Evaluation of parameters estimated by three growth analysis methods for predicting maize (*Zea mays* L.) productivity

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Identification of the best methods for growth analysis is critical for accurate prediction of crop productivity. Two important components of growth analysis in crops are growth rate (GR) and relative growth rate (RGR). Although several methods have been proposed for computing these and several other parameters of crop growth, there is paucity of information on the comparison of the methods and identification of the best method in computing GR and RGR especially of maize (*Zea mays* L.) in tropical environments. Dry matter samples obtained at 5-day intervals from 9 to 39 days after planting (DAP) from 16 maize varieties planted in three replicate randomized complete block design in four environments, were used to compute GR and RGR by three methods, in order to identify the best method for computing the growth parameters; and determine the relationship between the growth parameters and maize yield. Statistical analysis of the data showed significant differences among the methods ($P \leq 0.01$). The three methods were different in terms of mean GR and RGR. The coefficient of variation showed that the calendar-day and heat unit methods (about 49% and 13% for GR and RGR respectively) were not different from each other while the regression method (44% and 12% for GR and RGR respectively) was more efficient than both methods in computing the growth parameters. Correlation analysis showed that the calendar-day and heat unit methods were better than the regression method in predicting maize productivity. Our results revealed that the regression method was better than the calendar-day and heat unit methods in computing GR and RGR but was not as efficient as the two methods in predicting maize productivity.

Keywords: Crop physiology, growth analysis, growth rate, relative growth rate, maize (*Zea mays* L)

Maize (*Zea mays* L.), the most widely cultivated crop in the world, is an important food and feed crop, and is the third most important crop behind wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) (Ofor et al. 2010; Bakht et al. 2011). High productivity and low input requirements are two qualities that make maize an attractive crop for farmers in Africa and it is the most widely grown cereal crop in the continent (Jamil el al. 2012). Maize is mainly grown for its energy-rich grains and its production has continued to gain wider acceptability over other cereal crops in the savannas of West and Central Africa (WCA) (Fakorede et al. 2003). The numerous desirable qualities of maize have made it the crop of choice in combating the food security challenges in WCA (Badu-Apraku et al. 2010). The cultivation of maize is often impaired by biotic and abiotic factors. Biotic factors include attack by pest and diseases such as downy mildew (Fakorede et al. 2003), *Striga hermonthica* (Kanampiu et al. 2003) and stem borer (Khan et al. 2006). Abiotic constraints include extremes of weather such as drought or a sudden dry spell (Harrison et al. 2011) and declining soil fertility (Vanlauwe et al. 2006). The factors are accentuated when there is poor emergence of maize on the field followed by low seedling vigour and poor growth rate.

Accurate prediction of crop growth and development is crucial in crop production. Growth analysis involves monitoring of dry-matter accumulation in plants over time for predicting crop productivity. It uses simple primary data such as weights, area, volume and plant content to investigate processes within and involving the whole plant (Causton and Venus 1981; Hunt 1990; Hunt et al. 2002). Growth Rate (GR) and Relative Growth Rate (RGR) are important parameters in growth analysis (Hokmalipour and Darbandi 2011), both of which can be computed using different methods. The calendar-day, regression and heat unit are the most commonly used methods

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for the computation of GR and RGR in crops. The calendar-day method uses time interval between two successive samplings of dry weight as the divisor for change in dry weight and change in $\log_e$ of dry weight for GR and RGR, respectively (Radford 1967). The regression approach, on the other hand involves the linear regression of dry weight and $\log_e$ dry weight on days after planting and the regression coefficients are used as estimates of GR and RGR, respectively (Fakorede and Agbana 1983). The heat unit method is like the calendar-day method except for the divisor which is the change in accumulated heat units (a temperature index) (Russelle et al. 1984) as opposed to time used in the calendar-day method.

There is a paucity of information on the comparison of the three methods and identification of the best method for computing GR and RGR and their relationship with yield. Results of growth analysis studies summarised by Badu-Apraku and Fakorede (2017) indicated the need to investigate more deeply, the relationship between growth analysis and maize grain production in the tropical rainforest of WCA. Seedling vigour and growth parameters were found to be heritable and some of the traits showed positive correlation coefficients with grain yield. None of the studies used in the summarised report examined more than one growth analysis method. Abasi et al. (1985) compared calendar-day and heat unit in predicting silking but not growth parameters in maize. They found that the heat unit method may or may not be better than the calendar day method, depending on the equation used for the heat unit computation. Russelle et al. (1984) compared calendar-day and growing degree days (GDD), a temperature index, in carrying out growth analysis in some maize varieties that had been subjected to different treatments. They found that the use of GDD rather than calendar-days led to the recognition of physiological differences due to or associated with the treatment, which were previously masked by normal crop response to temperature. Soltani et al. (1995) carried out growth analysis on watermelon (*Citrullus lanatus*) by developing an asymmetrical curvilinear model based on cardinal temperature and found a good correlation between accumulated heat unit and early vegetative growth.

It is necessary to test the hypotheses that the different methods of computing GR and RGR are the same and that they are equally effective in predicting maize grain yield. The objectives of this study, therefore, were to (i) compute growth rate and relative growth rate of maize using the three methods; (ii) identify the best method for computing the vegetative growth parameters; and (iii) determine the relationship between the vegetative growth parameters and grain yield of maize varieties.

Materials and methods

The experiment was carried out at the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife (OAU T&R Farm) in 2013 late cropping season and in 2014 early and late cropping seasons. The farm is located at 7° 28’ N, 4° 33’ E and 244 m above sea level in the marginal areas of the rainforest agro-ecology of Southwestern Nigeria. Sixteen maize varieties were planted in a randomized complete block design in four environments represented by the different dates of planting which include plantings on 25 September 2013 and 23 May, 7 July and 29 September 2014 for environments 1, 2, 3 and 4 respectively. Environments 1 and 4 were drought stressed (210 mm and 124 mm of rainfall, respectively) while 2 and 3 were relatively well watered (474 mm and 522 mm of rainfall, respectively). Each plot contained three rows which were 5 m long and 0.75 m apart; within row spacing was 0.5 m. Each experiment was replicated three times. Prior to planting, the land was ploughed and harrowed. Three seeds were planted per hill and thinning was done at 2 weeks to two plants per stand giving an estimated plant population density of 53,333 plants ha^{-1}. Fertilizer was applied immediately after thinning at the rate of 60 kg ha^{-1} each for N, P_2O_5 and K_2O. Data on mature plant traits such as days to 50% tasselling, pollen shed, silking, and yield and its components were collected from two of the three rows. Beginning from 9 days after planting (DAP) till 39 DAP when seven samplings were completed, seedlings were removed from the third row of each plot and oven dried to constant weight at 80^{o}C and the dry weight was used to compute GR and RGR per plot by three methods.

(i) The calendar-day method, which uses time interval between two samplings as the divisor in the growth analysis formulae:

$$\mathbf{GR} = \frac{\mathrm{w2 - w1}}{\mathrm{t2 - t1}}$$

$$\mathbf{RGR} = \frac{\mathrm{logw2 - logw1}}{\mathrm{t2 - t1}}$$

where w_1 and w_2 are dry weights at times $t_1$and t_2.

(ii) The regression method, in which GR and RGR were obtained using the following linear regression models:

$$w = a + bt \text{ and } w_1 = a_1 + b_1t$$

where w is the dry weight per plant; w_1 is the log dry weight; t = time in DAP; a and a_1 are intercepts of the regression models; b and b_1 are regression coefficients representing GR and RGR, respectively.

(iii) The heat unit method in which accumulated heat units (a temperature index) between two successive samplings was used as the divisor instead of time used in the calendar-day method:

$$\mathbf{GR} = \frac{\mathrm{w2 - w1}}{\sum \mathrm{hu2} - \sum \mathrm{hu1}}$$

$$\mathbf{RGR} = \frac{\mathrm{logw2 - logw1}}{\sum \mathrm{hu2} - \sum \mathrm{hu1}}$$

Heat units were computed as:

$$HU = \sum_{i=1}^{n} \left(\frac{Xi^H + Xi^L}{2} \right) - 10$$

where X_i^H is the maximum temperature of the day adjusted to 30^{O}C where the maximum temperature of the day exceeds 30^{O}C; X_i^L is the minimum temperature of the day. The base temperature is 10^{O}C. Temperature data were collected from the meteorological station located within 100 m of the experimental plots.

Data obtained from the field and those computed, including GR and RGR were subjected to analysis of variance (ANOVA) using the PROC GLM procedure of the Statistical Analysis System, SAS (SAS, 2000), where environments and the interactions were considered random while varieties and methods were considered as fixed factors. The linear additive model for the ANOVA is given as:

$$Y_{ijkl} = \mu + \alpha_i + \beta_{j(i)} + \lambda_k + \rho_l + \alpha\lambda_{(ik)} + \alpha\rho_{(il)} + \lambda\rho_{(kl)} + \alpha\lambda\rho_{(ikl)} + \varepsilon_{ijkl.}$$

where Y_{ijkl} is the value obtained from method *l* for the kth genotype grown in rep *j* under environment *i*; μ is the grand mean; α_i is the effect of environment; $\beta_{j(i)}$ is the effect of replication nested within environment effect; λ_k is the effect of genotype (16 varieties) and ε_{ijkl} is the error term. Means were separated where significance was observed in the ANOVA using LSD at 5 % level of probability. Regression and correlation analyses were also carried out to establish the relationship between plant traits and growth analysis methods.

Results

In the combined ANOVA, highly significant differences were observed for the mean squares of the main effects i.e., environment and variety (Table 1). As expected, method of computation for GR was also significant. Environment and method of computation of mean squares were also significant for RGR but not for variety. There were also significant environment-by-method interactions for both parameters. All the relevant sources of variation (that is, without computation method, which was not a source of variation for yield) were significant for yield.

Table 1: Mean squares from the ANOVA of growth rate (GR) and relative growth rate (RGR) computed using three methods, and grain yield of 16 maize varieties in four environments

Source of variation	Df	GR[a]	RGR	Yield (t/ha)
Environment (E)	3	7.471**	0.026**	122.903**
Replication/environment	8	0.189	0.001*	2.125**
Variety (V)	15	0.610**	0.0006	4.368**
Method(M)	2	155.062**	5.484**	b
VxM	30	0.297	0.0004	b
VxE	45	0.409**	0.0008*	1.835**
ExM	6	3.466**	0.0107**	b
ExVxM	90	0.195	0.0004	b
Error	376	0.203	0.0005	0.353
CV,%		63.37	17.50	35.80

*,** significant F-test at 0.05 and 0.01 level of probability, respectively. CV- coefficient of variation.

[a] GR is in g/day in calendar-day and regression methods and in g/hu in heat unit method. RGR is in g/g/day in both calendar-day and regression methods; and in g/g/hu in heat unit method.

b Method is not a source of variation for yield.

Mean values for the two parameters were highest for the linear regression method followed by the calendar-day method and lowest for the heat unit method (Table 2).

Table 2: Mean and LSD values for the methods used in generating growth rate (GR) and relative growth rate (RGR)

Method	GR	RGR
Regression	1.7275 g/day	0.3214 g/g/day
Calendar	0.3791 g/day	0.0621 g/g/day
Heat unit	0.0242 g/hu	0.0040 g/g/hu
LSD$_{0.01}$	**0.1189**	**0.006**

LSD - Least Significant Difference

The highest mean value was in environment 1 for GR and the lowest was in environment 2 (Table 3). For RGR, environment 4 had the highest value, while environment 2 had the lowest. The four environments were significantly different for grain yield. Environment 3 had the highest yield, followed by environment 2 while environment 4 had the lowest yield

Table 3: Mean and LSD values for growth rate (GR), relative growth rate (RGR) and grain yield of 16 maize varieties evaluated in four environments

GR[a]		RGR		Yield	
Environ	Mean	Environ	Mean	Environ	Mean (t/ha)
1	0.9224	4	0.1410	3	2.7391
3	0.7960	3	0.1377	2	2.0752
4	0.7330	1	0.1272	1	1.1567
2	0.3897	2	0.1107	4	0.6750
$LSD_{0.01}$	**0.1373**	**$LSD_{0.01}$**	**0.0069**	**$LSD_{0.01}$**	**0.1815**

[a] GR is in g/day in calendar-day and regression methods and in g/hu in heat unit method. RGR is in g/g/day in both calendar-day and regression methods; and in g/g/hu in heat unit method.

Environment 2 was significantly lower in estimating GR than the other 3 environments using calendar-day and regression methods (Figure 1), but not for the heat unit method. The regression method and environment 2 had a significantly lower interaction mean than the interaction of the same method with the other three environments (Figure 2). This was not so for the calendar-day and heat unit methods and their interactions with the four environments because, the means for the interactions were not significantly different.

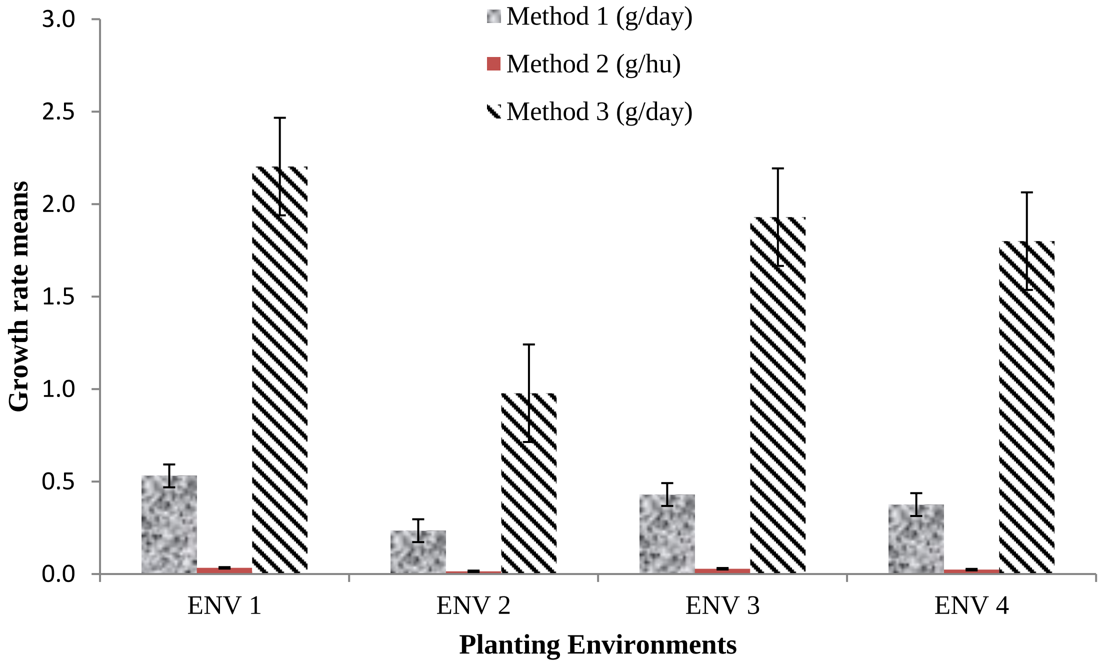

Figure 1: Mean (± standard error) for three methods of growth rate computation for 16 maize varieties evaluated in each of four environments. Method 1 – calendar-day method, method 2 – heat unit method, method 3 – regression method.

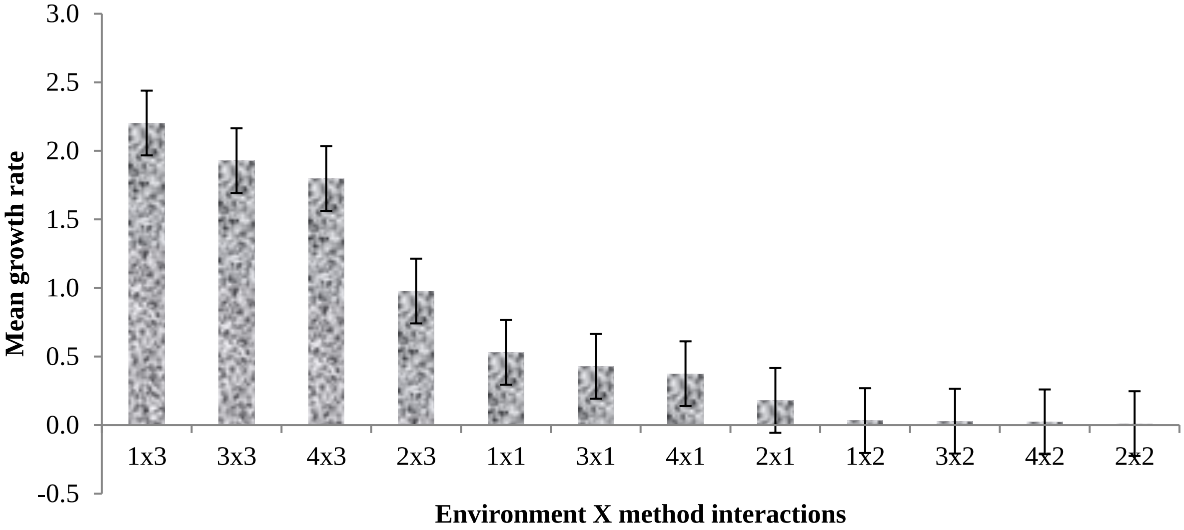

Figure 2: Mean (± standard error) of the interaction between environments and methods for growth rate. The first number in each interaction on the horizontal axis represents environment while the second number represents method e.g.1x3 implies environment 1 by method 3 interaction.

Table 4: Mean squares and coefficients of variation for growth rate (GR) and relative growth rate (RGR) for each of the three growth analysis methods

		CALENDAR –DAY		HEAT UNIT		REGRESSION	
Source of variation	Df	GR(g/day)	RGR(g/g/day)	GR(g/hu)	RGR(g/g/hu)	GR(g/day)	RGR(g/g/day)
Environment (E)	3	1.042**	0.0064**	0.00432**	0.000032**	13.357**	0.0418**
Replication/environment	8	0.016	0.00004	0.00006	0.0000002	0.391	0.0030*
Variety (V)	15	0.078**	0.00008	0.00031**	0.0000003	1.125*	0.0013
VxE	45	0.055*	0.00009*	0.00022*	0.0000003	0.745	0.0016
Error	120	0.035	0.00006	0.00014	0.0000003	0.586	0.0014
CV,%		**49.01**	**12.65**	**49.34**	**12.74**	**44.30**	**11.70**

,* significant F-test at 0.05 and 0.01 level of probability, respectively. CV- coefficient of variation

The coefficients of variation (CV) were between 44 - 49% for GR and 11 - 12% for RGR for the three methods (Table 4). The CVs estimated by the calendar-day and heat unit methods were quite similar for GR (49.01% and 49.34%) and RGR (12.65% and 12.74%). The regression method had the lowest CV of the three methods (44.30% for GR and 11.70% for RGR).

The calendar-day and heat unit methods (Tables 5 and 6) had similar correlation coefficients (r-values) with other agronomic traits, including grain yield. Of a total of 98-100 comparisons, each of the two methods had exactly the same 16 significant r-values of about the same magnitude, apart from slight 1-2 percentage point differences. The regression method (Table 7), on the other hand, had fewer significant r-values (12 of 100) with other agronomic traits. However, the magnitude and direction of the significant correlation coefficients were quite similar for the three methods. For example, plant height, ear heights and grain yield, whenever significant, showed positive r-values with GR and RGR for each of the three methods. All other significant r-values were negative.

Table 5: Correlation coefficients of growth rate (GR) and relative growth rate (RGR) obtained by the calendar-day method with other agronomic traits in 16 maize varieties planted in four environments

	Environment 1		Environment 2		Environment 3		Environment 4		All environments	
TRAITS	GR	RGR	GR	RGR	GR	RGR	GR	RGR	GR	RGR
DTT	-0.47	-0.51*	-0.13	-0.02	-0.31	-0.12	0.13	0.11	-0.20	0.09
DTA	-0.47	-0.46	-0.13	-0.01	-0.22	-0.04	0.18	0.18	-0.19	0.15
DTS	-0.56*	-0.44	-0.17	-0.03	-0.35	-0.19	-0.05	-0.11	-0.32	0.05
ASI	0.10	0.26	-0.12	0.16	-0.14	-0.22	-0.60*	-0.69**	-0.31	-0.40
PPP	-	-	-0.08	-0.19	0.08	0.07	-0.04	-0.31	-	-
PASP	-0.36	-0.12	-0.38	-0.05	-0.34	-0.47	-0.65**	-0.66**	-0.32	-0.39
PHT	-0.12	-0.37	0.36	0.29	0.68**	0.69**	0.45	0.62*	0.37	0.45
EHT	-0.32	-0.43	0.56*	0.53*	0.67**	0.72**	0.36	0.49	0.21	0.34
EASP	-0.50*	-0.28	-0.46	-0.05	-0.08	-0.26	-0.48	-0.48	-0.18	-0.40
Yield	0.37	0.32	0.48	-0.01	0.28	0.45	0.62*	0.82**	0.32	0.41

*,** significantly different from zero at 0.05 and 0.01 level of probability, respectively.

DTT= days to tasseling, DTA= days to anthesis, DTS= days to silking, ASI = anthesis-silking interval, PPP= number of plants per plot, PASP= plant aspect rating, PHT= plant height (cm), EHT= ear height (cm), EASP= ear aspect rating.

Table 6: Correlation coefficients of growth rate (GR) and relative growth rate (RGR) obtained by the heat unit method with other agronomic traits in 16 maize varieties planted in four environments

	Environment 1		Environment 2		Environment 3		Environment 4		All environments	
TRAITS	GR	RGR	GR	RGR	GR	RGR	GR	RGR	GR	RGR
DTT	-0.46	-0.55*	-0.13	-0.02	-0.32	-0.12	0.13	0.11	-0.20	0.08
DTA	-0.47	-0.49	-0.13	-0.01	-0.22	-0.04	0.18	0.18	-0.19	0.13
DTS	-0.55*	-0.46	-0.17	-0.03	-0.35	-0.20	-0.05	-0.11	-0.32	0.04
ASI	0.11	0.30	-0.12	0.16	-0.14	-0.22	-0.61*	-0.70**	-0.31	-0.36
PPP			-0.08	-0.19	0.09	0.06	-0.04	-0.31	-	-
PASP	-0.36	-0.08	-0.38	-0.05	-0.34	-0.47	-0.65**	-0.66**	-0.33	-0.40
PHT	-0.13	-0.40	0.36	0.29	0.68**	0.69**	0.45	0.62*	0.37	0.42
EHT	-0.31	-0.47	0.55*	0.53*	0.67**	0.72**	0.36	0.49	0.21	0.37
EASP	-0.50*	-0.25	-0.46	-0.05	0.08	-0.26	-0.48	-0.48	-0.18	-0.39
Yield	0.37	0.29	0.48	-0.01	0.28	0.45	0.62*	0.82**	0.32	0.42

*,** significantly different from zero at 0.05 and 0.01 level of probability, respectively.

DTT= days to tasseling, DTA= days to anthesis, DTS= days to silking, ASI = anthesis-silking interval, PPP= number of plants per plot, PASP= plant aspect rating, PHT= plant height, EHT= ear height, EASP= ear aspect rating.

Table 7: Correlation coefficients of growth rate (GR) and relative growth rate (RGR) obtained by the regression method with other agronomic traits in 16 maize varieties planted in four environments

	Environment 1		Environment 2		Environment 3		Environment 4		All environments	
TRAITS	GR	RGR	GR	RGR	GR	RGR	GR	RGR	GR	RGR
DTT	-0.41	-0.15	-0.27	-0.21	-0.31	-0.16	0.09	-0.003	-0.13	0.12
DTA	-0.43	-0.17	-0.27	-0.17	-0.21	-0.05	0.12	0.02	-0.12	0.15
DTS	-0.53*	-0.17	-0.32	-0.27	-0.35	-0.20	-0.05	-0.07	-0.24	0.07
ASI	0.09	0.07	-0.19	-0.10	-0.13	-0.17	-0.54	-0.37	-0.34	-0.36
PPP	-	-	-0.05	-0.33	0.13	0.09	0.05	-0.26	-	-
PASP	-0.41	-0.40	-0.20	0.02	-0.38	-0.44	-0.61*	-0.45	-0.37	-0.45
PHT	-0.08	-0.13	0.18	0.25	0.72**	0.76**	0.42	0.54*	0.41	0.46
EHT	-0.28	-0.02	0.34	0.43	0.69**	0.77**	0.28	0.38	0.29	0.44
EASP	-0.53*	-0.28	-0.26	-0.03	-0.11	-0.22	-0.51*	-0.28	-0.21	-0.44
Yield	0.41	0.56*	0.36	-0.05	0.29	0.39	0.55*	0.74**	0.38	0.39

*,** significantly different from zero at 0.05 and 0.01 level of probability, respectively.

DTT= days to tasseling, DTA= days to anthesis, DTS= days to silking, ASI = anthesis-silking interval, PPP= number of plants per plot, PASP= plant aspect rating, PHT= plant height, EHT= ear height, EASP= ear aspect rating.

Discussion

Results showed that the three methods of computing GR and RGR were different from one another. This probably resulted from the different approaches to computation in the three methods. The major difference between the calendar-day method and the heat unit method was in the divisor used in the respective equation. The divisor in the calendar-day method assumes a constant value of dry matter per day for each sampling interval whereas the heat unit method computes each parameter based on dry matter produced per heat unit. This was probably more realistic since the heat unit was not constant per day for any sampling interval. Indeed, throughout the course of this experiment, the mean heat units were not lower than 70 for each environment (77.0, 77.9, 70.7 and 76.3 in environments 1, 2, 3 and 4 respectively). In other words, while the divisor was constant in the calendar-day method, it was not in the heat unit method because the daily mean temperatures were rarely the same. The regression method has a flaw similar to that of the calendar-day method but perhaps on a wider scale. The method assumes a constant gain of dry matter per day, not just for the sampling interval but for the full period of experimentation. The method, however, has the advantage of taking the least square of all the data to arrive at a perfect fit. This might be a reason for the higher mean values observed for the method. Separate ANOVAs that were performed for individual methods showed that the significant traits in one method remain so in the other methods, the CV were quite comparable, especially for RGR, and the magnitude and direction of the significant r-values were also quite comparable.

As expected, the environments were also highly significantly different from one another. Under the natural cropping conditions of this study, environments 1 and 4 were drought-stressed while the other two were relatively well-watered. Apart from precipitation, there were also variations in temperature, solar radiation, evapotranspiration, and relative humidity. The fact that environment 2, being well-watered, had the lowest mean values for both GR and RGR when compared with the other environments was surprising. For this environment, planting was done on 23 May 2014, a typical early season with adequate rainfall for maize growth and productivity. However, drought conditions did not fully occur in the drought stress environments until flowering, or a few days prior to flowering. At OAU T&R Farm, rains did not cease altogether until the first week of November in both years 2013 and 2014 and both drought stressed experiments were planted in late September (27 and 29 for environments 1 and 4 in 2013 and 2014, respectively); although there were intermittent periods of short dry spells. Since sampling for dry matter lasted for 30 days i.e., from 9 – 39 DAP, the dry matter accumulation of the crops was not really affected by drought. Furthermore, since the solar radiation around this time became more intense which, in turn, caused an increase in temperature, the growth rate might be significantly altered. Also, the varieties used were either drought tolerant and/or early maturing. The earliness of maturity is a drought avoidance or escape mechanism. These reasons could be why the maize varieties evaluated under the well-watered environments did not outperform those planted in water-stressed environments in terms of mean GR and RGR, as would have been expected. Also, environment 1 produced a higher mean GR than 4. Both were water-stressed environments. Environment 3 also produced a higher mean GR than environment 2 both being well-watered environments. For RGR, in environment 4, mean was higher than environment 1 while environment 3 produced a higher mean than environment 2. Hence, the ranking of the two environments that were well-watered was consistent for both parameters while the ranking was reversed in the two water-stressed environments. This suggests that the availability of moisture or lack of it impacted the two growth parameters differently.

The trend observed for grain yield was contrary to that observed in the two growth parameters, although it is the expected trend in grain yield moving from well-watered to drought-stress environments. According to Harrison et al. (2011), warming temperatures speed up plant development, shortening the length of growth periods necessary for optimum plant and grain size. Schlenker and Lobell (2010) observed that impacts of aggregated crop yield due to temperature changes are much stronger than impacts due to precipitation changes, though this contradicts the finding of Rivington and Koo (2011) that precipitation variation had the greatest influence on crop yields for a number of crops. In the present study, both factors could be said to have affected the yield in environments 1 and 4 causing them to be significantly lower than the yield in environments 2 and 3, with precipitation change having a greater effect on maize yield (Waha et al. 2013).

It is a well-known fact that fluctuations in precipitation during the critical stage of flowering could cause a drastic yield reduction while increased temperature beyond a threshold could result in alteration in the physiology of crops, shortening the growth cycle especially the grain filling phase (White and Reynolds 2003), and failure in pollination (Harrison et al. 2011) thereby causing poor yield. Furthermore, temperature also influences other processes such as evapotranspiration which could cause moisture to be drained faster from the plant as well as the surrounding soil. Yield was higher in environment 3 than 2 (both well-watered environments), while environment 1 produced a higher grain yield than environment 4 which were both water stressed. The higher yield in environment 3 could be attributed to favorable climatic conditions but, more importantly, better soil conditions which were noticeable during the experiment. Similarly, the higher grain yield observed in environment 1 over environment 4 could be attributed to the severity of drought condition experienced in environment 4. At the OAU T&R Farm, it stopped raining shortly after flowering had begun at around mid-November, 2014 and it barely rained for the rest of that cropping season contrary to environment 1, in which there were few precipitations after flowering. The fact that the four environments did not rank the same for GR, RGR and yield indicated that the growth parameters might not be directly related to maize grain productivity.

The significant interaction between environment and method (Table 1) indicates that the efficiency of each method might be influenced by the type of environment used to estimate GR and RGR; efficient in one environment and may not be as efficient when the environment changes. This is an area where the regression method excelled. The regression method was sensitive enough to show that environment 2 interacted differently with it than the other three environments which would seem to corroborate the results observed in Table 3 where environment 2 had the lowest means for GR and RGR. The fact that the regression method was able to pick this up where the other two methods failed, is an indication of its advantage of finesse over the calendar-day and heat unit methods.

The CV showed that the calendar-day and heat unit methods were not better than each other. Abasi et al. (1985) suggested parameters estimated by the heat unit method may or may not be better than those estimated by the calendar-day method if the structure of the equation used in computing heat units is not much related to the true effects of recorded temperatures on growth in a particular environment. Results of the present study corroborate their suggestion to the extent that there was no clear-cut difference between the two methods even though the heat unit equation used in this study was the one Abasi et al. (1985) found to be the best in computing the heat units in their study. The regression method, on the other hand, because it had the lowest CV, seemed the most efficient of the three methods for computing GR and RGR. However, the regression method had fewer correlations with grain yield and other agronomic traits than the other two methods which were not different from each other in their correlations with grain yield and other agronomic traits. It would seem therefore, that the regression method is less efficient for estimating growth parameters to accurately predict maize productivity.

Conclusion

It can be concluded that the calendar-day, heat unit and regression methods were different in estimating GR and RGR. The regression method was better than the calendar-day and heat unit methods in computing GR and RGR but was not as efficient as the other two methods in predicting maize productivity.

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