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Effects of manure and variety on growth and yield of maize under managed water stress at Salima in Malawi

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Drought and low soil fertility are the primary constraints to maize productivity in Malawi. An experiment was conducted at Lifuwu Agricultural Research Station in Malawi during the 2016 dry season under furrow irrigation to evaluate the impact of goat manure application and drought on the growth and grain yield of the hybrid DKC8053 variety and the synthetic ZM523 variety. These varieties share a maturity period ranging from 110 to 130 days and are characterized as drought and low nitrogen tolerant. Manure application rates ranged from 0 to 10 t ha-1 and were halved for both basal and top dressing. Application of manure significantly mitigated the adverse effects of drought on both the growth and grain yield of maize. Without manure application, there was a highly significant decrease (p<.001) in growth and grain yield for both varieties, with DKC8053 experiencing a more pronounced effect, measuring 89.60 cm and 1060 kg ha^{-1}, respectively, compared to ZM523 with 96.48 cm and 2140 kg ha^{-1}, respectively. However, with manure application rates of 5 and 10 t ha^{-1}, maize plant growth significantly increased (p<.001) from 89.60 cm to 251 cm. Under water stress treatments, ZM523 exhibited a 5% greater height (155.63 cm) compared to DKC8053 (141.53 cm), whereas DKC8053 demonstrated greater height under well-watered, well-fertilized conditions (251.55 cm). The application of manure consistently increased maize grain yield from 1060 to 8882 kg ha^{-1}. When subjected to water stress, ZM523 showed a higher increase in grain yield (8521 kg ha^{-1}) compared to DKC8053 (7234 kg ha^{-1}). However, under well-watered, well-fertilized conditions, both varieties performed similarly, yielding 8661 kg ha^{-1} and 8882 kg ha^{-1}, respectively. Therefore, maize varieties ZM523 and DKC8053 exhibited better yields under manure application, as it helped conserve water holding capacity.

Key words: Organic manure, drought, low soil fertility, DKC8053, ZM523.

INTRODUCTION

Maize (*Zea mays L.)* stands as a dominant crop according to the FAO (2014), with the same authors asserting its status as the principal food crop for Malawi. Despite being cultivated annually in Malawi, food shortages persist due in part to recurring droughts and low soil fertility, among other challenges. Stevens and Madani (2016) highlighted recent droughts and floods in Malawi, underscoring the country's vulnerability to climate

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change impacts. Similarly, Akinnifesi et al. (2007) noted Malawi's food insecurity, even in years with favorable rainfall, attributing it to overused, degraded, and depleted soils. The country has faced frequent food shortages, notably in 2005, 2012, and 2015, sometimes necessitating reliance on imported maize due to lower-than-average maize production (FAO, 2014). The Government of Malawi (2004) pointed out that the majority of small-scale agriculture in the country relies on rain-fed methods, making domestic food availability and the economy highly susceptible to climatic variations. For instance, in 2005, a lack of rain during crucial maize growth stages led to the worst maize harvests in a decade, with an average yield of only 0.76 t/ha, covering 57% of the national food requirement and leaving 5 million people in need of food aid (Denning et al., 2009). Sahley et al. (2005) similarly described Malawi as persistently experiencing food shortages and high levels of nutritional deprivation. MVAC (2015) reported that between October 2015 and 2016, 2.8 million people in Malawi required humanitarian assistance due to poor harvests caused by the late onset of rains in the 2014/2015 maize growing season and subsequent flooding from heavy rainfall. Despite an increase in fertilizer use due to fertilizer subsidies, average yields have only ranged from 40 to 60%, falling short of potential yields.

Banziger et al. (2000) suggested that during drought, insufficient nutrient uptake by maize plants leads to chlorosis, hindering photosynthesis and respiration due to cell denaturation. As drought persists, photosynthetic pigments denature, affecting enzymatic activities and causing plant senescence. Additionally, Bista et al. (2018) noted that drought decreases nitrogen and phosphorus concentrations in plant tissues and reduces nutrient uptake from the soil. However, using drought and low nitrogen-tolerant maize varieties can help mitigate these impacts. Researchers at the International Maize and Wheat Improvement Centre (CIMMYT), as stated by Banziger et al. (2000), have developed maize germplasm with improved drought and low nitrogen tolerance, aiming for varieties capable of withstanding a wide range of drought and nitrogen availability. Certain plant traits, less relevant under normal conditions, become crucial for yield under drought and nitrogen stress, such as a genotype's ability to produce grain-bearing ears during drought stress at flowering. Application of organic manure enriches the soil with essential elements like nitrogen, phosphorus, and potassium, and enhances soil structure, aiding moisture retention (Hossain et al., 2007). However, as mentioned by Hossain et al. (2007), nutrient replenishment through organic manure application is necessary annually due to nutrient uptake by maize plants and nutrient loss through erosion and leaching. Evaluating the performance of hybrids and new synthetics under both drought and low fertility conditions is essential for developing technological solutions for agro-ecological intensification. Therefore, the objective of this study was to assess the effect of organic manure application and managed drought on the growth and grain yield of DKC8053 and ZM523 maize varieties.

MATERIALS AND METHODS

Study site description

This study was conducted at Lifuwu Agricultural Research Station in the Salima district as an on-station experiment. Lifuwu is situated at an altitude of 500 meters above sea level, with coordinates at latitude 13° 40' South and longitude 34° 35' East (Nicholson et al., 2014). The area experiences erratic rainfall annually, with mean maximum and minimum temperatures of 29°C and 19°C, respectively, although the average annual rainfall is 1,228 mm. Precipitation at Lifuwu falls short of evapotranspiration in most months. According to Chilimba and Nkosi (2014), the station has two distinct soil types: vertisols predominant in the paddy fields, and mostly sandy soils in the upland area. In the paddy fields, the soils crack when dry but become very sticky when wet, with low nitrogen (<0.08 to 0.12%) and phosphorus (9 to 18 ppm) content and pH values ranging from 7 to 8 (Chilimba and Nkosi, 2014). However, this study was conducted in the upland fields.

Experimental set-up and treatment description

In this study, the treatments consisted of two maize varieties, DKC8053 and ZM523, each assigned to control plots with 0 t ha^{-1} organic manure application; stress and non-stress plots with application of 5 t ha^{-1} organic manure; and stress and non-stress plots with application of 10 t ha^{-1} organic manure. In total, there were twelve treatment combinations arranged in a split-split plot design of 2 x 2 x 3. Each treatment combination was replicated four times. Each experimental unit measured 5 rows wide, 5 m long, with an inter-row spacing of 0.75 m, resulting in a gross plot size of 18.75 m^2. However, the net plot consisted of the three middle rows, with one planting station discarded at both ends of the ridges, resulting in a net plot size of 10.125 m^2. The variety ZM523 is a synthetic variety with a maturity period of 110 to 130 days and is described as drought tolerant (Kaonga, 2011). Similarly, the variety DKC8053 is a hybrid with a maturity period of 110 to 130 days and is also described as drought tolerant (Duvick, 1999). The goat manure used in the study was sourced from the farm at Chitala Research Station within the Salima district.

Organic manure and baseline soil chemical characteristics

Goat manure was collected as a composite sample from four different heaps within one kraal and placed into a well-labelled plastic jumbo. Subsequently, it was transported to the laboratory at Lilongwe University of Agriculture and Natural Resources, where three tests were conducted to assess its nutrient quality (Table 1). The results revealed that the sampled goat manure exhibited high alkalinity with a pH of 9.9, along with significant nutrient values: organic matter (2.8%), nitrogen (1.4%), available phosphorus (394 ppm), and potassium (0.62%). These findings suggest that the manure possesses the capability to supply nutrients and enhance yields. Mugwirwa and Murwira (1997) also reported similar nutrient values for goat manure, with percentages of 1.69% for nitrogen, 0.34% for phosphorus, 0.73% for potassium, and 19.1% for organic carbon. This aligns with the findings of Awodun et al. (2007), who noted that goat dung is rich in organic matter and contains more nitrogen compared to potassium, calcium, and magnesium.

Table 1. Chemical characteristics of goat manure from Chitala farm, 2016 dry season.

Variable	Mean	SE of Means (n=3)
pH	9.9	0.25
OC (%)	2.8	0.1
Available P (ppm)	394	0.726
Total N (%)	1.4	0.05
K (ppm)	0.62	0.005

SE of Means = Standard error of means.

Table 2. Baseline soil characteristics for Lifuwu, 2016 summer season.

Soil characteristic	Mean	Nutrient threshold rating (Chilimba and Nkosi, 2014)	SE of Means (n=3)
pH	5.3	Acidic	0.176
OM (%)	1.95	Low	0.012
Available P (ppm)	5.9	Very low	0.115
Total N (%)	0.2	Medium	0.012
K (ppm)	0.01	Very low	0.009
Clay (%)	35		1.325
Silt (%)	9		0.488
Sandy (%)	56		1.453
Texture class	SCL		

SCL: Sandy clay loam; SE: Stand error of means.

Table 2 illustrates the baseline soil characteristics. Composite soil samples were collected once from six different points at the experimental site, mixed in a bucket, and then packed into labelled duplicate plastic jumbos. Three tests were conducted for each targeted chemical element during laboratory analysis. These samples were collected to assess the basic soil nutrient status of the site before the implementation of the experiment at Lilongwe University of Agriculture and Natural Resources. The results revealed that the soils in the study area were slightly acidic, with a pH reading of 5.3, and exhibited low chemical properties, including organic matter content (1.95%), nitrogen (0.2%), available phosphorus (5.9 ppm), and potassium (0.01%). Soil textural analysis indicated a sandy clay loam texture, with 35% clay, 9% silt, and 56% sand.

Type of irrigation

In this experiment, furrow irrigation was used, and water (6-8 mm), as water requirement by depth was supplied to the maize crop in both blocks for every week. Therefore, water volume was 60-80 litres/ha, which was equivalent to 11.3-15 litres/plot. This was done until when the maize was nearly about to tassel that the water stressed block ceased from receiving water up to harvest.

Data collection

Data collected included soil samples, emergence count, plant height (cm), days to 100% anthesis (DA), days to 100% silking (DS), anthesis-silking interval (ASI), leaf rolling (%) on a scale of 1-5 (where 1= unrolled, turgid; 2= leaf rim starts to roll; 3= leaf has the shape of a V; 4= rolled leaf rim covers part of leaf blade; and 5= leaf is rolled like an onion), and leaf senescence scaled from 1 to 10 (where 1= 10% dead leaf area and 10= 100% dead leaf area), as utilized by Banziger et al. (2000). Additionally, data included harvest count, ear number, ear weight (kg), number of kernel rows per ear, number of kernels per row, usable grain weight (kg), 100-grain weight sample (g), and grain moisture content (%).

Statistical analysis

Data collected from all the calculated parameters were subjected to ANOVA using Genstat Discovery Computer Package 16th Edition to determine if significant differences were existing between treatment means. The LSD test was used to determine significant ($P<0.05$) differences between treatment means. Pearson correlation and regression analysis were used to detect any association between grain yield and yield components, and, grain yield and manure application rates, respectively.

RESULTS

Effect of water stress and manure on days to anthesis, days to silking and anthesis-silking interval

The results for days to anthesis (DA), days to silking (DS), and anthesis-silking interval (ASI) of ZM523 and DKC8053 for grain yield under stress and non-stressed treatments are presented in Table 3. Highly significant differences ($P<0.001$) were observed for all these characters. Plants under non-stressed conditions

Table 3. Water stress and manure interaction effect on DA, DS and ASI, Lifuwu 2016 summer season.

Manure	Water stress	DA	DS	ASI
0 t ha^{-1}		61	70	8
5 t ha^{-1}	Stress	59	65	6
10 t ha^{-1}		55	57	2
Mean		58	64	5
0 t ha^{-1}		56	59	3
5 t ha^{-1}	Non-stressed	55	56	1
10 t ha^{-1}		53	54	1
Mean		55	56	2
F pr. (S*M)		*P*<.001	*P*<.001	*P*<.001
$LSD_{0.05}$		0.7188	0.909	0.5701
CV (%)		1.2	1.3	12.9

DA= days to anthesis; DS= days to silking; ASI=anthesis-silking-interval; CV (%) = Coefficient of Variation; F pr. =F probability test; $LSD_{0.05}$ = Least Significant Difference at 5%; (*P*<.001) = highly significant at 1%.

exhibited normal days to anthesis and fewer days to silk formation, resulting in a significantly reduced anthesis-silking interval compared to those under stress treatments. Additionally, water-stressed plants under 10 t ha^{-1} organic manure application showed a shorter anthesis-silking interval. These results are consistent with the findings of Collins (2012), who reported that genotypes exhibited an increased interval between anthesis and silking under drought stress, with the ASI gap being reduced under well-watered conditions. However, interactions between water stress versus variety, variety versus manure, and manure x stress x variety did not show any significant effects in this aspect during this study.

In Table 4, results for leaf senescence, leaf rolling (%), and plant height (cm) are presented, with significances between treatment means attributed to the overall interaction effects of water stress, variety, and organic manure. Mean values for leaf rolling significantly differed (P=0.043), with ZM523 scoring 3 while DKC8053 scored 4 under drought treatments. Conversely, under well-watered, well-fertilized treatments, both varieties responded similarly. Similarly, mean values for ZM523 and DKC8053 significantly differed (P=0.028) for the leaf senescence trait. Under stress conditions, on average, ZM523 scored 3 while DKC8053 scored 6, but under non-stress conditions, both varieties had a similar score of 1, implying higher mean values under stress conditions. However, Collins (2012) reported contrasting findings, stating that there were no significant differences among genotypes in leaf rolling and senescence under drought stress conditions. Results in this study also showed highly significant differences (P<.001) between the varieties for plant height, with their mean values higher when non-stressed. Dao et al. (2017) reported similar findings, noting that the direct effect on plant height was high and negative under severe drought.

Table 5 presents the results for kernel row number per ear and kernel number per row due to the interaction effects of water stress, variety, and organic manure. Highly significant differences (P<.001) were observed for kernel rows per ear between ZM523 and DKC8053, with their mean values higher under well-watered, well-fertilized treatments compared to those under stress. The mean values for kernel number per row for both varieties significantly differed (P=0.001), with higher values observed under optimum conditions. These findings are supported by Oluwaranti et al. (2016), who reported that variety effects were highly significant for kernel row number, indicating differences in the performance of varieties for kernel row number.

Maize grain yield and yield components

Correlations between grain yield and yield components

Tables 6 and 7 present a relationship between maize grain yield and yield components. A positive correlation is desirable between maize grain yield and its yield components, implying that the more increase in the yield components, the higher the maize grain yield output and vice versa.

Relationship between maize grain yield and yield components under stressed treatments.

Under stress conditions, maize grain yield for varieties ZM523 and DKC8053 was positively correlated with number of kernel rows per ear (0.86***), number of kernels per row (0.97***) and plant height (0.99***), but strongly and negatively correlated with 100% days to anthesis (-0.91***), days to silking (-0.94***), anthesis-silking interval (-0.94***), leaf rolling (-0.81***) and leaf senescence (-0.48*) (Table 6). In addition, there was no correlation found between maize grain yield and 100 grain weight.

Furthermore, number of kernel rows per ear strongly and positively correlated with number of kernels per row (0.87***) and plant height (0.87***), but strongly and negatively correlated with days to anthesis (-0.77***), days to silking (-0.78***), anthesis-silking interval (-0.75***), leaf rolling (-0.90***) and leaf senescence (-0.71***). However, no correlation was found with 100 grain weight. Number of kernels per row strongly and positively associated with plant height (0.97***), but strongly and negatively correlated with days to anthesis (-0.90***), days to silking (-0.92***), anthesis-silking interval (-0.91***), leaf rolling (-0.81***) and leaf

Table 4. Water stress, variety, and manure interaction effect on maize pant growth, Lifuwu 2016 summer season.

Water stress	Variety	Manure	Leaf senescence (score 1-10)	Leaf rolling (score 1-5)	Height (cm)
	ZM523	0 t ha^{-1}	3.000	3.750	96.48
		5 t ha^{-1}	3.000	3.000	126.53
		10 t ha^{-1}	3.000	2.000	155.63
Stress			3.000	2.916	126.21
	Mean DKC8053	0 t ha^{-1}	7.250	5.000	89.60
		5 t ha^{-1}	6.000	4.750	114.40
		10 t ha^{-1}	4.750	2.750	141.53
			6.000	4.166	115.18
	Mean ZM523	0 t ha^{-1}	1.750	1.000	106.70
		5 t ha^{-1}	1.000	1.000	225.10
		10 t ha^{-1}	1.000	1.000	237.45
Non-stressed			1.250	1.000	189.75
	Mean DKC8053	0 t ha^{-1}	2.000	1.000	100.20
		5 t ha^{-1}	1.000	1.000	231.93
		10 t ha^{-1}	1.000	1.000	251.55
Mean			1.333	1.000	194.56
F pr. (s*v*m)			P=0.028	P=0.043	*P*<.001
$LSD_{0.05}$			0.7994	0.3599	1.590
CV (%)			19.1	11.6	0.6

Height = plant height in cm between the plant base and the insertion of first tassel branch of the same plant; CV= Coefficient of Variation; F pr. =F probability test; $LSD_{0.05}$= Least Significant Difference at 5%; (P=0.028) = significant; (P=0.003) = significant; (*P*<.001) = highly significant.

Table 5. Water stress, variety, and manure interaction effects on maize yield components, Lifuwu 2016 summer season.

Water stress	Manure	Variety			
		Rows/ear ZM523	DKC8053	Kernels/row ZM523	DKC8053
	0 t ha^{-1}	9	7	23	19
Stress	5 t ha^{-1}	13	9	37	29
	10 t ha^{-1}	19	11	49	41
	Mean	14	9	36	30
	0 t ha^{-1}	11	7	29	31
Non-stressed	5 t ha^{-1}	13	11	21	49
	10 t ha^{-1}	21	19	37	51
Mean		15	12	29	44
F pr. (s*v*m)		P<0.001		P<0.001	
$LSD_{0.05}$		0.9020		2.899	
CV (%)		4.7		4.0	

Rows/ear=number of kernel rows/ear; kernels/row=number of kernels/row; CV (%) =coefficient of variation; F pr. = F probability test; $LSD_{0.05}$=5% Least significant difference at 5%; (P=0.001) = very significant; (*P*<.001) = highly significant.

senescence (-0.49*). However, number of kernels per row did not correlate with 100 grain weight.

Days to anthesis strongly and positively associated with days to silking (0.98***), anthesis-silking interval

Table 6. Pearson correlation coefficients between maize grain yield and yield components for varieties ZM523 and DKC8053 under stress treatments.

	GY	KR	Kern	100 gr	DA	DS	ASI	LR	Se
GY									
KR	0.86***								
Kern	0.97***	0.87***							
100 gr	0.13^{ns}	-0.26^{ns}	0.03^{ns}						
DA	-0.91***	-0.77***	-0.90***	-0.20^{ns}					
DS	-0.94***	-0.78***	-0.92***	-0.20^{ns}	0.98***				
ASI	-0.94***	-0.75***	-0.91***	-0.19^{ns}	0.93***	0.98***			
LR	-0.81***	-0.90***	-0.81***	0.09^{ns}	0.79***	0.79***	0.76*		
Se	-0.48*	-0.71***	-0.49*	0.37^{ns}	0.42*	0.39^{ns}	0.34^{ns}	0.75***	
Ht.	0.99***	0.87***	0.97***	0.12^{ns}	-0.94***	-0.96***	-0.94***	-0.84***	-0.46*

ns= not significant; *= (P<0.05); **= (P<0.01); ***= (P<.001); GY= grain yield; KR= kernel rows/ear; Kern= kernels/row; 100 gr=100 grain weight; DA= days to anthesis; DS= days to silking; LR= leaf rolling; Se= leaf senescence; Ht= plant height.

Table 7. Pearson correlation coefficients between maize grain yield and yield components for varieties ZM523 and DKC8053 under non-stressed treatments.

	GY	KR	Kern	100 gr	DA	DS	ASI	Se
GY								
KR	0.80***							
Kern	0.91***	0.96***						
100 gr	0.23^{ns}	0.01ns	0.08ns					
DA	-0.84***	-0.94***	-0.95***	0.01^{ns}				
DS	-0.95***	-0.89***	-0.96***	-0.11^{ns}	0.96***			
ASI	-0.95***	-0.60**	-0.75***	-0.31^{ns}	0.67***	0.85***		
Se	-0.76***	-0.49*	-0.58**	-0.42*	0.53*	0.68***	0.82	
Ht.	0.98***	0.68***	0.82***	0.35^{ns}	-0.73***	-0.89***	-0.97***	-0.77***

ns: not significant; *: (P<0.05); **: (P<0.01); ***: (P<.001); GY: grain yield; KR: kernel rows/ear; Kern: kernels/row; 100 gr: 100 grain weight; DA: days to anthesis; DS: days to silking; Se: leaf senescence; Ht: plant height.

(0.93***), leaf rolling (0.79***) and leaf senescence (0.42*), but had strong negative correlation with plant height (-0.94***). Days to silking strongly and positively related with anthesis-silking interval (0.98***) and leaf rolling (0.79***), instead, had a strong negative relationship with plant height (-0.96***). However, number of days to silking showed no correlation with leaf senescence. In terms of anthesis-silking interval and leaf rolling, there was a positive association (0.76*), but strongly and negatively correlated with plant height (-0.94***). However, no association was found been anthesis-silking interval and leaf senescence. Leaf rolling and leaf senescence had a strong positive correlation (0.75***), but correlated strongly and negatively with plant height (-0.84***), whilst, leaf senescence and plant height had a negative significant correlation (-0.46*). Weight of 100 grains did not associate with any other yield component.

Relationship between maize grain yield and yield components under optimum conditions

Under optimum conditions, maize grain yield for varieties ZM523 and DKC8053 strongly and positively correlated with number of kernel rows per ear (0.80***), number of kernels per row (0.91***), and plant height (0.98***), but strongly and negatively correlated with days to anthesis (-0.84***), days to silking (-0.95***), anthesis-silking interval (-0.95***) and leaf senescence (-0.76***) (Table 7). However, maize grain yield did not associate with 100 grain weight.

Number of kernel rows per ear had strong and positive correlation with number of kernels per row (0.96***) and plant height (0.68***), but had strong and negative correlation with days to anthesis (-0.94***), days to silking (-0.89***), anthesis-silking interval (-0.60**) and leaf senescence (-0.49*). However, there was no correlation

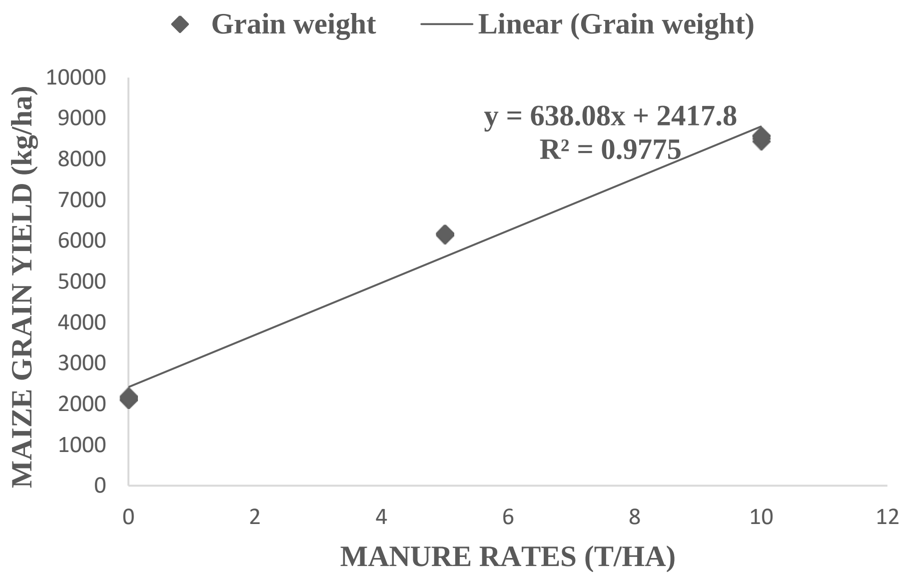

Figure 1. Manure rates correlating with maize grain yield for variety ZM523 under stress treatments across replicate means.

found between number of kernel rows per ear and 100 grain weight. As for number of kernels per row, a strong and positive correlation was found with plant height (0.82***), whilst strong but negative correlations were found with days to anthesis (-0.95***), days to silking (-0.96***), anthesis-silking interval (-0.75***) and leaf senescence (-0.58**). However, there was no correlation found between number of kernels per row and 100 grain weight.

With regard to days to anthesis, strong and positive correlations were found with days to silking (0.96***), anthesis-silking interval (0.67***) and leaf senescence (0.53*). However, there was a strong negative correlation between days to anthesis and plant height (-0.73***). In terms of days to silking, there was a strong positive relationship with anthesis-silking interval (0.85***) and leaf senescence (0.68***), whereas as, a strong negative correlation was found with plant height (-0.89***). As for the anthesis-silking interval, there was a strong positive correlation with leaf senescence (0.82***), but a strong negative correlation with plant height (-0.97***). Leaf senescence, had a strong but negative correlation with plant height (-0.77***). However, no correlations were found for 100 grain weight with the rest of the yield components, instead, only negatively correlated with leaf senescence (-0.42*).

Graphical relationships of maize grain yield and manure application

From the Figures 1 to 5, it is evident that stressed conditions are crucial for maize grain yield for both ZM523 and DKC8053 maize varieties. In Figure 1, there was a positive correlation observed between manure application rates and grain yield under stress treatments. Specifically, manure application rates showed a strong positive and highly significant relationship with maize grain yield data ($r = -0.989$, $p<0.001$) under stress conditions, with 98% of the grain yield being explained by the linear regression line. Maize grain yield increased by 638.08 kg for every increase in the manure application rate.

Figure 2 also demonstrates a strong positive relationship ($r = -0.942$, $p<0.001$) between manure application rates and maize grain yield for variety ZM523 under non-stressed treatments across replicates. As the application rates increased, maize grain yield significantly increased by 531.15 kg.

Figure 3 depicts a strong positive association ($r = -0.994$, $p<0.001$) of manure application rates with maize grain yield data for variety DKC8053 under stress treatments. Maize grain yield significantly increased by 617.35 kg with an increase in manure application rates. Low manure application led to a significant decrease in grain yield.

Figure 4 shows a strong positive and highly significant correlation ($r = 0.974$, $p<0.001$) between manure application rates and maize grain yield for variety DKC8053 under non-stress treatments across replicates. Maize grain yield significantly increased by 655.23 kg due to an increased application rate, with 95% of the grain yield being explained by the linear regression.

Figure 5 illustrates the correlation of maize grain yield data (kg ha^{-1}) for varieties ZM523 and DKC8053 with the three factors: stress, variety, and organic manure after regression analysis across replicates. It is evident that stress conditions are crucial for maize grain yield for both

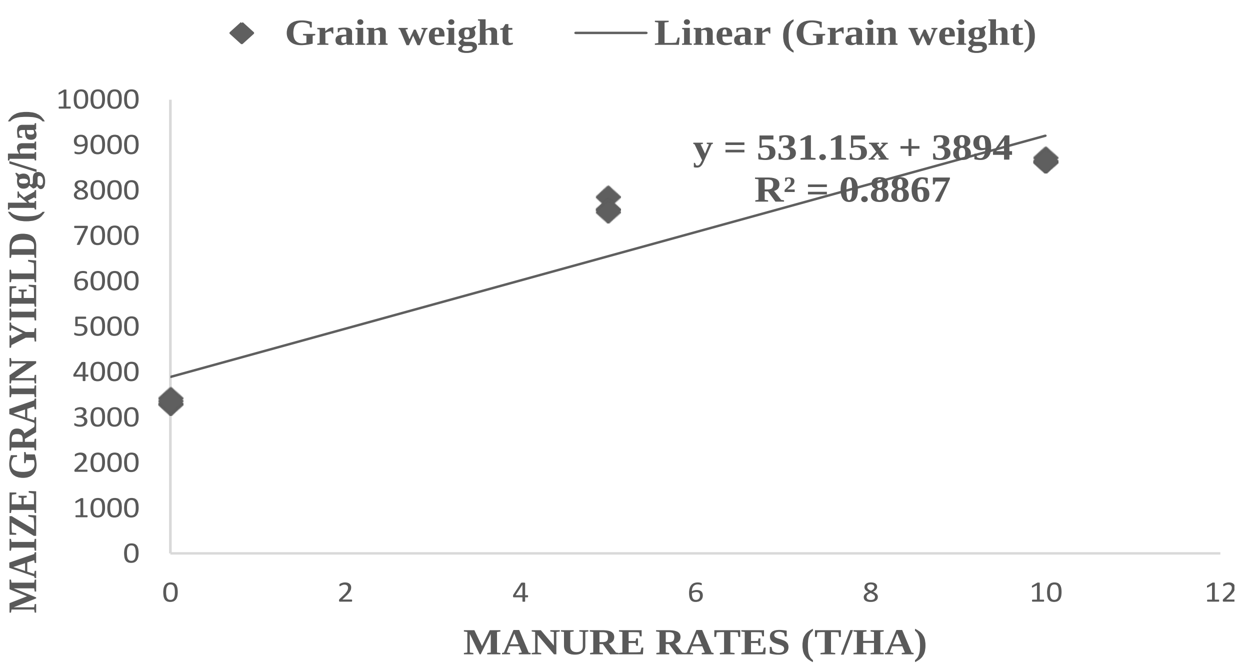

Figure 2. Manure rates correlating with grain yield for variety ZM523 under non-stress treatments across replicate means.

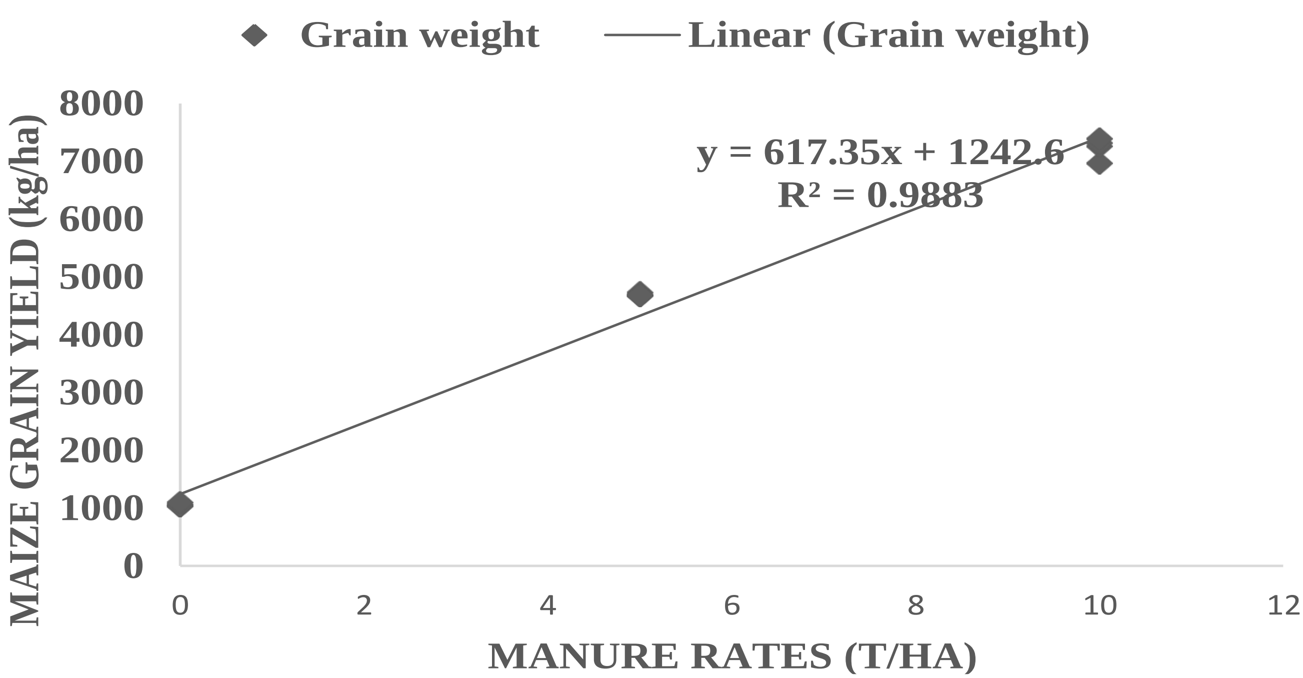

Figure 3. Manure rates correlating with grain yield for variety DKC8053 under stress treatments across replicate means.

ZM523 and DKC8053 maize varieties. Both varieties significantly differed in performance due to water stress and manure application rates. Under optimal conditions, both varieties performed similarly. However, when stressed, ZM523 had a higher grain yield than DKC8053. A goat manure application rate of 5 t ha^{-1} implied an increase, while a decrease in maize grain yield was observed for ZM523 and DKC8053, respectively, whereas a manure application rate of 10 t ha^{-1} resulted in an increase in grain yield for both varieties.

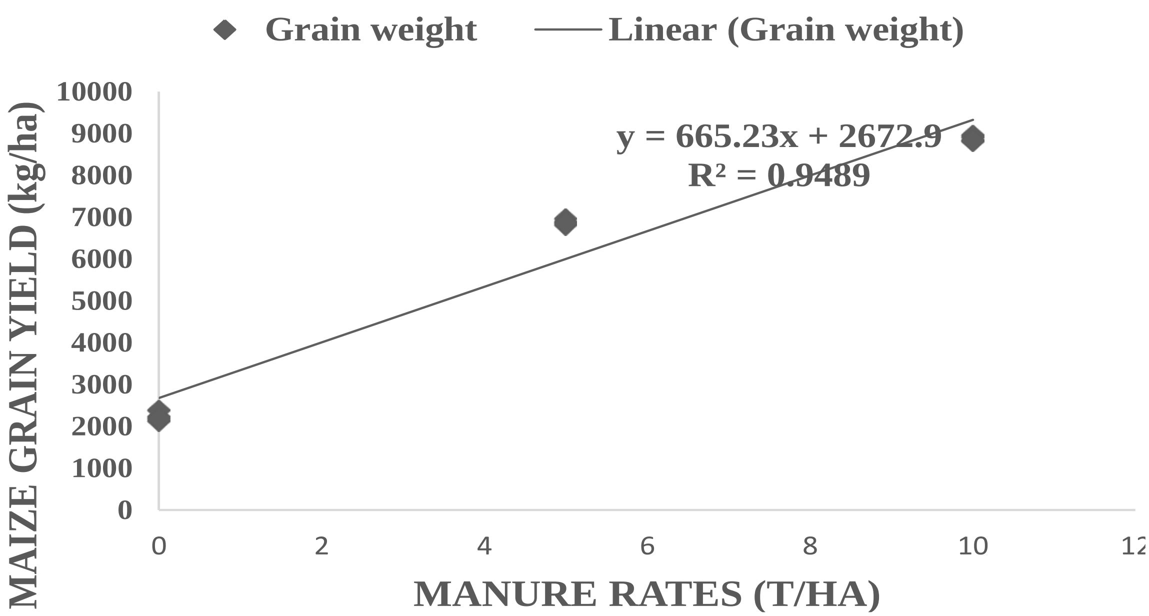

Figure 4. Manure rates correlating with maize grain yield for variety DKC8053 under non-stress treatments across replicate means

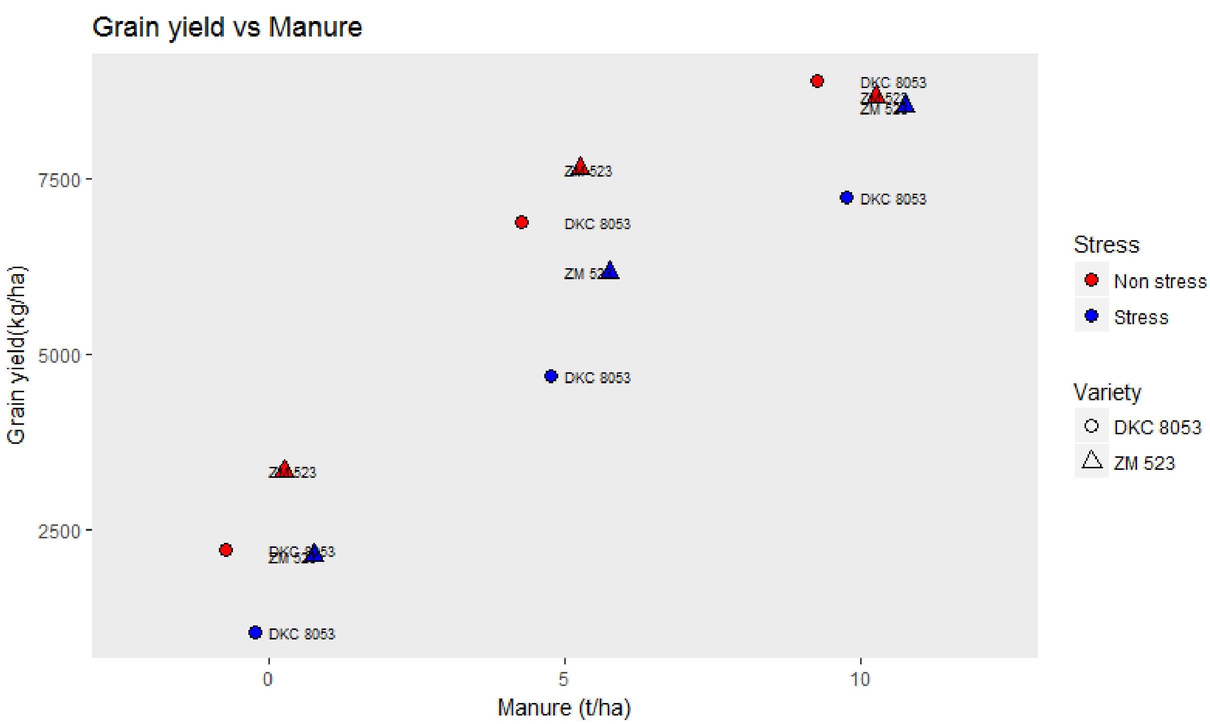

Figure 5. Correlation between maize grain yield and three factors; stress, variety and manure across replicate means.

DISCUSSION

Manure effects on variety performance

At zero application of goat manure, there was no significant effect on grain yield for both varieties ZM523 and DKC8053 under stressed and non-stressed conditions, possibly because there was no nitrogen applied to boost high grain yield. This is consistent with the findings of Banziger et al. (2000), who emphasized that nitrogen is an essential component of all enzymes and therefore necessary for plant growth and development. Instead, grain yield increased due to manure application, where both low and high application rates of 5 and 10 t ha^{-1} showed significant effects for ZM523 on increased grain yield, and only the high application rate of 10 t ha^{-1} showed significant effects on DKC8053, implying the tolerance ability of ZM523 even to poorly fertilized conditions and the latter only to well-fertilized conditions. This also indicates that goat manure alone can influence high maize grain yield. In support, Awodun et al. (2007) reported that the effects of goat manure at 5.0, 7.5, and 10.0 t ha^{-1} were significant ($p>0.05$) depending on growth and yield parameters of pepper.

Maize grain yield due to variety effect and water stress

Grain yield is lower at 0 t ha^{-1} when water stressed for both varieties ZM523 and DKC8053, although the former variety shows a slight increase, suggesting that the limited available nutrients naturally existing in the soil were sufficient for it to yield. Furthermore, ZM523 offers more grain yield both at 5 and 10 t h^{a-1} when water stressed, indicating that the nutrients applied through these rates supported its adaptability. This also suggests that the significantly higher grain yield at this low rate of 5 t ha^{-1} was probably due to the ability of synthetic ZM523 to tolerate low fertility levels.

Therefore, organic manure application of 10 t ha^{-1} is wasteful when applied to synthetic ZM523 under water stress or non-stressed environments, unlike hybrid DKC8053. This implies the ability of ZM523 to compete with low inputs even under drought conditions, unlike DKC8053. In support, Garg (2003) and McWilliams (2003) indicated that plant species and genotypes of a species may vary in their response to mineral uptake under water stress.

Maize grain yield due to water stress, variety and manure interaction effect

Under well-watered, increased fertilized conditions, grain yield for DKC8053 was slightly higher, implying its greater nutrient requirement, and this contributed to its reduced grain yield loss. This supports the findings of Garg (2003) and McWilliams (2003), who reported that decreasing water availability under drought generally results in limited total nutrient uptake and diminished tissue concentrations in crop plants. These results demonstrate that the combination of the three factors - stress, variety, and manure - is necessary for significant maximum grain yield return. Garg (2003) and McWilliams (2003) stated that as nutrient and water requirements are closely related, fertilizer application is likely to increase the efficiency of crops in utilizing available water.

Correlations of grain yield and yield components under stress and non-stress treatments

Maize grain yield correlating with kernel rows per ear

Maize grain yield for the varieties ZM523 and DKC8053, whether stressed or non-stressed (Tables 6 to 7), strongly and positively correlated with the number of kernel rows per ear, number of kernels per row, and plant height. This is likely due to the fully developed ears with more kernel rows of fully developed kernels under non-stressed conditions. This demonstrates that a maize ear with an increased number of kernel rows results in more grain yield than one with reduced kernel rows, depending on environmental stresses such as drought and low nitrogen fertility that cause stunted growth and sometimes result in barrenness of the maize ears due to a delay in silk formation. Variety and genotypic trait composition related to drought tolerance mechanisms could be another contributing factor when both varieties were exposed to stress conditions, with ZM523 bearing more developed kernel rows than DKC8053 (Table 5) (Figure 5). In support, Ghimire and Timsina (2015) stated that grain yield per hectare increases with an increase in the value of the number of kernels per row.

Maize grain yield associating with kernels per row

The results on the relationship between grain yield and the number of kernels per row for ZM523 and DKC8053 maize varieties were highly and positively significant, indicating that every increase in the number of kernels per row resulted in an increase in grain yield. However, both varieties had a higher number of kernels under non-stressed treatments than under stress, implying that a maize plant under good optimal conditions bears an ear with fully developed and increased kernels in a row, which positively increases grain yield, and vice versa. Similar results were reported showing that grain yield is normally highly correlated with the kernel number per unit area and per plant rather than with weight per kernel (Bolaños and Edmeades, 1996; Edmeades et al., 1999; Andrade et al., 1999). Edmeades et al. (2000a) added that one universal phenomenon observed when maize flowers under drought is the delay of silking in relation to pollen shed, giving rise to the anthesis-silking interval (ASI), whose duration is highly correlated with kernel set.

Maize grain yield correlating with plant height

This study has also demonstrated a strongly positive and highly significant correlation between maize plant height and grain yield for varieties ZM523 and DKC8053, suggesting that improvement in vegetative growth of stressed or non-stressed maize plants through manure application can enhance grain yield. In support, Al-Tabbal and Al-Fraihat (2012) indicated that tall plants exhibit high dry matter accumulation due to the large number of leaves they possess.

Conversely, Munawar et al. (2016) reported that taller plants require more plant nutrients to complete more vegetative growth than the reproductive phase, resulting in delayed maturation of the cob. However, under water stress with organic manure application, both varieties exhibited increased height and grain yield, with ZM523 showing greater increases than DKC8053, possibly due to the genotypic traits of drought and low nitrogen tolerances that the variety possessed. This underscores that improving vegetative growth of stressed maize plants through organic manure application can enhance grain yield.

Maize grain yield correlated with days to anthesis

Maize grain yield for the varieties ZM523 and DKC8053 strongly and negatively correlated with the number of days to anthesis, days to silking, anthesis-silking interval, leaf rolling, and leaf senescence (Tables 6 to 7). A delay in days to anthesis during stress caused a significant reduction in grain yield, while a decreased number of days under non-stressed conditions led to increased grain yield production, resulting in the formation of a significant and strong negative relationship with grain yield. This suggests the impact of stress conditions on days to anthesis in terms of serious pollen yield loss or flower abortion as a result of delayed silk formation, hence development of ears with fewer kernels. This is in agreement with Grant et al. (1989), who reported that almost complete barrenness can occur if maize plants are stressed in the interval from just before tassel emergence to the beginning of grain fill. Similarly, Schussler and Westgate (1995) stated that maize is thought to be more susceptible at flowering than other rain-fed crops because its female florets develop virtually at the same time and are usually borne on a single ear on a single stem.

Maize grain yield correlating with days to silking

The significant negative correlations maize grain yield had with days to silking exhibited maize grain yield loss when stressed due to the increased number of days to silking, and high maize grain yield when non-stressed due to the reduced number of days to silking, suggesting the dependency of maize grain yield on the period of time taken for silk formation. This also suggests that varieties with earliness to silk formation stand a better chance of increasing grain yield since they are able to escape stresses. Netaji et al. (2000) reported similar results which indicated a significant negative association between grain yield and its component traits, days to 50% tasseling and days to 50% silking. These results are also in line with the findings of Ghimire and Timsina (2015) who reported that days to 50% silking, days to 50 percent tasseling, and days to maturity showed a negative correlation with grain yield per hectare.

Maize grain yield correlating with anthesis-silking interval

The negatively and significantly associated grain yield with anthesis-silking interval (ASI) results suggest the total dependency of grain yield both on days to anthesis and silk formation, as shown in this study. Under stress conditions, grain yield significantly decreased as the ASI increased, whereas when non-stressed, grain yield significantly increased as the interval decreased. The implication is that the lower the ASI, the higher the grain yield, and conversely, the higher the ASI, the lower the grain yield. Therefore, earliness to silk formation implies complete fertilization of the developed ovules by the normally timely developed pollen. Thus, under water-limiting conditions, selecting a shorter ASI would result in increased yield. A longer ASI results in less partitioning of assimilates to the developing ears (Banziger and Lafitte, 1997; Ribaut et al., 1996; Ribaut et al., 1997). Similarly, Bolaños and Edmeades (1996) explained that drought tolerance mechanisms in maize are conferred by a shorter ASI, whereas drought escaping mechanisms are conferred by a longer ASI.

Relationship between maize grain yield and leaf rolling

Results from this study (Tables 6 to 7) indicated a weak to moderate relationship between leaf rolling (%) and grain yield, suggesting the impact of insufficient water on the growing maize plant when stressed. In such cases, the severity of leaf rolling contributed to the reduction in grain yield. Leaf rolling had minimal effect on ZM523 under drought stress, resulting in higher grain yield, while it was somewhat more severe on DKC8053. This negative correlation suggests that the lower the leaf rolling score, the higher the grain yield. However, there was no significant impact on either variety under well-watered, well-fertilized treatments. Banziger et al. (2000) reported that genotypes with leaf rolling indices greater than 2 might be susceptible to drought because at that stage, the leaf rim actually begins to roll. Leaf rolling scores in this study were assessed on a scale of 1-5 following the steps outlined by Banziger et al. (2000), where 1 referred to unrolled, turgid; 2 indicated the leaf rim starting to roll; 3 represented the leaf having the shape of a V; 4 indicated the leaf rim covering part of the leaf blade; and 5 indicated the leaf being rolled like an onion, respectively.

Correlating maize grain yield with leaf senescence

A weak negative correlation between leaf senescence and grain yield, as shown in Tables 6 and 7 in this study, likely implies a reduction in chlorophyll pigment, which affected the harvesting of solar energy by the plant, leading to a complete failure of photosynthetic activities. This resulted in reducing the size of the developing ear, hence decreased grain yield due to insufficient soil moisture. This aligns with previous findings by Hafsi et al. (2013), who reported no correlation between leaf senescence parameters and kernel weight. The weak relationship in this study suggests that the lower the scores for leaf senescence, the higher the grain yield, depending on the scale of 1-10 used by Banziger et al. (2000), whereby a score of 1 referred to 10% dead leaf area and a score of 10 referred to 100% dead leaf area. This indicates that leaf senescence had a weak impact on ZM523 in relation to grain yield, with a score of 3 under stress treatments, while it had a stronger impact on DKC8053 with scores of 7, 6, and 4 (Table 4), implying efficiency and inefficiency of the varieties in maintaining high plant water status, respectively. However, the effect was reduced on both varieties for scoring the same; 2, 1, and 1 under optimum conditions, implying a strong association with grain yield. It should be noted that the two varieties, during this study, were exposed to drought-prone conditions just a few days (7 days) before flowering, as supported by Banziger et al. (2000), who emphasized that the situation is worse at the flowering stage because the photosynthetic part and translocation of assimilates to the developing ear become blocked, hence resulting in an increased number of barren ears with fewer developed kernels, thus reducing maize grain yield production.

Maize grain yield associating with 100 grain weight

A non-significant correlation between grain yield (kg/ha) and weight of 100 grains for maize varieties ZM523 and DKC8053, as presented in Tables 6 and 7, implies that grain weight may not be the best predictor of maize yield in this study. This finding contrasts with Ghimire and Timsina (2015), who indicated that grain yield per hectare increases with an increase in the value of five hundred kernel weight. Similarly, Nawar et al. (1999) explained that grain yield showed a highly significant positive correlation with 100-grain weight. In this study, the results likely suggest that fully developed kernels under non-stress treatments result in high grain yield output, in contrast to those under stress treatments.

Graphical relationships of maize grain yield and manure application rates

Under both stress and non-stress treatments, grain yield for ZM523 and DKC8053 maize varieties was strongly positively correlated with manure application rates (Figures 2 to 5), implying the high nutrient efficiency of goat manure in promoting good vegetative growth and increased grain output, whether stressed or non-stressed. The significant increase in grain yield observed with manure application rates of 0, 5, and 10 t/ha is consistent with the available organic matter and other nutrients contained in the manure, as indicated in Table 3. These results align with the findings of Awodun et al. (2007), who reported that goat dung was high in organic matter and had elevated nitrogen levels. The same authors mentioned that goat dung increased leaf nitrogen, phosphorus, potassium, calcium, and magnesium content of pepper in 2003 and 2004, with the 10 t/ha goat dung treatment exhibiting the highest values among the different dung treatments.

Conclusion

Effect of variety depended on water and manure, whereby:

1) Variety ZM523 performs better under manure stress (V*M). Therefore, farmers can be advised to grow variety ZM523 using organic manure.
2) Variety ZM523 performs better under water stressed treatments (V*S). Therefore, variety ZM523 can help increase maize grain yield during drought.
3) Both varieties DKC8053 and ZM523 perform similarly when non-stressed (V*S*M). Therefore, goat manure has a mitigating impact on increasing maize grain yield under both stress and non-stressed conditions.

RECOMMENDATIONS

Based on these results, the following recommendations can be made from this study:

1) Manure application should be encouraged on improvement of soil moisture retention to alleviate drought effects.
2) Maize production through use of ZM523 seed should be encouraged in drought prone areas.
3) The future research should include analysis of sulphur, calcium and magnesium in goat manure, soil and plant

samples.
4) It is also recommended that a highly susceptible check be included to add to the data of research findings.
5) The recommended rate, 92 kg N/ha, of inorganic fertilizer should be included as well for comparisons.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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