorn.org/news/timeless/VStageMethods.html. [Accessed: 08-Jul-2016].
[25] S. W. Ritchie, J. J. Hanway, and G. O. Benson, “How a corn plant develops,” 1993.
[26] S. Asseng, I. R. P. Fillery, G. C. Anderson, P. J. Dolling, F. X. Dunin, and B. A. Keating, “Use of the APSIM wheat model to predict yield, drainage, and NO3’(-) leaching for a deep sand,” *Aust. J. Agric. Res.*, vol. 49, no. 3, pp. 363–377, 1998.
[27] A. N. Karuma, C. K. K. Gachene, P. T. Gicheru, P. W. Mtakwa, and N. Amuri, “Effects of tillage and cropping systems on maize and beans yield and selected yield components in a semi-arid area of Kenya,” *Trop. Subtrop. Agroecosystems*, vol. 19, no. 2, pp. 167–179, 2016.
[28] D. S. NeSmith and J. T. Ritchie, “Effects

of soil water-deficits during tassel emergence on development and yield component of maize (Zea mays),” *Field Crops Research*, vol. 28, no. 3. pp. 251–256, 1992.

[29] K. O’Keeffe, *Procrop Maize growth & development*. State of New South Wales : NSW Department of Primary Industries, 2009.

[30] B. Ahmadi, A. Hosein, S. Rad, and B. Delkhosh, “Evaluation of plant densities on analysis of growth indices in two canola forage (Brassica napus L.),” *Eur. J. Exp. Biol.*, vol. 4, no. 2, pp. 286–294, 2014.

[31] F. A. Adebo and G. Olaoye, “Growth Indices and Grain Yield Attributes in Six Maize Cultivars Representing Two Era of Maize Breeding in Nigeria,” *J. Agric. Sci.*, vol. 2, no. 3, 2010.

[32] A. R. Saberi and H. S. Aishah, “Growth Analysis of Forage Sorghum (Sorghum Bicolor L) Varieties Under Influenced of Salinity and Irrigation Frequency,” *Int. J. Biotechnol.*, vol. 2, no. 7, pp. 130–140, 2013.

[33] G. W. McKee, “A Coefficient for Computing Leaf Area in Hybrid Corn,” *Agron. J.*, vol. 56, no. 2, p. 240, 1964.

[34] M. Ahmad, A. Khaliq, R. Ahmad, and A. M. Ranjha, “Allometery and Productivity of Autumn Planted Maize Hybrids under Narrow Row Spacing,” *Int. J. Agric. Biol.*, vol. 12, pp. 661–667, 2010.

[35] F. de Mendiburu, *agricolae: Statistical Procedures for Agricultural Research. R package version 1.2-4.* 2016.

[36] S. Zardari, S. N. Elahzade, S. Zehtab-salmasi, and B. Mohammad, “Study of growth analyze of bean (phaseolus vulgaris) in different intercropping patterns with dill (Anethum graveolens),” no. 1919, pp. 559–564, 2013.

[37] M. Hussain, W. Bashir, S. Farooq, and A. Rehim, “Root Development , Allometry and Productivity of Maize Hybrids under Terminal Drought Sown by Varying Method,” *Int. J. Agric. Biol.*, vol. 15, pp. 1243–1250, 2013.

[38] M. Arif, M. T. Jan, N. U. Khan, H. Akbar, S. A. Khan, M. J. Khan, A. Khan, I. Munir, M. Saeed, and A. Iqbal, “Impact of Plant Populations and Nitrogen Levels on Maize,” vol. 42, no. 6, pp. 3907–3913, 2010.

[39] N. Bashir, S. A. Malik, and S. Mahmood, “Influence of urea application on growth , yield and mineral uptake in two corn (Zea mays L .) cultivars,” vol. 11, no. 46, pp. 10494–10503, 2012.

[40] B. P. Yadav, D. N. Yadav, K. B. Koirala, K. R. Pandey, and Thapa R B, “Effect of preceding crops and nitrogen rates on crop growth indices of winter,” *Int. J. Curr. Res.*, vol. 8, no. 8, pp. 35520–35527, 2016.

[41] Chisanga, C. B. Phiri, and E. Shepande, “Effect of planting date and nitrogen application rate on maize (Zea mays L.) growth and yield in Lusaka, Zambia,” *Zambian J. Agric. Sci.*, vol. 9, no. 1, pp. 64–70, 2014.

[42] S. Gul, M. H. Khan, B. A. Khanday, and S. Nabi, “Effect of Sowing Methods and NPK Levels on Growth and Yield of Rainfed Maize (Zea mays L .),” *Hindawi Publ. Corp.*, vol. 2015, pp. 1–7, 2015.

[43] L. Sangoi, “Understanding plant density effects on maize growth and development: an important issue to maximize grain yield,” *Ciência Rural*, vol. 31, no. 1. pp. 159–168, 2001.

[44] J. Singh and M. S. Hadda, “Phenology and thermal indices of maize (Zea mays L.) influenced by subsoil compaction and nitrogen fertilization under semi-arid irrigated conditions,” *J. Appl. Nat. Sci.*, vol. 6, no. 2, pp. 349–355, 2014.

[45] Inamullah, N. Rehman, N. H. Shah, M. Arif, M. Siddiq, and I. A. Mian, “Correlations among grain yield and yield attributes in maize hybrids at various nitrogen levels,” *Sarhad J. Agric.*, vol. 27, no. 4, pp. 531–538, 2011.

[46] R. C. Muchow, T. R. Sinclair, and J. M. Bennett, “Temperature and Solar Radiation Effects on Potential Maize Yield across Locations,” *Agron. J.*, no. 2, pp. 338–343, 1990.

[47] K. A. Gomez and A. A. Gomez, *Statistical Procedures for Agriculture Research*, Second Edi. New York: John Wiley & Sons, 1984.
[48] A. R. Nemati and R. S. Sharifi, “Effects of rates and nitrogen application timing on yield, agronomic characterstics and nitrogen use efficiency in corn,” *Int. J. Agric. Crop Sci.*, vol. 4, no. 9, pp. 534–539, 2012.
[49] E. E. E. Kandil, “Response of Some Maize Hybrids (Zea mays L.) to Different Levels of Nitrogenous Fertilization,” *J. Appl. Sci. Res.*, vol. 9, no. 3, pp. 1902–1908, 2013.
[50] D. R. Rudnick and S. Irmak, “Impact of Water and Nitrogen Management Strategies on Maize Yield and Water Productivity Indices Under Linear-Move Sprinkler Irrigation,” *Trans. Asabe*, vol. 56, no. 5, pp. 1769–1783, 2013.

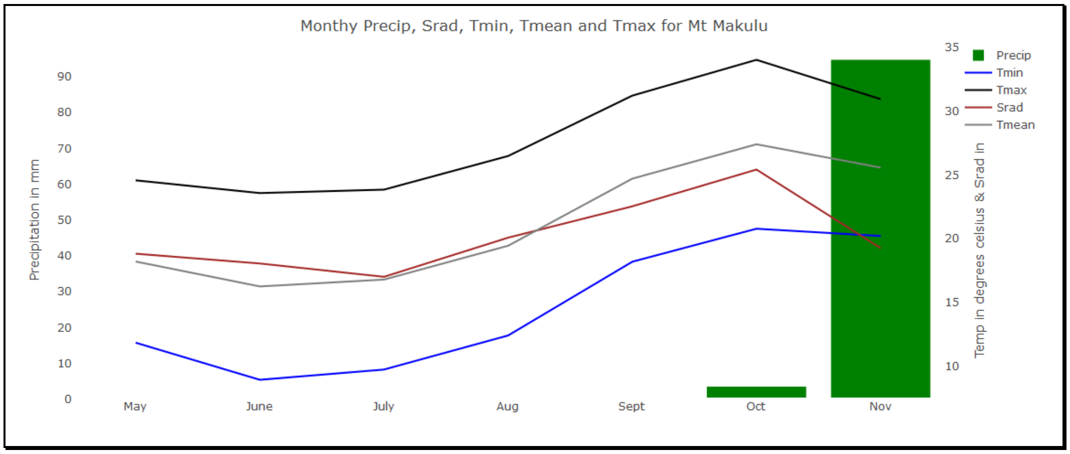


Figure 1: Monthly weather data for Mount Makulu

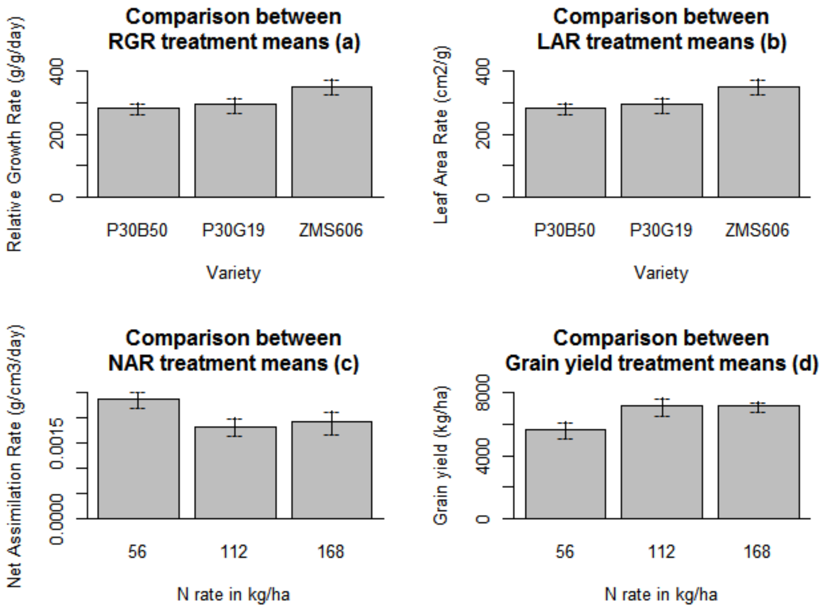


Figure 2: Comparison between treatment means for RGR, LAR, NAR and grain yield

ISSN: 3471-7102

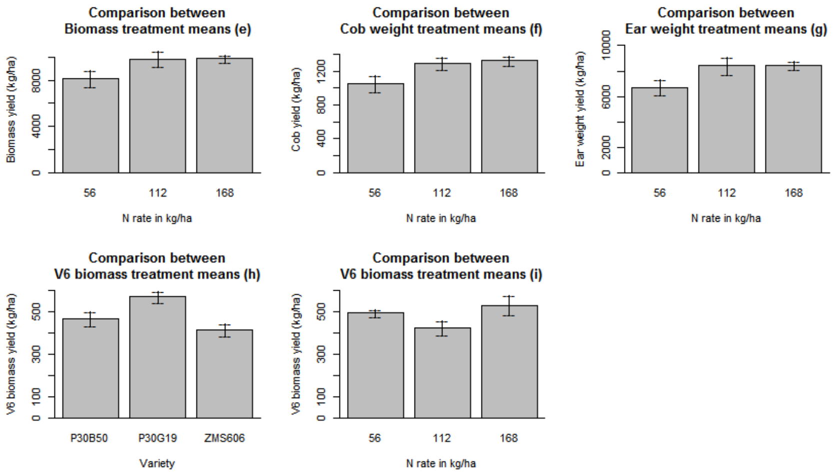


Figure 3: Comparison between treatment means for biomass, cob, ear and V6 biomass

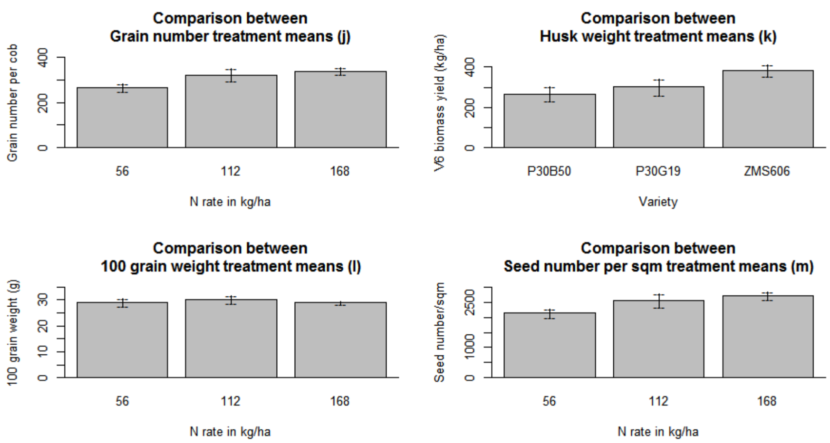


Figure 4: Comparison between treatment means for grain number, husk weight ha-1, 100 grain weight and seed number m-2

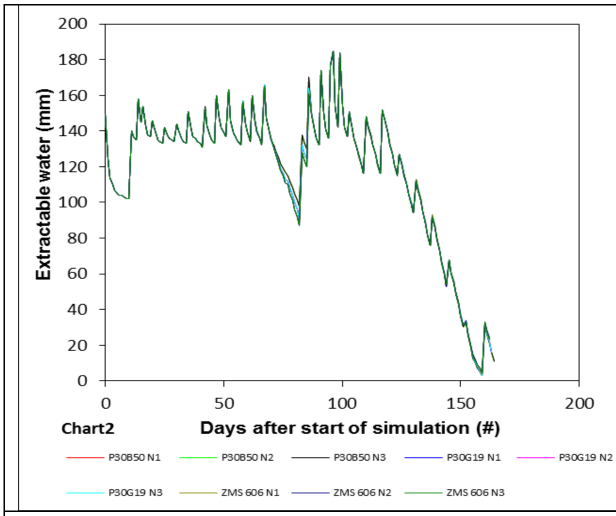
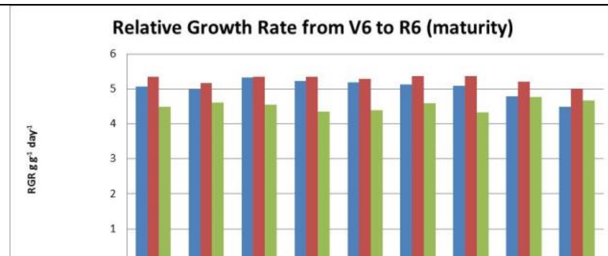


Figure 5: Extractable soil water (mm)



	N1 P30B50	N2 P30B50	N3 P30B50	N1 P30G19	N2 P30G19	N3 P30G19	N1 ZMS606	N2 ZMS606	N3 ZMS606
rgr_r1_v6.mean	5.0743	4.9817	5.3323	5.225	5.187	5.1227	5.083	4.7837	4.4913
rgr_r4_r1.mean	5.3523	5.1637	5.3453	5.3437	5.2893	5.3567	5.362	5.1957	5.0127
rgr_r6_r4.mean	4.484	4.6117	4.541	4.3527	4.3873	4.5853	4.3237	4.7613	4.676

Figure 6: RGR from V6 to R6

TABLE 1A: YIELD, YIELD COMPONENTS AND GROWTH INDICES

	Grain yield	Grain No.	Stover	Biomass	Seed no sqm^{-1}	Cob wt.	Ear wt.	Husk	Stem	Veg	Leaf
Treatment/variety											
ZMS606	7171.57[a]	349.83[a]	2668.23[a]	9839.80[a]	2798.67[a]	1172.06[a]	8343.64[a]	383.94[a]	476.83[a]	847.94[a]	371.11[a]
P30B19	6117.01[b]	292.64[a]	2590.51[a]	8707.53[a]	2341.10[b]	1224.87[a]	7884.22[a]	301.56[ab]	430.00[a]	808.44[a]	378.44[a]
p30G50	6620.01[b]	281.87[a]	2723.91[a]	9344.00[a]	2254.94[b]	1264.13[a]	7884.22[a]	267.27[a]	498.47[a]	915.44[a]	416.96[a]
Significance	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
LSD 5%	1043.9	42.67	421.91	1277.9	341.36	177.29	1212.80	108.19	127.70	235.32	118.53
CV %	15.31	23.00	18.70	21.8	23.00	24.3	23.70	14.50	19.00	23.2	33.5
Nitrogen (N) rate											
N1	5656.87[b]	266.57[b]	2509.77[a]	8166.65[b]	2132.55[b]	1050.60[b]	6707.48[b]	375.48[a]	440.01[a]	815.25[a]	375.23[a]
N2	7114.69[a]	320.35[b]	2740.85[a]	9855.54[a]	2562.81[a]	1290.29[a]	8404.86[a]	289.70[a]	498.00[a]	897.48[a]	399.48[a]
N3	7137.11[a]	337.42[a]	2732.03[a]	9869.14[a]	2699.35[a]	1320.29[a]	8457.41[a]	287.59[a]	467.29[a]	859.09[a]	391.81[a]
Significance	**	**	ns	*	**	*	*	ns	ns	ns	ns
LSD 5%	1043.90	42.67	421.91	1277.90	341.36	177.29	1212.80	108.19	129.70	235.32	118.53
CV %	15.30	13.50	15.44	13.40	13.50	14.14	15.00	33.17	27.00	26.73	29.68
Interaction (V*N)											
Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

TABLE 2B: YIELD, YIELD COMPONENTS AND GROWTH INDICES

	HI	100 grain wt	LAI at V6	V6 biomass	LAI at R4	R1 biomass	R4 biomass
Treatment/variety							
ZMS606	0.72[a]	27.53[c]	0.30[ab]	415.11[b]	3.04[a]	10270.00[b]	18483.56[a]
P30B19	0.80[a]	29.33[b]	0.26[a]	572.44[a]	3.66[a]	15197.33[a]	21042.37[a]
p30G50	0.71[a]	31.39[a]	0.37[a]	467.56[b]	3.41[a]	14244.44[ab]	20003.56[a]
Significance	ns	**	ns	*	ns	ns	ns
LSD 5%	0.04	1.72	0.10	79.92	0.80	3257.20	4095.10
CV %	2.70	4.47	33.00	14.60	22.80	25.00	16.00
Nitrogen (N) rate							
N1	0.69[a]	29.04[a]	0.30[a]	496.00[ab]	3.05[a]	14198.22[a]	21424.00[a]
N2	0.72[a]	30.26[a]	0.29[a]	426.67[b]	3.70[a]	12544.89[a]	19004.44[c]
N3	0.72[a]	28.96[a]	0.35[a]	532.44[a]	3.38[a]	12968.89[a]	19101.33[b]
Significance	ns	ns	ns	*	ns	ns	ns
LSD 5%	0.04	1.72	0.10	79.92	0.80	3257.20	4095.10
CV %	5.12	4.47	31.24	16.04	22.84	24.00	20.10
Interaction (V*N)							
Significance	ns	ns	ns	ns	ns	ns	ns

TABLE 3C: YIELD, YIELD COMPONENTS AND GROWTH INDICES

	LAD	CGR (V6-R1)	CGR (R1-R4)	CGR (R4-R6)	RGR (V6-R1)	RGR (R1-R4)	RGR (R4-R6)	LAR (V6-R4)	NAR (V6-R4)
Treatment/variety									
ZMS606	130.43[a]	2.24[b]	4.46[a]	-4.16[a]	4.79[b]	5.19[a]	4.59[a]	46.21[a]	0.002[a]
P30B19	157.02[a]	3.15[ab]	3.32[ab]	-5.93[a]	5.18[a]	5.33[a]	4.44[a]	32.05[b]	0.002[a]
p30G50	143.77[a]	3.25[a]	3.13[b]	-4.76[a]	5.12[a]	5.29[a]	4.55[a]	41.27[ab]	0.001[a]
Significance	ns	ns	ns	ns	*	ns	ns	*	ns
LSD 5%	42.31	0.97	1.16	1.83	0.32	0.20	0.31	9.48	0.0006
CV %	22.49	25.69	24.35	-28.32	4.81	2.89	5.18	18.19	21.65
Nitrogen (N) rate									
N1	130.08[a]	3.09[a]	3.97[a]	-6.23[a]	5.127[a]	5.35[a]	4.39[a]	37.22[a]	0.0023[a]
N2	155.41[a]	2.72[a]	3.55[a]	-4.31[a]	4.984[a]	5.22[a]	4.59[a]	43.98[a]	0.0018[b]
N3	145.74[a]	2.82[a]	3.39[a]	-4.30[a]	4.982[a]	5.24[a]	4.60[a]	38.33[a]	0.0019[ab]
Significance	ns	ns	ns	ns	ns	ns	*	ns	*
LSD 5%	42.31	0.71	2.34	2.12	0.32	0.20	0.31	13.57	0.0005
CV %	22.49	24.10	62.52	-41.69	4.81	2.89	5.18	33.16	20.55
Interaction (V*N)									
Significance		ns	ns	ns	ns	ns	ns	ns	ns

Means sharing the same letter in the table do not differ statistically at $p < 0.05$; N1=52 kg N ha-1; N2 = 112 kg N ha-1; N3 = 168 kg kg N ha-1; LSD = Least Mean Differences; * = Significant at 5% level; ** = Highly significant at 5%; NS = Non significant; sqm=square meter; wt = weight