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Diagnosing Maize Growth for Determination of Optimum Fertilizer Application Time in Northern Malawi

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Abstract

Plant diagnosis was proven to be useful for predicting maize growth condition. The number of days to male flowering and that to silk emergence differed among the four sites, reflecting differences in growth condition. Maize stalk weight decreased when the number of days to male flowering exceeded 65. Two growth indexes (GIs), plant height and stem diameter, well predicted maize fresh weight as expressed by the equation: Fresh weight = -0.013 + 1.26 × (Plant height × Stem diameter) ($r^2 = 0.57$). Those two parameters changed with the growth stage according to the maize growth condition. GI monitoring revealed that week 4 (W4) or week 8 (W8) after germination was the determinant of overall maize growth. Leaf color also changed in the course of growth; leaf color at W4 was the best indicator of maize grain yield. Such plant diagnosis parameters as GI and leaf color are useful for the determination of optimum fertilizer application time.

Keywords: plant diagnosis, growth index (GI), compost, leaf color

1. Introduction

Maize (*Zea mays* L.) is the most important crop in Malawi (JAICAF, 2008). However, Malawi has been experiencing high seasonal variability in maize yield in the last few decades. A 43% national food deficit was recorded in 2005 and a 53% surplus, in 2007 (Denning et al., 2009). Besides climatic condition, one of the major factors controlling maize yield is fertilizer application. The government of Malawi has been offering chemical fertilizer subsidies to farmers since 2006 (Dorward & Chirwa, 2011). For one bag of fertilizer (50 kg) sold at the market price of around 15,000 MKT (60 US dollars as of Oct 2014), farmers could purchase it at 500 MKT (= 1 US dollar).

Concern about farm nutrient management has grown given the high fertilizer price in Malawi. It is therefore important to apply an optimum amount of fertilizer at the time when it is most efficiently utilized. There is room for improvement of fertilizer use. Delayed access to seeds and fertilizers is a recurring complaint among farmers in Malawi and elsewhere in Africa. The timing of fertilizer application should be specified as delayed application can sharply reduce uptake efficiency (FAO/IFA 2000; Denning et al., 2009). A simple yet appropriate method is therefore required to determine the optimum fertilizer application time.

Plant diagnosis involves the monitoring of crop growth condition using the growth index (GI) that adopts appropriate and convenient crop parameters, such as crop height and leaf color. Leaf color well explained rice N condition (Takebe & Yoneyama, 1989). N fertilizer requirements of maize crops were measured by a leaf color chart (LCC) and found to be positively correlated with the actual levels of N required (Efendi et al., 2012). Leaf color, which reflects maize N nutrient status, can be easily identified by a chlorophyll meter or LCC.

The Sustainable Land Management Promotion Project (SLMP) was implemented in November 2011 through collaborations between the governments of Malawi and Japan. The aim of SLMP is to promote the use of sustainable land management technologies among smallholder farmers in the country. SLMP also intends to improve soil fertility through compost application. Different types of compost were made primarily from maize residue. In this study, we assessed the growth of maize variety SC627 through GI measurements and examined the usefulness of LCC in determining leaf N status. Moreover, the relationship between LCC and maize growth was examined in two cropping seasons.

2. Materials and Method

2.1 Site Description

This study was conducted at four research stations of the Department of Agricultural Research and Service (DARS) located in the northern districts of Malawi (Figure 1). The average annual precipitation at the four stations from 2002 through 2012 was 1,219 mm for Banga, 1,008 mm for Lunyangwa, 1,346 mm for Ntchenachena, and 1,439 mm for Nkhatabay. The major upland soils of this zone were ferralsols and acrisols (FAO/Unesco, 1974).

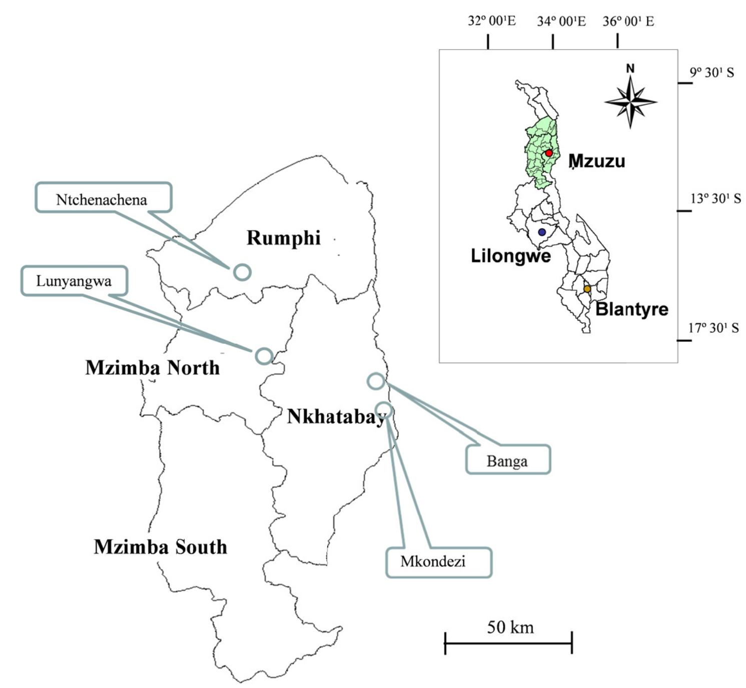

Figure 1. Locations of four study sites: Lunyangwa, Banga, Mkondezi, and Ntchenachena DARS stations

Variety SC637 was cultivated for the maize growing test in the 2013/14 and 2014/15 cropping seasons. A split plot measuring 3 × 3.5 m was designed with three replications. In order to avoid border effects, maize from two middle rows of each split plot was harvested and weighed fresh *in situ* to examine correlation with leaf color.

2.2 Compost Preparation

Two methods (Changu and Windrow) in three environments (Open, Shade, Plastic) were adopted for compost making (Figure 2). The amount of compost applied was calculated on the basis of N content in the respective composts. Application rate was adjusted to 92 kgN/ha, the recommended level in the Guide to Agricultural Production published by the Ministry of Agriculture (MOA, 1991). 46 kgN was used for basal application and the remaining 46 kgN was used as top dressing. In the case of chemical fertilizer application, two application rates, recommended rate (92 kgN/ha) and conventional rate (46 kgN/ha), were adopted. NPK (Nitrogen, Phosphorous, and Potash (Potassium)) was used for basal application and urea, as top dressing.

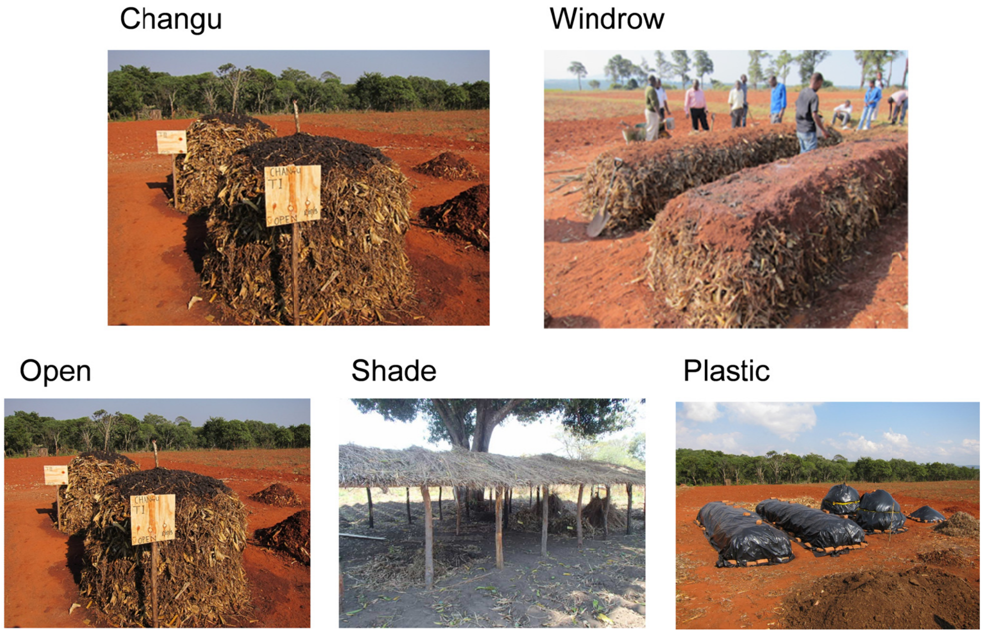

Figure 2. Two methods (Changu, Windrow) and three environments (Open, Shade, Plastic) for composting

Table 1. Compost and inorganic fertilizer application rates

Treatment Category		Results of Analysis		Application Rate	
		Total Nitrogen (%)	**Moisture** (%)	**Basal** (kg/plot)	**Top Dressing** (kg/plot)
Compost	Open	1.13	33.4	6.4	6.4
	Changu Shade	1.13	25.6	5.7	5.7
	Plastic	1.12	26.9	5.9	5.9
	Open	1.10	33.4	6.6	6.6
	Windrow Shade	1.11	25.6	5.8	5.8
	Plastic	1.13	26.9	5.8	5.8
RCF	NPK 23-21-0	23		0.11	
	Urea	46		0.05	0.11
CCF	NPK 23-21-0	23		0.21	
	Urea	46			0.11
Mixture	Compost	1.32	19.8	4.6	
	Urea	46			0.11
Control	No composts and no inorganic fertilizers				

Note. RCF = Recommended Chemical Fertilizer (92 kgN/ha); CCF = Conventional Chemical Fertilizer (46 kgN/ha); Mixture = Chemical Fertilizer (Urea) 50% + Compost 50%.

2.3 Plant Diagnosis

A two-year crop calendar at the four stations was made for Control in which sowing, germination, male flowering, silk emergence, and harvest dates were recorded. Effect of the number of days to male flowering on maize stalk weight was examined in Mkondezi. In order to elucidate the growth parameters related to maize yield, ten parameters, namely, stem perimeter and diameter, ear height and diameter, leaf number, cob weight, fresh weight, leaf weight, stalk weight, and cob sheath, were measured at harvest in 30 individual maize plants in Lunyangwa.

Leaf color was monitored for two years at the four stations. At each fertilizer treatment, leaf color was measured by the Leaf Color Chart (Fujihira Co., Ltd., Japan). Leaf color was measured in 24 leaves at weeks 4 (W4), 8 (W8), 10 (W10), and 13 (W13), and the mean values were used for analysis. Multiple regression analysis was conducted with maize yield as the independent variable and leaf color index at different times as the dependent variable, using software JMP 8.0.2 version for Windows (SAS Inc., 2009).

3. Results and Discussion

3.1 Maize Growth

The dates of germination and male flowering give meaningful information of crop growth condition. Germination started 10 days after sowing at all stations except Lunyangwa, where germination started 5 days after sowing. The number of days from germination to male flowering was 51 in Banga, 65 in Mkondezi and Ntchenachena, and 77 in Lunyangwa (Figure 3). The 2- to 3.7-week difference between Lunyangwa and the other stations could be attributed to differences in growth condition.

The number of days to male flowering is the most important indicator of growth condition. The long time to male flowering in Lunyangwa represents an unfavorable condition for maize growth. Rainfall for the period between 30 December 2013 (germination) and 19 February 2014 (male flowering) was 358.2 mm in Banga and 364.9 mm in Lunyangwa. As the rainfall amounts were identical at both stations, soil condition, such as water holding capacity, would have a larger influence on the germination than rainfall.

Table 2. Two-year germination rates at the stations

	2013/14				2014/15		
	Lunyangwa	Ntchena-chena	Banga	Mkondezi	Ntchena-chena	Banga	Mkondezi
Changu	93.7	99.9	97.1	99.4	90.7	78.4	69.5
Windrow	93.4	96.8	95.1	98.9	90.3	79.5	71.0
RCF	92.9	99.4	89.9	90.2	97.0	82.1	58.9
CCF	90.5	95.5	97.1	100.0	93.5	66.7	67.0
Mixture	94.0	100.0	98.9	99.2	88.0	75.6	80.4
Control	96.4	100.0	95.9	97.3	96.5	82.1	64.3

The germination rates in 2013/14 showed little difference; the rates exceeded 90% at the four stations and for all treatments (Table 2). In contrast, the germination rates in 2014/15 differed markedly. The germination rates decreased in the order of Ntchenachena, Banga, and Mkondezi, indicating that soil fertility decreased in that order. The germination rates in the control plots at Ntchenachena and Banga were high, but was only 64% in Mkondezi. Chemical fertilizer plots, particularly RCF in Mkondezi, showed a low germination rate, whereas Mixture had a high germination rate.

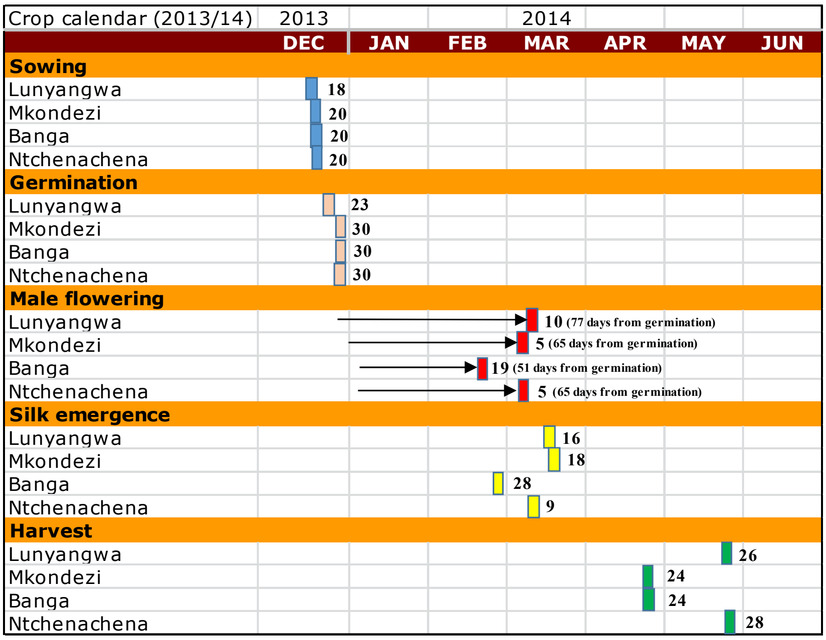

Figure 3. Crop calendar (2013/14) of maize growth at the four stations

Note. Dates of sowing, germination, male flowering, silk emergence and harvest were recorded in Control.

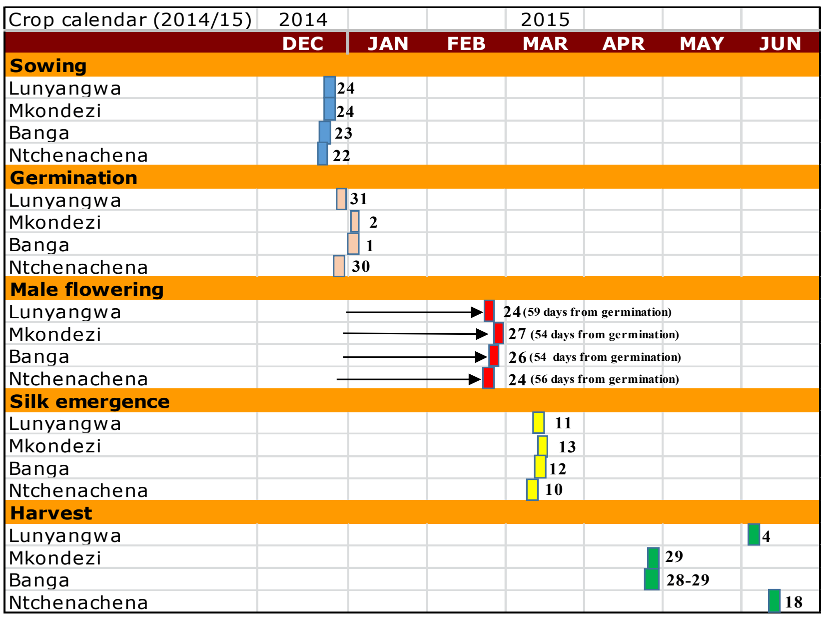

Figure 4. Crop calendar (2014/15) of maize growth at the four stations

Note. Dates of sowing, germination, male flowering, silk emergence and harvest were recorded in Control.

Germination started a few days earlier in the second year than in the first year (Figure 4). Male flowering also started earlier in the second year than in the first year at all stations except Banga.

Table 3. Days to male flowering in 2013/14 and 2014/15 at the stations

	2013/14				2014/15		
	Lunyangwa	Ntchena-chena	Banga	Mkondezi	Ntchena-chena	Banga	Mkondezi
Changu	87.6	77.2	60.1	67.6	68.3	54.0	58.1
Windrow	87.7	76.6	58.3	65.6	68.5	55.2	58.2
RCF	89.7	76.0	58.7	68.5	68.5	82.1	67.5
CCF	90.0	77.5	59.3	73.5	68.0	66.7	67.0
Mixture	87.3	75.5	55.3	74.5	69.0	75.6	62.0
Control	88.3	75.5	70.3	74.0	69.0	82.1	73.5

The number of days to male flowering in 2014/15 showed a decrease relative to that in 2013/14 at most of the stations (Table 3), which might indicate that growth condition was improved in 2014/15 compared to 2013/14. The number of days to male flowering in chemical fertilizer (RCF, CCF), Mixture, and Control in Banga was increased, in contrast to the reduced number of days in the compost application plots. This indicates that compost application improved growth condition and shortened the number of days to male flowering.

The number of days to male flowering was decreased in Banga and Mkondezi relative to Lunyangwa and Ntchenachena, and could be affected by climate condition. The fact that Banga and Mkondezi are located in a warmer region with higher rainfall may have shortened flowering time.

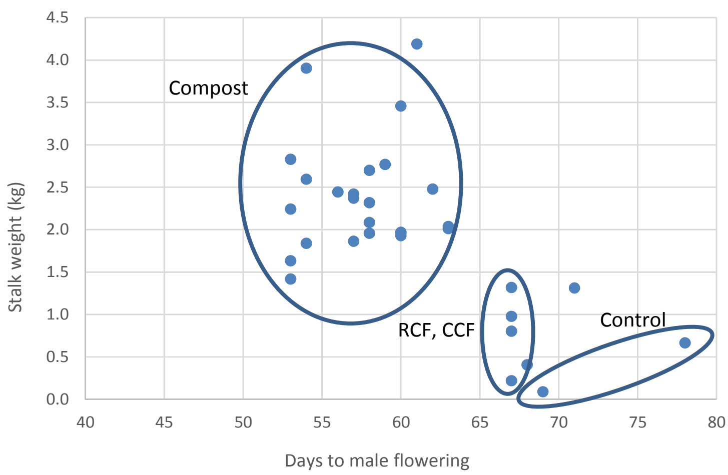

Figure 5. Effects of number of days to male flowering on maize stalk weight in Mkondezi

The number of days to male flowering was found to influence maize stalk weight in Mkondezi (Figure 5). Maize stalk weight was decreased when the number of days to male flowering exceeded 65. Moreover, compost application decreased the number of days to male flowering and consequently increased stalk weight. As stalk weight was correlated with maize fresh weight (Figure 6), the number of days to male flowering can also be used to judge the fate of maize yield.

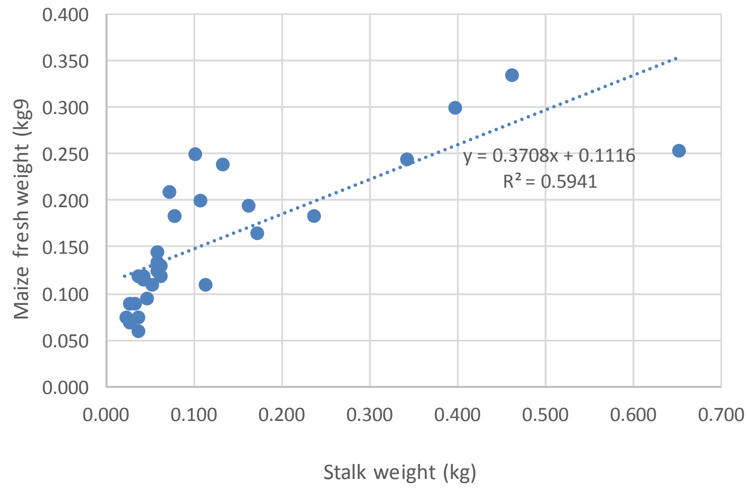

Figure 6. Correlation of maize stalk weight with maize fresh weight

3.2 Maize Growth Parameters

The measurement of plant growth parameters has two important meanings. One is to understand maize growth condition, and the other is to identify factors influencing growth at the growth stage.

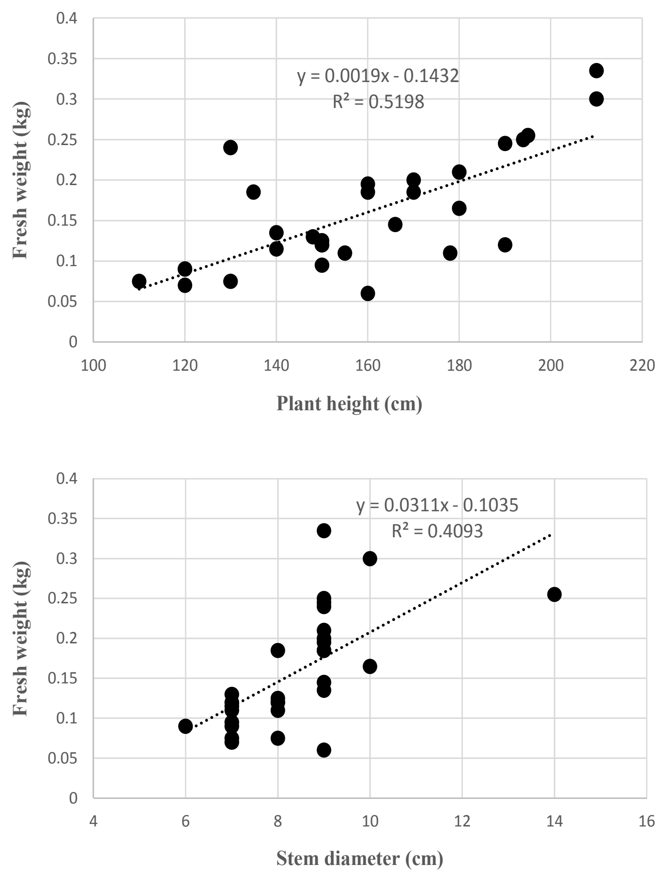

Figure 7. Relationship of grain fresh weight (kg) with stem diameter (left) and plant height (right) at Lunyangwa station

From 30 measurements of harvested maize in Lunyangwa, it was found that maize fresh weight was correlated with plant height and stem diameter, as expressed by the following equations:

$$\text{Fresh weight (kg)} = -0.14 + 0.0019 \times \text{Plant height} \quad (r^2 = 0.52) \tag{1}$$

$$\text{Fresh weight (kg)} = -0.10 + 0.031 \times \text{Stem diameter} \quad (r^2 = 0.41) \tag{2}$$

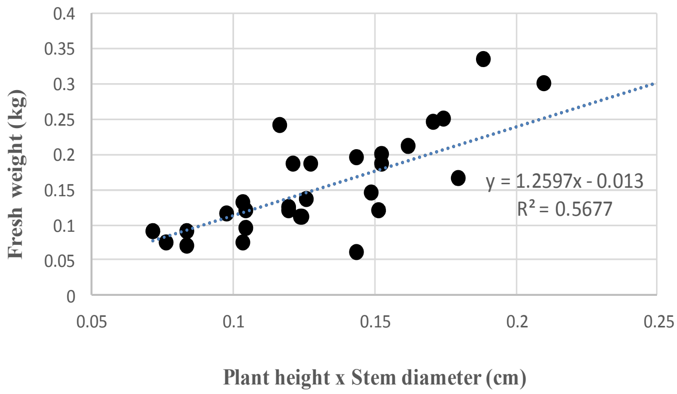

Figure 8. Relationship between (plant height × stem diameter) and fresh weight

Maize fresh weight was correlated with plant height and stem diameter (Figure 7), indicating that maize growth could be predicted by plant height and stem diameter during the growth season. When those two parameters (plant height and stem diameter) were combined, maize fresh weight was better predicted with the following equation:

$$\text{Fresh weight} = -0.013 + 1.26 \times (\text{Plant height} \times \text{Stem diameter}) \quad (r^2 = 0.57) \tag{3}$$

Since the combined parameter (plant height and stem diameter) was correlated with maize fresh weight (Figure 8), this parameter could be utilized as an appropriate indicator of maize growth. Then, the chronological change of this parameter during the growth period was examined. In Lunyangwa, this parameter was significantly different at week 4 (W4) and week 8 (W8) after germination, indicating that those periods were critical to maize growth (Figure 9). Likewise, W4 and W8 in Banga; W4, W8, and W10 in Mkondezi; and W8 and W10 in Ntchenachena were identified as the critical periods. It could be postulated that the growth condition at W4 or W8 was the determinant of overall maize growth, and that maize required large amounts of N at those growth stages.

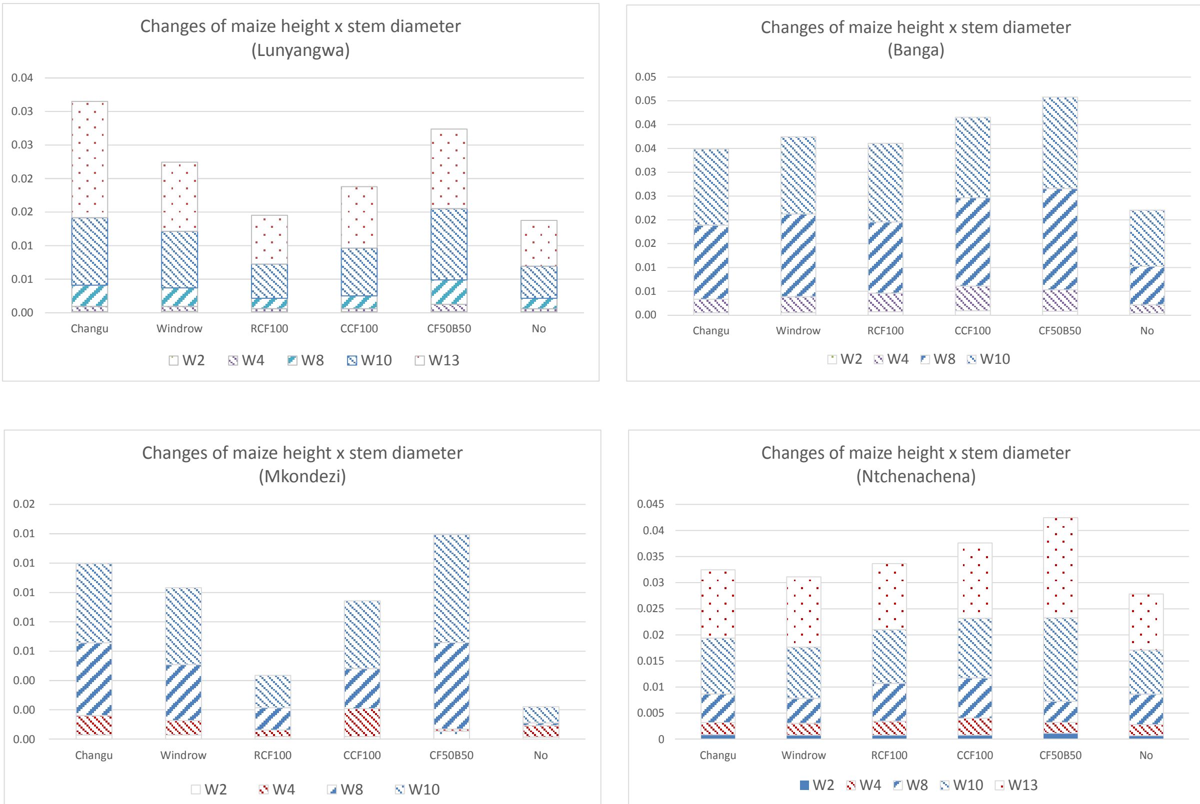

Figure 9. Changes of growth parameter (plant height × stem diameter) at the four stations

3.3 Leaf Color

In the northern regions in Malawi, farmers realize that leaf color is useful for checking maize growth condition. A SLMP-conducted interview of 140 farmers revealed that leaf color categorized into four levels (bad, fair, good, and very good) by the farmers was well correlated with actual maize yield. Maize height and yield were high when farmers identified leaf color as good. This fact may reinforce the idea that leaf color is a useful indicator of maize growth condition.

Leaf color varied according to maize growth stage (Figure 10). Leaf color turned dark at W2 and W4 after germination, i.e., the vegetative stage, and no significant plant height increase was noted at this stage. Maize grew at W8 while retaining the same color, indicating that the reproductive stage started between W4 and W8. As maize requires more nutrients at the reproductive stage, it is necessary to apply N fertilizer as top dressing at the start of this stage.

Leaf color started to fade from W8 onwards until W13. This was brought about by N transport from leaf to maize plant for utilization in reproduction.

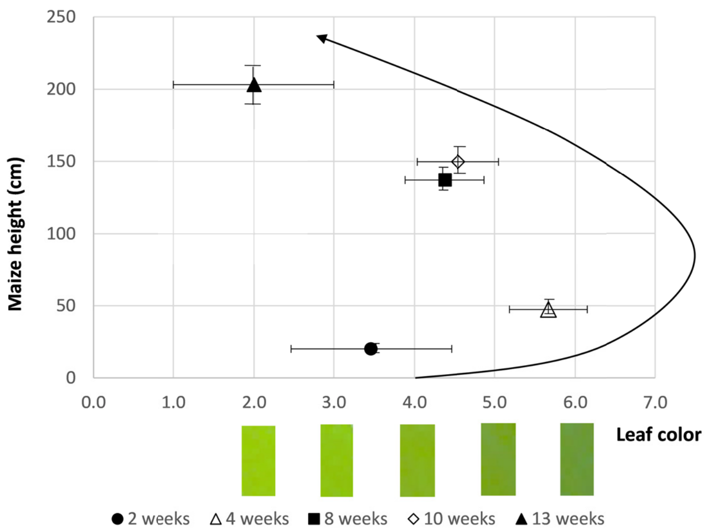

Figure 10. Changes of leaf color according to maize growth in the control plot of Banga (2015)

Note. Error bars show the standard deviation of leaf color and maize height (n = 24).

Besides the color change pattern shown in Figure 10, an irregular pattern was observed in LNG in 2014 and 2015, which was caused by unfavorable conditions for maize growth, such as shortage of nutrients and moisture.

In the 2013/14 cropping season, leaf color showed a high correlation with maize growth at all stations, and the coefficients of determination were ≥ 0.67 (Table 4). As all stations showed a high correlation with leaf color at W4, W4 could be the optimum fertilizer application time. In addition, as W4 was also shown to be the critical time for maize growth in Figure 8, it was ascertained that W4 would be an important time for growth of maize variety SC627.

Table 4. Correlation of leaf color at different weeks after germination with maize yield at the four stations in the 2013/14 cropping season

Station	Weeks after germination						r^2
	W2	W4	W6	W8	W10	W13	
Lunyangwa	○	○					0.67
Banga		○	○		○		0.68
Mkondezi		○		○			0.86
Ntchenachena		○		○	○		0.71

Note. ○: Significantly correlated with maize yield.

Regression analysis was performed for maize grain yield using leaf colors at different growth stages in Lunyangwa. Leaf color at W2 and W4 was well correlated with maize grain yield, as expressed in the following equation:

$$\text{Fresh weight of grains (g)} = 220.1 \times \text{W2 Leaf color} + 174.8 \times \text{W4 Leaf color} - 2336.3 \quad (R^2 = 0.67) \quad (4)$$

The Equation (4) implies that the nutrient status at W2 and W4 is the determinant of maize yield and chemical fertilizer application after W4 would not have a significant effect on maize yield.

Leaf color was also correlated with maize grain yield at the other stations. Every station showed a high correlation coefficient, the highest being 0.86 in Mkondezi. The week that showed leaf color correlation with maize grain yield differed depending on the station, and only W4 showed leaf color correlation with maize grain yield at all the stations.

Average chemical fertilizer application rate in Malawi is 18 kgN/ha (Snapp et al., 2001). Because this rate is relatively low, fertilizer should be applied at the optimum time. Most farmers in Malawi had been unaware that fertilizer should be applied at the optimum time and that application at the optimum time would lead to increased profits (Kamanga et al., 2013). Leaf color could indicate the optimum time for fertilizer application. As was shown in this study, the optimum fertilizer application time for Lunyangwa was at 4 weeks after germination. Similar research will be conducted at a different location and with a different variety or local maize to determine the optimum fertilizer application time.

4. Conclusion

Simple and inexpensive measures for plant diagnosis were shown to be effective in enhancing our understanding of maize growth condition. The crop calendar indicated the dates of remarkable growth events, such as germination, silk emergence, and harvest, providing general information on the growth condition. Moreover, the growth index explained growth behavior in detail and could be used to determine the optimum fertilizer application time. Leaf color measured by the leaf color chart could predict as much as 67% of maize grain yield with the following equation: Fresh weight of grains (g) = 220.1 × W2 Leaf color + 174.8 × W4 Leaf color – 2336.3 (R^2 = 0.67). Leaf color was also shown to be a useful index for the determination of the optimum fertilizer application time.

Acknowledgements

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