ASSESSMENT OF MAIZE YIELD RESPONSE TO NITROGEN FERTILISER IN TWO SEMI-ARID AREAS OF KENYA WITH SIMILAR RAINFALL PATTERN

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Abstract
Five maize varieties were evaluated for two seasons in two semi-arid areas of Kenya; at Jomo Kenyatta University of Agriculture and Technology (JKUAT) Farm and at Longonot, in Naivasha Division. Three of the maize varieties were imported and the other two were locally produced. Nitrogen fertiliser was applied as urea at 0 and 36 kg N/ha; the latter was split applied in equal quantities at 20 and 40 days after emergence. The experimental design was a randomised complete block laid as split plot and replicated three times. The fertiliser and maize variety were main plots and sub-plots respectively. The phenological, biomass accumulation and grain yield data were analysed using Genstat Version 6.1 software. There were no significant differences in grain yield among the varieties between the sites within season but there were grain yield differences between the sites and seasons. Grain yield response to nitrogen fertiliser was significant only at JKUAT in 2004, where there was some rainfall received during the reproductive phase. Water use efficiency was 60% higher at JKUAT than at Longonot possibly due to high evaporation rate at Longonot, and late season drought.

Key words: Maize variety, nitrogen, water use efficiency, semi-arid, Kenya

1.0 Introduction

Kenya's agricultural sector faces the challenge of producing food for a rapidly increasing population, estimated to be growing at 2.5 % per annum (Shiluli *et al.,* 2003). The population pressure has led to opening up of dry and marginal areas for crop cultivation, resulting in accelerated land degradation (Mutisya and Mutiso, 1998). Maize (*Zea mays* L.) is one of the major crops whose production has spread into marginal areas. The average national yield is low (0.5–1 t/ha) because of inadequate and poorly distributed rainfall, low and declining soil fertility and mismatching maize varieties and agro-climatic zones (Onyango and Chege, 2000).

Rainfall distribution within a season influences the crop yield. Rainwater in the drylands is usually scarce during critical stages of growth. The critical period in maize growth is the reproductive phase that includes the periods immediately before and after anthesis/silking (Calvino *et al.,* 2003). Water stress delays silk emergence relative to pollen shed, which results in poor grain set (Otegui and Slafer, 2004). The later fertilised ovaries often abort thereby reducing kernel set. This leads to low grain yields as demonstrated by low harvest index (Sinclair, 2004; Carcova *et al.,* 2000).

Phenological development and water requirements are important attributes when evaluating the suitability of a crop for semi-arid environment (Shisanya, 2001). Crop production in the arid areas can be increased by maximising on the water use efficiency (WUE). Most agricultural production systems in the arid and semi-arid areas are characterised by limited water supply. The relationship between crop yield (total dry matter) and water supply may be expressed as:

$$WUE = \frac{Y}{ET}$$

where WUE is water use efficiency ($kgha^{-1}mm^{-1}$) Y the total dry matter yield ($kgha^{-1}$) and ET the evapotranspiration (mm).

WUE can also be calculated by dividing the total yield per hectare by the total rainfall received during the entire cropping period (Bolton 1981). Water use efficiency can be improved by increased soil moisture storage and reduced evaporation losses, planting better adapted crop varieties and improved agronomic practices.

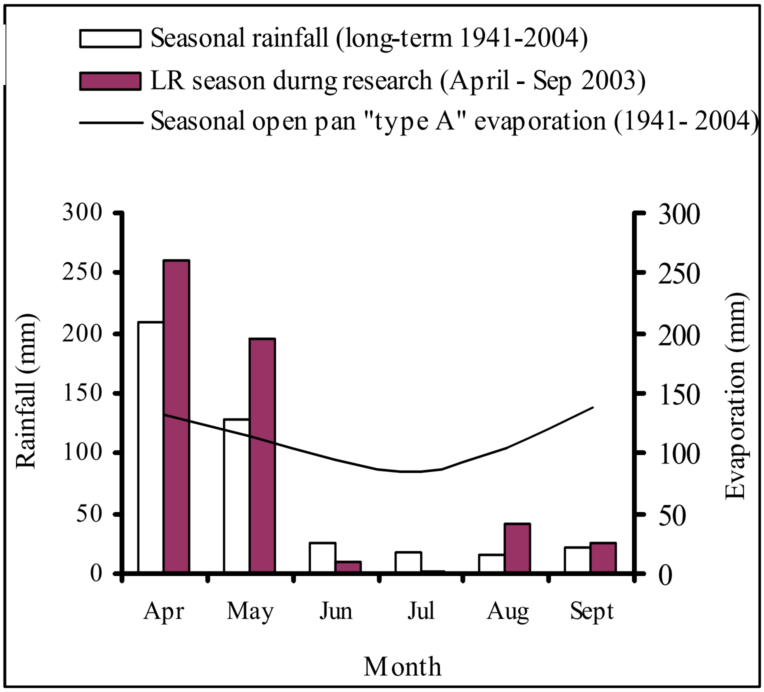
Although soils in semi-arid areas are low in nitrogen, limited water supply and low crop yield discourages widespread use of nitrogen fertilisers (Vlek *et al.,* 1981; Sombroek *et al.,* 1982). However, with an ever-increasing demand for food, crop production in the drylands needs to be increased. Introduction of improved crop varieties and use of nitrogen fertiliser has been tried in an attempt to increase grain yield and protein content in maize (Novoa and Loomis, 1981). Application of nitrogen fertiliser increases the grain yield depending on the amount of soil water available at the time of application (Nadar and Faught, 1984; Muli *et al.,* 2000).

The research objective was to assess maize yield response to nitrogen fertiliser application in three imported and two locally produced maize varieties in two semi-arid areas of Kenya.

2.0 Materials and Methods

Field research was carried out at Jomo Kenyatta University of Agriculture and Technology (JKUAT) Farm and at Longonot in Naivasha Division to assess maize yield response to nitrogen fertiliser application. JKUAT is located approximately 40 kilometres north of Nairobi City (37° 01' E and 1° 05' S) at 1520 m above sea level. The average annual rainfall is 700 mm and comes in two rainy seasons; long rains (March-May) and short rains (October-December) where on average 380 mm and 320 mm is received in each season respectively (Anonymous, 1984). See Figure 1. The soils at the experimental site are eutric cambisol which are well drained, shallow, dark brown, gravelly clay, over petrolinthite (murram) and low in Nitrogen and Phosphorous (FAO-UNESCO, 1977; Muchena, *et al.,* 1978). Longonot is located approximately 70 kilometres west of Nairobi City (36° 31' E and 0° 53' S) in Ewaso Kedong Valley in the Rift Valley at 1740 m above sea level. The average annual rainfall is 650 mm that comes in two rainy seasons; long rains (March-May) and short rains (October-December) where on average 290 mm and 360 mm is received in each season respectively (Anonymous 1984) (Figure 1). The soils are shallow, well drained, ando-calceric Regosols with moderate amount of N and P (FAO-UNESCO, 1977; Jaetzold and Schmidt, 1983).

(a) JKUAT



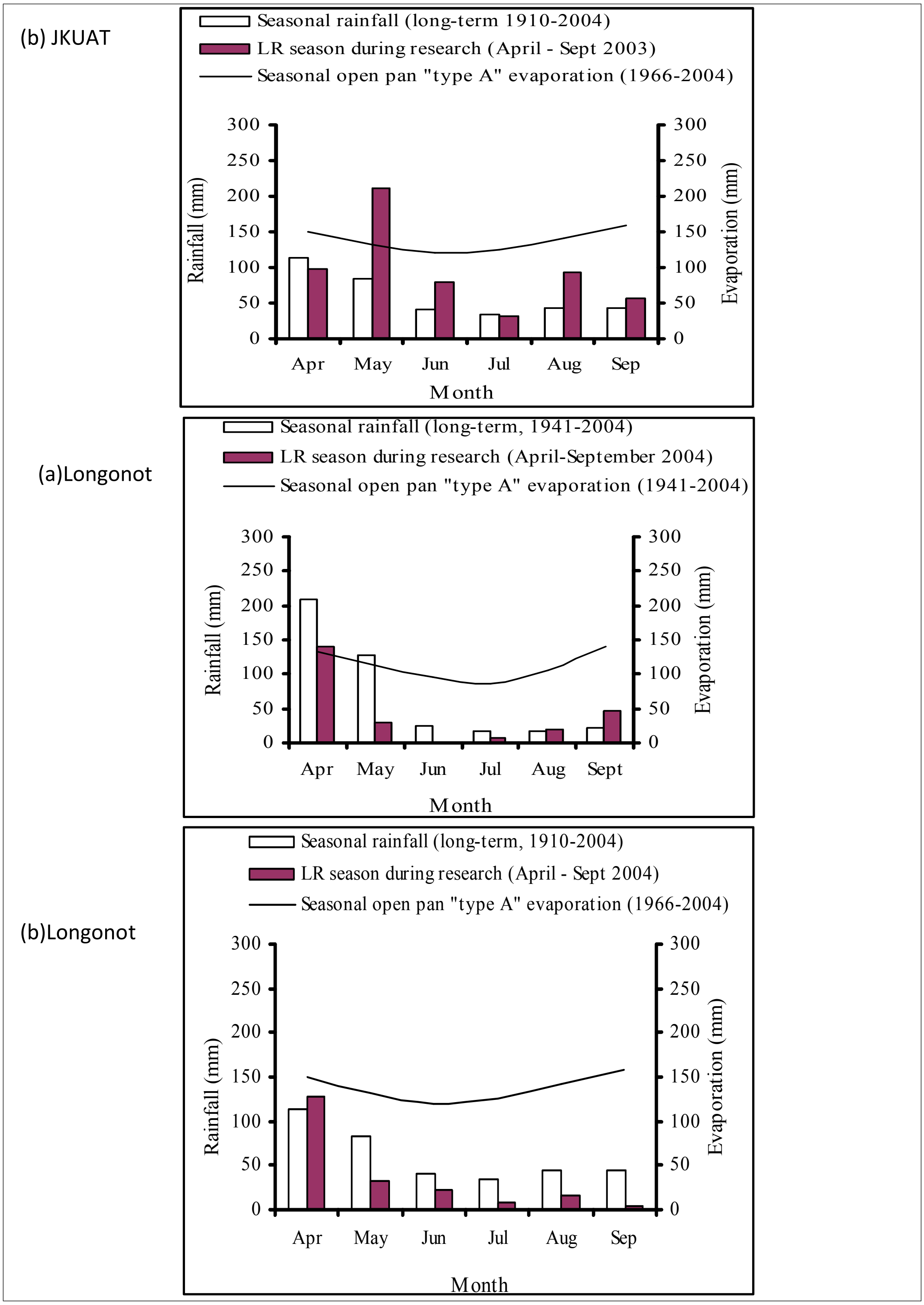


Figure 1: Mean monthly rainfall distribution in two long rain seasons of April–Sept at (a) JKUAT 2003, (b) JKUAT 2004, (c) Longonot 2003 and (d) Longonot 2004 and long-term seasonal rainfall and open pan evaporation (1941-2004)

Three of the maize varieties tested (Cargil 4141, Pannar 67 and Pioneer) are imported into the country from South Africa, while the other two (H513 and DH02) are locally produced. DH02 is early maturity (80-90 days) while the other four varieties are medium maturity (110-120 days).

Phosphorus was applied as a basal fertiliser in all plots in form of triple superphosphate (TSP) at 18 kg P/ha. Nitrogen fertiliser was applied as urea at 20 and 40 days after emergence (18 kg N/ha each time) as a basic recommendation for maize.

The experimental design was a randomised complete block laid as a split plot and replicated three times. The two levels of N (0, 36 kg N/ha) were allocated to the main plots and maize varieties to the sub-plots. The sub-plots were 7 m by 4 m with inter and intra-row spacing of 75 cm x 30 cm respectively. Two seeds were planted per hole and later thinned to one plant to give a population of 44000 plants/ha.

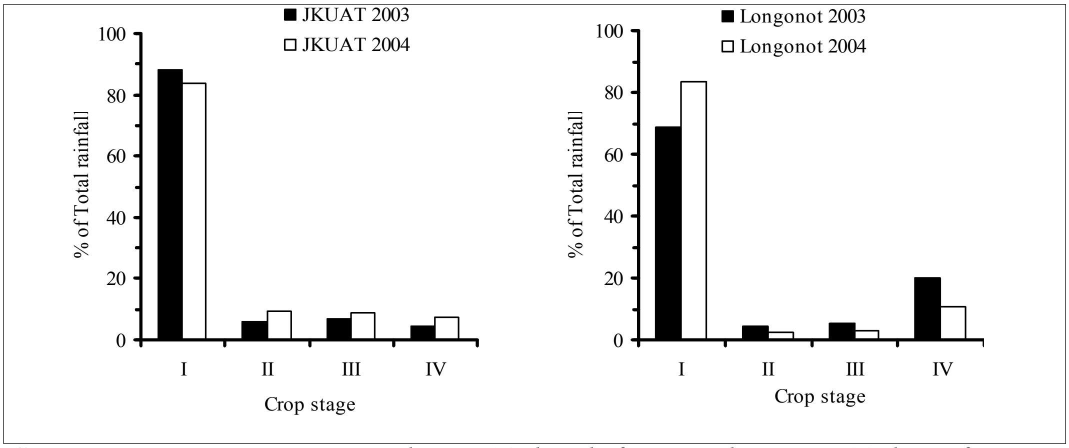
The data collected was on phenological changes, biomass accumulation and grain yield. The data on phenological changes was based on recording the days from sowing to 50 % emergence, days after emergence (DAE) to 50 % tasseling, DAE to 50 % silking, DAE to physiological maturity and taking the plant height at ear formation. Cumulative dry matter yield was determined by harvesting four plants per plot at fifteen day intervals after emergence. The fresh weight was recorded and a sample of chopped plants was dried in the oven at 80 ^{0}C for 24 hours to a constant weight. In 2003 season, maize was sown at JKUAT on 28th March and harvested on 5th September, while at Longonot sowing was on 24th April and harvesting on 14th October. In 2004 season, sowing at JKUAT was on 29 March and harvesting on 3rd August, while at Longonot maize was sown on 1st April and harvested on 19th August. The data was analysed using Genstat Version 6.1 software. Analysis of variance (ANOVA) was done for data collected at each site and the means separated with least significant difference (LSD).

3.0 Results

3.1 Rainfall Amount and Distribution during Research

The peak rainfall in both sites was highest in April and May. In 2003, the seasonal rainfall received at JKUAT and Longonot was higher than the long-term seasonal average (28 % and 58% respectively). JKUAT received 6% less total rainfall than Longonot in 2003. The seasonal rainfall received at both sites in 2004 was lower than the long-term seasonal average (42% and 29% at JKUAT and Longonot respectively) and JKUAT received 5% less than Longonot. The coolest month was July when the evaporation was lowest at both sites. Rainfall exceeded evaporation in the months of April and May in 2003 and 2004 at JKUAT, but only in May 2003 at Longonot.

The pattern of rainfall distribution within the growing season was more critical than the total seasonal rainfall in determining the final crop yield. The proportion of rainfall received at various stages of crop growth is given in Figure 2. The rainfall distribution in the two seasons at the two sites indicated that between 70- 88% of the total seasonal rainfall was received before tasseling which is the vegetative growth phase. The remaining amount (12-30%) was distributed within the reproductive phase stages II and IV (Figure 2).



Crop stages: I = vegetative growth, II = 20 days before tasseling, III 20 days after tasseling and IV = physiological maturity.

Figure 2: Rainfall distribution within the crop growth stages during long rain seasons (2003 and 2004) at JKUAT and Longonot.

The rainfall distribution at both sites (JKUAT and Longonot) was similar in both seasons where more than 70% of the seasonal rain fell during the phase of vegetative growth. In 2003, there was 17% more rain at JKUAT than at Longonot during the vegetative growth and 90% more rain in Longonot than JKUAT during the reproductive phase at around flowering stage. In 2004, there was 10% more rain at JKUAT than at Longonot during the vegetative growth and 98% more rain at Longonot than at JKUAT during the reproductive phase.

3.2 Maize Phenological Changes

The maize variety (DH02) had the shortest duration from planting to physiological maturity followed by Cargil 4141. There was no significant difference amongst the other three medium maturity varieties. The varieties DH02 and Cargill 4141 were significantly shorter in height than the rest of the varieties (Table 1).

Table 1: Phenology of five maize varieties planted at JKUAT in 2004

Maize variety	DAE to 50% emergence	DAE to 50% tasseling	DAE to 50% silking	DAE to physiological maturity	Height at cobbing (cm)
DH02	6	49	59	93	49
CG 4141	6	60	70	112	58
Pioneer	7	69	79	126	60
H513	7	70	80	128	60
PAN 67	7	70	80	129	62
LSD (variety)	0.8^{*}	1.8^{**}	1.8^{**}	4^{**}	1.8^{**}
CV%	9.2	2.2	1.9	2.5	2.3

Note: DAE = Days after emergence
* *= Significant difference (P < 0.05)*
** *= Significant difference (P <0.001)*

3.3 Cumulative Dry Matter Yield (kg/ha)

The peak of dry matter accumulation for all varieties planted for two seasons at JKUAT was between 95 and 102 days after emergence (Figure 4). The maximum dry matter yield for CG 4141, H513, Pan 67 and Pioneer was not significantly different (P ≤ 0.05) in the two seasons and ranged between 12000 and 14000 kg/ha in 2003 and 8000 and 9300 kg/ha in 2004 respectively. Dry matter yield of DH02 was significantly lower (P ≤ 0.05) than the others in both seasons, with a mean of 9600 kg/ha in 2003 and 6200 kg/ha in 2004. The seasonal rainfall was higher by 55% in 2003 than in 2004 and resulted to higher yields in 2003 than in 2004.

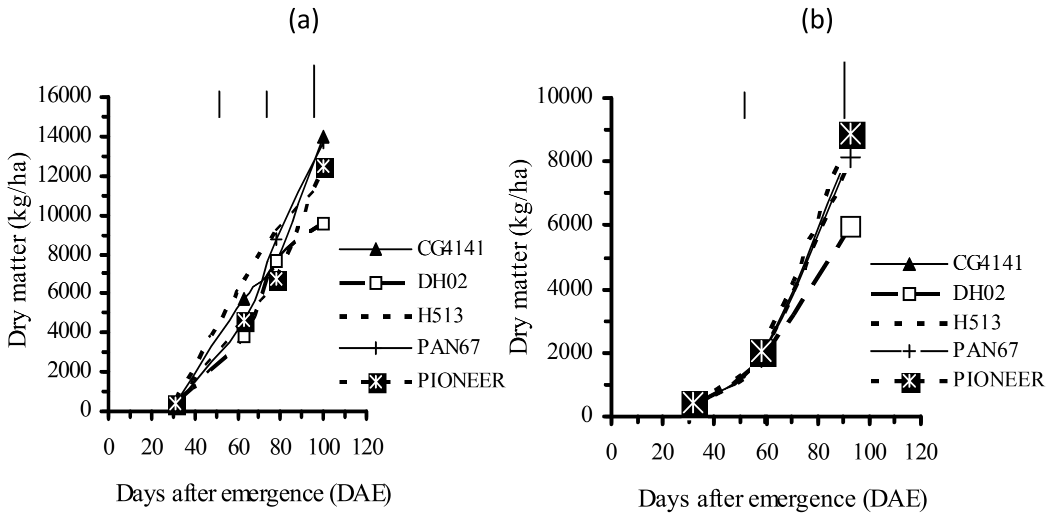


Figure 4: Cumulative dry matter (DM) prior to physiological maturity of five maize varieties planted at JKUAT for two long rains seasons in (a) 2003 and (b) 2004. The vertical error bars represent least significant difference (LSD) of means (P ≤ 0.05)

3.4 Maize Yield

There was no significant difference (P ≤ 0.05) in grain yield within sites among the five maize varieties planted for the two seasons (Table 2), but there was significant difference (P ≤ 0.05) in grain yield between the sites in both seasons. Grain yield was highest at both sites in 2003 and lowest in 2004 and JKUAT had the highest grain yield in both seasons. The difference in grain yield was due to variations in rainfall amount between the years and between the sites. The high maize yield at JKUAT may have been due to lower evaporation losses compared to Longonot.

Table 2: Grain yield (kg/ha) of five maize varieties in two seasons at JKUAT and Longonot

Site/Season	(Apr-Sep 2003)	(Apr-Sep 2004)	(Apr-Sep 2003)	(Apr-Sep 2004)
	JKUAT		**Longonot**	
CG 4141	2047	1341	1474	411
DH02	1978	1293	1616	426

H513	1834	1266	1453	375
PAN 67	2175	1349	1668	437
Pioneer	2186	1150	1732	452
LSD (N)	622.8*	441.2 ns	675 ns	228.4 ns
CV %	26.9	31.6	31.9	28.9

Note: * = *significant difference ($P \leq 0.05$)*
ns = *not significant ($P \leq 0.05$)*

At Longonot, there was some rainfall received during the flowering period in 2003 whereas in 2004 there was inadequate rainfall during the flowering period that lowered the grain yield. The variation of grain yield with rainfall distribution indicated that about 87% was due to the amount of rainfall received before flowering, 80% due to the total amount of seasonal rainfall, and 96% due to rainfall received after flowering (Figure 5).

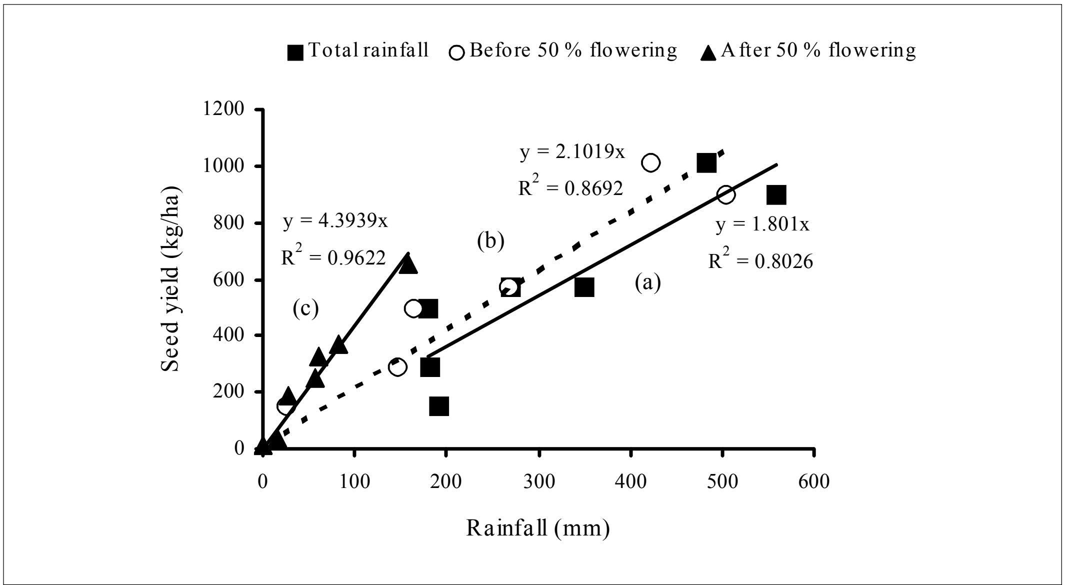


Figure 5: Grain yield and rainfall quantities at different crop stages at JKUAT.
(a) total rainfall (b) rainfall before flowering and (c) rainfall after flowering.
Pooled data for 2003 and 2004.

There was no significant difference ($P \leq 0.05$) in the total dry matter (TDM) yield among the four medium maturity varieties, which had a mean yield of 5770 kg/ha. The early maturity variety DH02 had the lowest mean dry matter yield of 4243 kg/ha. TDM was higher at JKUAT than at Longonot in 2003 by 48%. There was significant difference ($P \leq 0.05$) in the harvest index among the varieties and between the two sites. The short maturity variety (DH02) had the highest harvest index (0.35), while there was no significant difference ($P \leq 0.05$) among the medium maturity varieties that had a mean of 0.25 (Table 3). The difference could be due to drought escape traits of DH02 where the silking and grain filling occurs early in the season when there was still some amount of moisture in the soil. The medium maturity varieties are affected by late season drought that impairs translocation of plant nutrients and hence low harvest index.

Table 3: Overall average yield (kg/ha) of five maize varieties at JKUAT and Longonot in 2003 and 2004 seasons.

	TDM yield (kg/ha)	Grain yield (kg/ha)	Harvest index	100 seed wt (g)	Shelling %
Site					
JKUAT	7172	1662	0.29	21.4	25
Longonot	3757	1043	0.27	21	35
LSD	229**	733**	0.002**	0.75 ns	0.77**
CV%	42	54	0.8	3.3	2.6
Year					
2003	6538	1855	0.28	21.3	30
2004	4391	850	0.28	21.1	30
LSD	931**	93**	0.05 ns	0.9 ns	3 ns
CV%	18	22	20	4.7	12
Variety					
CG 4141	4958	1361	0.3	21	28
DH02	4243	1350	0.36	22	27
H513	6402	1244	0.22	21	33
PAN67	5882	1428	0.27	21	29
Pioneer	5838	1380	0.27	21	33
LSD	3628 ns	1160 ns	0.004 ns	1.1 ns	1.2**
CV%	42	54	0.8	3.3	2.6

*Note: * = significant difference ($P \leq 0.05$)*
*** = significant difference ($P \leq 0.05$)*
ns = not significant

There was no significant difference ($P \leq 0.05$) in 100 seed weight, but there was a significant difference in shelling percentage among the varieties and between the two seasons. The shelling percentage was low due to poor grain setting in almost all the varieties. It was noted that some cobs would have very few grains, and this lowered the shelling percentage. H513 and Pioneer were similar while the other varieties (Cargill G 4141, DH02 and Pan 67) were similar in shelling percentage levels.

3.5 Maize Yield Response to Nitrogen Fertiliser Application

There was no significant ($P \leq 0.05$) yield response to nitrogen fertiliser application except in 2003 season at JKUAT due to higher amount of rainfall. The highest increase in yield was noted in DH02, CG 4141 and PAN 67 (81%, 81% and 86% respectively) while H513 and Pioneer had the lowest yield response to nitrogen fertiliser application (21% and 29% respectively). In 2004, there was no yield response to nitrogen fertiliser application due to the low amount of rainfall received at JKUAT in the growing season (209 mm). There was no yield response to nitrogen fertiliser application at Longonot in both seasons, possibly due to low amount of rainfall received (Figure 6).

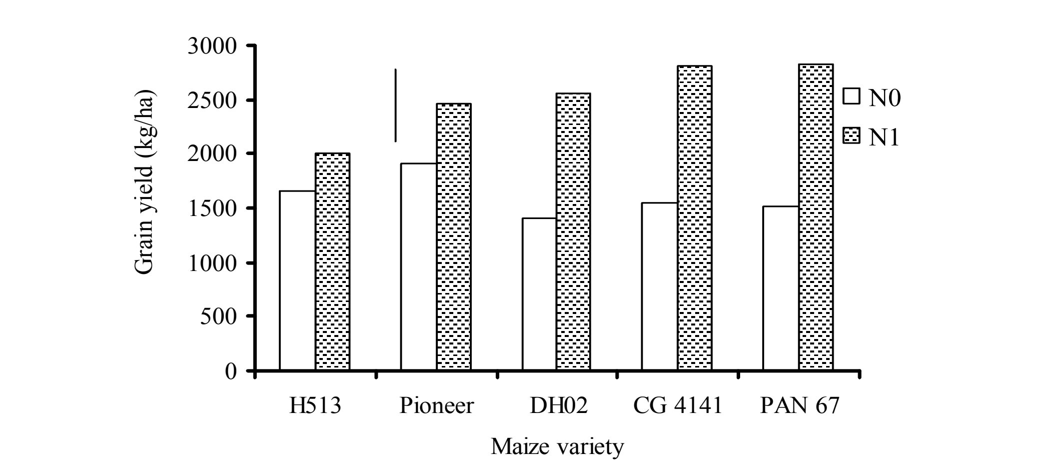


Figure 6: Maize variety and grain yield response to Nitrogen fertiliser application at JKUAT. Error bar represents least significant difference (LSD) of means (P ≤ 0.05)

3.6 Water Use Efficiency

There was significant difference in rainwater use efficiency between the two sites in both seasons, but there was no difference among the varieties. JKUAT had higher water use efficiency than Longonot (4.5 and 2.8 kg grain/mm/ha respectively). The difference could be due lower mean monthly evaporation at JKUAT than at Longonot (138 and 671 mm respectively). The water use efficiency at both sites in the two seasons was considerably below the typical value of 10-12 kg grain/mm/ha that can be achieved with high input system in the arid and semi-arid areas (Dines, 2002).

4.0 Discussion

There was no significant (P ≤ 0.05) variation in grain yield within the five maize varieties at JKUAT and at Longonot in the two seasons. Both the imported and local hybrid varieties had similar yield. The variety DH02 matured earlier than the other four varieties and had the highest harvest index. This indicated that it was more efficient in nutrient translocation than the others. DH02 reached the reproductive phase early in the season when there was still some amount of soil moisture and hence capable of escaping the late season drought. The second early maturity variety was Cargill 4141, while the other three medium maturity varieties H513, Pan 67 and Pioneer had almost the same duration to physiological maturity.

There was a significant difference (P ≤ 0.05) in grain yield between the two sites. The grain yield was 30% higher at JKUAT than at Longonot in 2003, and 200% higher at JKUAT than at Longonot in 2004. The surface evaporation at JKUAT was lower by 23% than at Longonot. The variation in grain yield at both sites could be explained in terms of the rainfall distribution within the growing season. The highest variation (96%) was due to the amount of rainfall after flowering, while 80 % was due to the total seasonal rainfall and 87 % due to the amount of rainfall received before flowering. Rainfall distribution within the growing season is therefore more critical in determining the final crop yield than just the total seasonal rainfall amount. The lowest seasonal rainfall received at Longonot (189 mm) yielded about 400 kg grains/ha. Stewart and Kashasha (1984) reported that 1000 kg/ha of maize were obtained with a gross rainfall of 155 mm that was well distributed within the growing season in Machakos district.

Nitrogen fertiliser application increased maize yield in only one season at JKUAT where some rainfall was received during the reproductive phase. The increase could have been due to increased N uptake when there was some amount of soil moisture. Three varieties DH02, Cargill 4141 and Pan 67 had the highest yield response to nitrogen application, while H513 and Pan 67 had the lowest yield response.

5.0 Conclusion

Nitrogen fertiliser application increased maize yield in only one season at JKUAT when there was more rainfall received than at Longonot. There was no significant yield response to fertiliser application at Longonot due to low and poorly distributed rainfall, which may have limited N uptake. The imported varieties did not show significant difference ($P \leq 0.05$) in yield compared to the locally produced varieties. Increasing soil moisture storage in the drylands through water harvesting would be more beneficial in increasing crop yield than fertiliser application.

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