Original Research Article

Effects of Nitrogen and Phosphorus Application Rates on Growth and Yield of Two Sorghum Cultivars in Semi-Arid Eastern Kenya Case study of Machakos County

ABSTRACT

Declining soil fertility is a main constraint toward attaining improved crop yields across the Africa continent. The soils within the area of study are generally poor in fertility, thus the importance of using chemical fertilizer to increase crop productivity. Experimental data from two sorghum cultivars (Gadam and Seredo) grown under four levels of nitrogen (N) and three levels of phosphorus (P) in the year 2014 and 2015 long and short rainfall seasons at Katumani Research Center in Machakos County, Kenya, were used to assess the effect of nitrogen and phosphorus on phenological parameters, harvested biomass and grain yield.

Analysis of variance depicted a statistically insignificant effect of N and P on phenological parameters in majority of the experiments. The two sorghum cultivars were significantly different from each other with Gadam taking approximately twelve (12) and seven days (7) less when compared to Seredo in flowering and maturity. Only Experiment 2 showed statistically significant effect of N and P on harvested biomass. Seredo produced higher average biomass (27.3 %) than gadam in all the four experiments. N application significantly increased biomass accumulation in seredo by 10.9 and 25.3% with application of 50Nkgha^{-1}, 10.9 and 6.5% at 75Nkgha^{-1} over the control for Experiments 1 and 4, respectively. Statistically significant response of Seredo among the different rates of fertilizer was present in Experiment 2. Seredo grain yield in Experiments 1, 2 and 4 responded positively to application of nitrogen with yields increase of 28.8%, 13.9% and 14.9%, respectively over the control (N1P1).

The sorghum plants responded more to N inorganic fertilizer. Existence of elevated amounts of soil P in the soil restricted the efficient utilization of P inorganic fertilizer by the sorghum plants.

Key Words: *Nitrogen, Phosphorus, Gadam, Seredo*

1. INTRODUCTION

According to FAO classification, Acrisols, Ferrasols and Luvisols prevail in the lower Eastern Kenya. These soils are characterized by reduced fertility levels and diminishing contents in soil organic carbon [1]. Diversity in soil types is due to the natural soil and variability of the landscape in the Eastern Kenya [2]. Generally, the soils are highly porous resulting to variability in the water holding capacity depending on the texture of the soil. Majority of the soils within the study area are relatively high in sand content leading to reduced water holding capacity and thus vulnerability to erosion is increased. These soils are not able to build up moisture pools to counteract the irregular distributed seasonal rainfall and thus pose an additional challenge to crop growth.

In addition to the limitations caused by texture of the soil, soils in Eastern Kenya are characterized by deficient nutrients and low levels of organic matter [3]. In the past management of soil fertility was mainly based on longer fallow periods, practicing shifting cultivation and the use of external farm inputs for example animal manure. Increased growth in population has led to increased pressure on the available natural resources and decreased farm sizes. This has further forced the smallholder farmers to practice continuous cultivation and prevents the practice of extended fallow periods [2]. Generally, deficient nutrients are returned back in to the soil to restore those removed by the crops [4]. The use of manure by smallholder farmers in the farms is highly variable owing to its limited availability and coupled labour demand [4]. The use of other external farm inputs for example chemical fertilizer is very low due to the limited financial resources of the smallholder farmers or fertilizers are scarce or inaccessible [5]. As a result, a constant decrease in nutrient levels and organic matter in the soil, specifically nitrogen and phosphorus, has been noted in the past, and thus degradation of lands has become a major problem in semi-arid parts of Eastern Kenya [5]. Smallholder agriculture in sub-Saharan Africa is therefore designated by low external farm input, declining crop yields, food insecurity and land degradation [6, 7, 8].

Enhancing crop yields and being food self-reliance under rapid growing population is a principal goal for achieving food security and alleviating persistent hunger in Africa [9, 10]. However, declining soil fertility is a main barrier towards attaining improved crop yields across Africa [8, 11, 12, 13]. Improvement of soil fertility has been known to be the basic prerequisite to attain lasting food security and improve the basic living standards of majority of smallholder farmers [14, 15]. Fertilizer use constitutes an essential part of improved soil fertility and thus improved crop production. It has been renowned that proper amount and timing of fertilizer application is the key to bumper crop production [16, 17]. Previous studies [18, 19, 20] have indicated the significance of inorganic fertilizer use to restore depleted nutrients into the soil. In any farming system the use of chemical fertilizers is vital as they provide the essential nutrients in forms readily available for uptake by plants. The growth, development and yield of any crop can be negatively affected by limited or too much application of any of the essential nutrients.

Nitrogen is by and large the major limiting nutrient in sorghum production [21]. Increased application rates of N fertilizer generally results in enhanced sorghum grain yield [22, 23, 24, 25, 26, 27, 28]. The response of sorghum grain yield to phosphorus (P) is usually variable; however, responses can be significant on soil containing low available P. Other researchers found that phenological parameters (days to 50% flowering and physiological maturity) decreased with fertilizer application [29, 30].

In order to attain food security, it’s necessary to increase crop productivity rather than increasing the piece of land. Little information has been reported on the response of sorghum cultivars (Gadam and Seredo) to different nitrogen and phosphorus fertilizers application rates in rain fed condition. The objective of this paper was to assess the influence of N and P on the growth, development and grain yield, of gadam and seredo sorghum cultivars in Machakos County.

2. MATERIAL AND METHODS

2.1 Study Site

The research was carried out in the National Dryland Farming Research Centre at Katumani. Katumani Research Centre (01°35'S; 37°14'E, 1600m) is positioned in the dry lowlands of Machakos County in the semi-arid Eastern Kenya. It is located in the transitional agro-climatic zone IV/V [31].

The study area experiences a semi-arid tropical climate identified by hot days and cold nights with temperatures varying from a mean annual minimum and maximum of 13.7^{o}C and 24.7^{o}C, respectively [32]. The rainfall pattern is bimodal, the long and the short rainfall seasons, which occur from March to May (MAM) and from October to December (OND), respectively. The average seasonal rainfall for the long and short rains is approximately 277mm and 300mm, respectively [33], while annual mean is approximately 655mm [32]. The short rains in semi-arid parts of Kenya are more reliable, uniformly distributed and sufficient for crop production. On the other hand, the long rains are connected with nearly all crop failures due to its unreliability, poor distribution and insufficiency for productivity of crops [34].

2.2 Experimental Layout and Design

The test crop in the field experiments was sorghum. Two cultivars of sorghum, the early maturity Gadam and the late maturity Seredo were planted in the experimental plots at research station in Katumani during the MAM and OND growing seasons for the years 2014 and 2015. The field experimental plots of 6 m by 7.5 m (45 m^2) in size were established for four seasons. The field experiments were laid out in a Randomized Complete Block Design (RCBD) with two replications. Inter-row (between rows) and intra-row (within rows) spacing was 0.75m and 0.20m, respectively, to give a plant density of 6.7m^2. Because of drier and less fertile conditions, wider spacing and low plant population are highly recommended for optimum sorghum growth [35]

Sorghum was sown in furrows because the seeds are too small to be spaced apart like corn. More seeds were planted than needed then thinned two weeks after emergence to allow a spacing of 20cm within the rows. The blocks and plots were alienated from each other by a distance of 2m and 0.5m, respectively to avoid cross contamination of treatments between blocks and plots. Guard rows of Gadam cultivar were planted to limit bird damage and also to reduce the impact of other factors outside the experiments.

Three levels of phosphorous [0, 50 and 100 Kg P_2O_5 ha^{-1}] in the form of diammonium phosphate $(NH_4)_2HPO_4$ and four levels of nitrogen [0, 50, 75 and 100 Kg Nha^{-1}] in the form of ammonia nitrate (NH_4NO_3) were applied at sowing and 35 days after sowing, respectively. The twelve (12) combined treatments are presented in Table 1. During the year 2014 gadam and seredo cultivars were planted on 2nd April and 20th October in MAM and OND seasons, respectively. In 2015 sowing was done on 28th March and 22nd October in MAM and OND seasons, respectively.

Table 1: Treatments with different levels of inorganic fertilizer

Treatment combination	N (Kg/ha)	P_2O_5(Kg/ha)	Treatment
N1P1 (Control)	0	0	T1
N2P1	50	0	T2
N3P1	75	0	T3
N4P1	100	0	T4
N1P2	0	50	T5
N2P2	50	50	T6
N3P2	75	50	T7
N4P2	100	50	T8
N1P3	0	100	T9
N2P3	50	100	T10
N3P3	75	100	T11
N4P3	100	100	T12

2.3 Soil Sampling

Preliminary soil sampling was performed in the experimental field a day before sowing. A soil auger was used to get samples of soil at various soil depths (0-15cm, 15-30cm, 30-60cm and 60-90cm) and placed into sampling bags. The soil samples were directly sent to the National Agricultural Research Laboratory (NARL) in Kabete for the physiochemical analysis.

Only the physiochemical properties required as input parameters in the ASPIM model were analyzed. These include the following initial soil water content, bulk density, field capacity, soil particle distribution, saturated volumetric water content (SAT), wilting point (LL15), available phosphorus, cation exchange capacity (CEC), exchangeable bases, soil organic carbon, soil pH, soil total nitrogen, finert, fbiom and initial ammonium and nitrate concentrations.

2.4 Sampling and Data Collection

Sorghum parameters including phenological parameters (days to 50% flowering and physiological maturity), growth parameters (above ground biomass) and grain yield were collected and recorded. The date of 50% flowering was pinpointed when more than half of the sorghum plants in the experimental plot exhibited exposed anthers. Likewise, physiological maturity was singled out as the date when a dark (black) layer at the base of the kernel had appeared. Number of days to 50% flowering and physiological maturity of the sorghum plants were then estimated by deducting the sowing date from date of 50% flowering and date of physiological maturity, respectively [36].

During harvesting time, above-ground biomass and sorghum grain yield were determined. The grain yield was estimated by harvesting panicles in all the experimental plots from the central plot (area 3m by 3m) and threshing was later done so as to segregate the grains from the panicles. The grains for each cultivar, plot and replicate were then oven dried at 70℃ for 48 hours (2 days) until an invariable weight was achieved. The dry weights were measured and recorded. The grains dried weights were used to estimate the dry weight from the harvested area which was then expressed as Kg/ha. Biomass was also harvested by cutting a number of sorghum plants just immediately above the ground surface and their fresh weight recorded. Sub-samples from the two cultivars and replicate were then oven dried at 70℃ for 48 hours (2 days) until a constant weight was obtained. Above-ground biomass was then expressed in Kg/ha as for the sorghum grain yields [36].

2.5 Statistical Analysis

The effect of crop cultivar, nitrogen and phosphorus levels on the field measurements of sorghum parameters were analyzed using the analysis of variance (ANOVA) structure in DSAASTAT version 1.514. DSAASTAT is an excel macro used to perform basic statistics analyses on agricultural experiments. ANOVA was executed on the field data which was obtained from the experiments. ANOVA was used to test two hypothesis; null hypothesis (all treatment means are equivalent) and alternative hypothesis (at least one treatment mean is different from the rest). F- Test was used to determine the hypothesis to be accepted. Significantly different treatment means were identified using Fishers Least Significant Difference (LSD) at $P< 0.05$ (Equation 1).

$$LSD = t_{\alpha/2}\sqrt{MSE\left(\frac{2}{n}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\boldsymbol{if}\ \left|\overline{y_i} - \overline{y_j}\right| \geq \boldsymbol{LSD}, reject\ null\ hypothesis$$

In Equation 1: t is the critical value from the t-distribution table, MSE is the mean square error obtained from the ANOVA test, n is the number of observations, ybar is the treatment mean, ‘i’ and ‘j’ represents two different treatments.

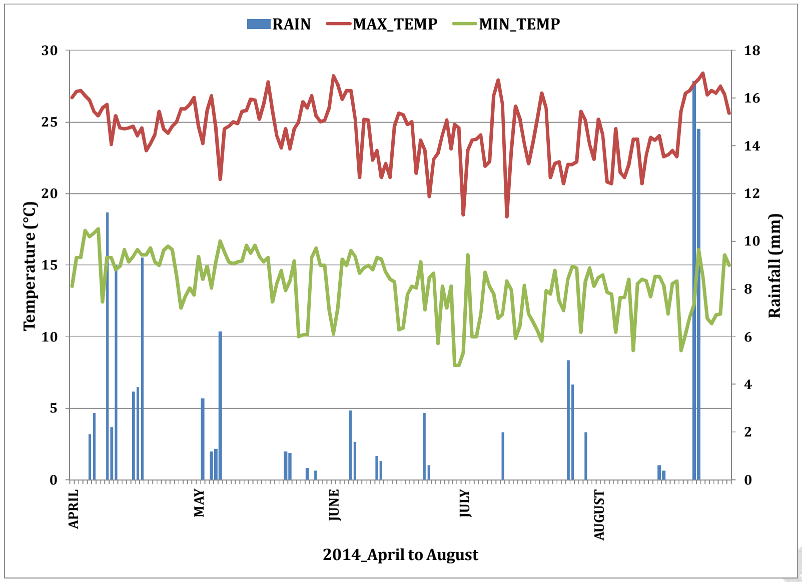
3. RESULTS

3.1 Environmental Conditions

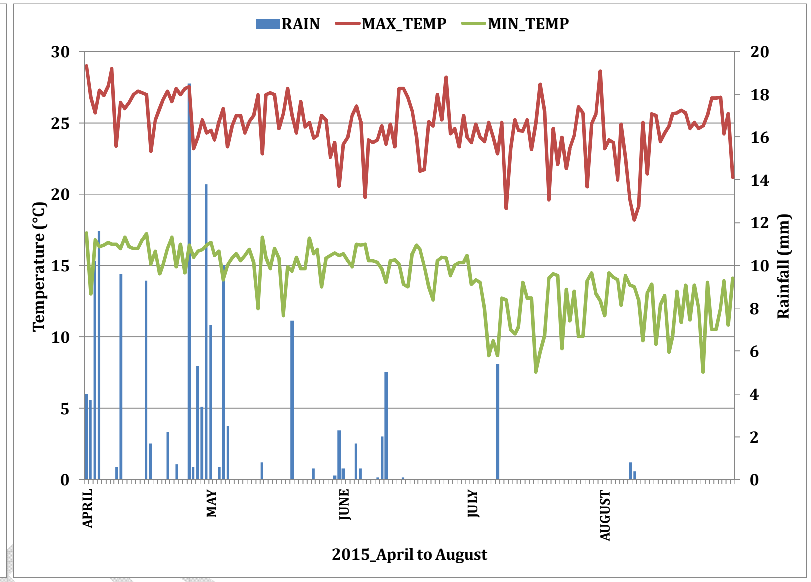
Temperatures patterns during the two long rainfall seasons 2014 and 2015 were fairly similar, with the average maximum temperatures of 24.5℃ and 24.8℃ and minimum temperatures of 13.6℃ and 14.2℃, respectively. On the other hand, the mean maximum temperatures during the short rainfall season was 27.0℃ and 26.0℃ and minimum temperatures was 14.7℃ and 15.1℃ for the year 2014 and 2015, respectively. Absolute minimum temperatures measured during the long (short) rainfall growing seasons in 2014 and 2015 were 8 (11) and 7.5 (10.8) ℃, while absolute maxima were 28.4 (31.9) and 29 (30) ℃, respectively (Figure 1). In contrast to the similar temperature patterns, rainfall distribution was diverse during the two years. The total rainfall for the long rainfall season of 2014 and 2015 were 114.4mm and 143.2mm, respectively. These rainfall amounts were 44.7% and 30.8% lower than the long term mean (1981 to 2012). The total rainfall for the short rainfall season during 2014 and 2015 was 246.1mm and 563.7mm, respectively. The long term mean for the short rainfall season was 425.4mm. In 2014, rainfall amount recorded during the short rainfall period was below the long-term mean. However during the short rains of 2015, total rainfall was higher than the long-term mean, and approximately 317.6 mm additional rain was recorded in 2015 compared to 2014. From planting to flowering, the rainfall amount received in 2014 and 2015 was 175.7mm and 507.7mm, respectively, in comparison to the long term mean of 290.1mm.

In 2014 short rainy season, rainfall distribution was poor, with a long dry spell period occurring towards end December to mid February. Because of the extended dry spell period it was mostly clear leading to increased total solar radiation in the 2014 short rainy season in comparison to the 2015 season.

(a)


RAIN
MAX_TEMP
MIN_TEMP
Temperature (°C)
Rainfall (mm)
30
25
20
15
10
5
0
18
16
14
12
10
8
6
4
2
0
APRIL
MAY
JUNE
JULY
AUGUST
2014_April to August

(b)


RAIN
MAX_TEMP
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Temperature (°C)
Rainfall (mm)
30
25
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6
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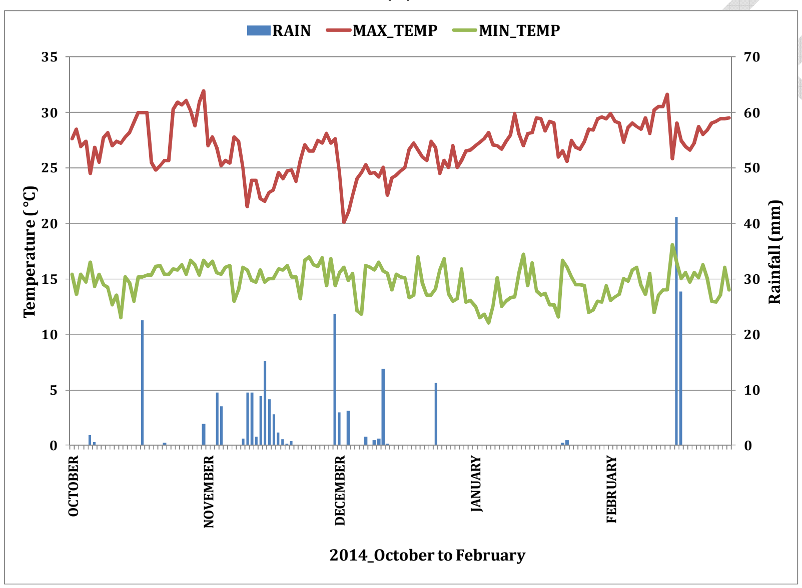
APRIL
MAY
JUNE
JULY
AUGUST
2015_April to August

(c)


RAIN
MAX_TEMP
MIN_TEMP
Temperature (°C)
Rainfall (mm)
35
30
25
20
15
10
5
0
70
60
50
40
30
20
10
0
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
2014_October to February

(d)

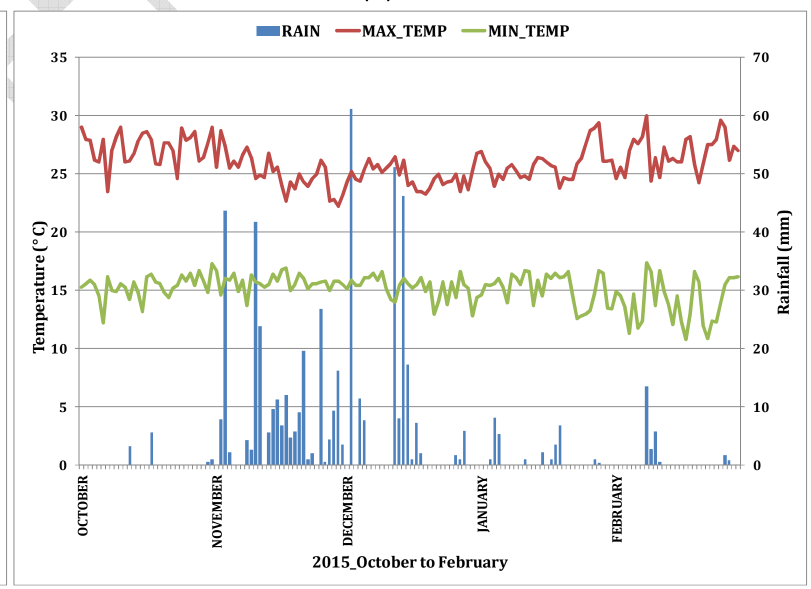

RAIN
MAX_TEMP
MIN_TEMP
Temperature (° C)
Rainfall (mm)
35
30
25
20
15
10
5
0
70
60
50
40
30
20
10
0
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
2015_October to February

Figure 1: Daily rainfall, minimum and maximum temperatures during the long and short rainfall seasons at KALRO Katumani, Kenya

3.2 Soil Characterization

Table 2 gives an overview of the physical and chemical attributes of soils at Katumani Research station in 2014. The soils in Katumani are sandy clay in all the layers. The soil profile depicted a decreasing trend in the bulk density. DUL and LL15 showed a decreasing trend in the 1^{st} two layers then an upward trend in the subsequent layers. Air dry and SAT depicted an increasing trend throughout the layers (Table 2).

The soil pH was slightly acidic with values ranging between 6.0 and 6.5. The average Organic Carbon and total Nitrogen in the soil was 0.85% and 0.065%. The exchangeable cations of the soils within the study area were also recorded. The average values obtained were 3, 6.2, 0.25 and 0.7 cmol(+)kg^{-1} for Calcium, Magnesium, Sodium and Potassium, respectively.

Table 2: Pre-Planting Soil Characteristics at Katumani Research Station in 2014

Soil Depth (cm)	**0-15**	**15-30**	**30-60**	**60-90**
Particle size distribution (%)				
Sand	68	69	62.5	50.5
Clay	25.3	23.5	31.5	40
Silt	6.7	7.5	6.0	9.5
Bulk Density (g/cc)	1.57	1.57	1.55	1.51
DUL (mm/mm)	0.24	0.23	0.30	0.35
Air Dry (mm/mm)	0.10	0.11	0.20	0.24
LL15 (mm/mm)	0.16	0.15	0.20	0.24
SAT (mm/mm)	0.24	0.34	0.37	0.38
Sorghum LL (mm/mm)	0.16	0.15	0.20	0.27
Soil pH (1:5 water)	6.5	6.5	6.2	6.0
Exchangeable Cations (cmol(+)/kg				
Calcium	3.5	4.1	2.3	2.1
Magnesium	6.6	6.2	6.1	5.9
Sodium	0.3	0.3	0.2	0.2
Pottasium	0.9	0.8	0.7	0.4
% Organic Carbon	0.9	0.8	1.0	0.7

% Total Nitrogen	0.08	0.07	0.06	0.05
Phosphorus (ppm)	50	40	20	20
NO_3^- N*(kg/ha)*	13.44	9.53	10.05	3.93
NH_4^+ N*(kg/ha)*	1.92	0.19	0.40	0.39
Fbiom	0.035	0.020	0.015	0.010
Finert	0.390	0.470	0.520	0.620

Source: Adapted from [36]

DUL: Drained Upper Limit (Field capacity), Air Dry: Soil moisture content at air dry point, LL15: Lower Limit of water extraction by the crop at 15 bar metric pressure (Wilting Point), SAT: saturated volumetric water content, NH_4^+N: Ammonium nitrogen, NO_3^-N: Nitrate nitrogen, Fbiom: fraction of soil organic matter that is decomposable and originally present in the fast decomposing pool, Finert: fraction of soil carbon which is not vulnerable to decomposition

3.3 Effect of N and P on Days to 50% Flowering

The effect of fertilizer treatments on days to 50% flowering of the sorghum crop is presented in Table 3. There was no significant difference amongst the treatments in the days to 50% flowering for both cultivars ($p< 0.01$ and $p<0.05$, Table 3) except for Experiment 4 (OND2015) for the gadam cultivar whereby there was some significant difference between the control (N1P1) and some of the different treatments.

In experiments 1 and 3, days to 50% flowering in gadam ranged from 60 to 63 days between different treatments. More days to 50% flowering were required in experiments 2 and 4 with days ranging from 82 to 84 and 74 to 79, respectively.

Seasonal effect portrayed a slower crop development by delaying days to 50 % flowering with an average of 22 days during the October to February growing season (83 days) compared to the April-August growing season (61 days) for gadam cultivar (Expt. 2 vs. Expt.1). However, slightly less difference in the days to 50% flowering (17 days) was observed in seredo cultivar (94 vs. 77). On the other hand, Experiments 3 and 4 also depicted the same trend with slightly less difference between the two growing seasons (15 days and 5 days) for gadam and seredo cultivar, respectively. Seredo cultivar took more days (86 and 82) to flower compared to the gadam cultivar (72 and 69) during the year 2014 and 2015, respectively. Year effect on days to 50% flowering in sorghum was significant. The crop took more days to flower during 2014 as compared to 2015.

The effects of cultivar, N and P on days to 50 % flowering are presented in Table 4. Cultivar significantly affected days to 50 % flowering in all the four experiments ($p < 0.05$). The effect of N and P was not present in the four experiments apart from experiment 4 where the effect of P was observed for the two cultivars. There were no observed significant ($P < 0.05$) interactive effects of N, P and cultivar in the four experiments (Table 4).

Table 3: Duration of Gadam and Seredo growth from sowing to 50% flowering expressed in calendar days after treatment with fertilizer

Treatment Combinations	N applied	P applied	Expt. 1		Expt. 2		Expt. 3		Expt. 4	
			G	S	G	S	G	S	G	S
			Calendar days							
N1P1	0	0	62	78	84	94	62	78	77bc	84
N1P2	0	50	60	77	83	93	61	77	76ab	82
N1P3	0	100	63	77	83	92	60	79	75ab	83
N2P1	50	0	61	78	84	93	61	77	79c	84
N2P2	50	50	61	77	82	94	60	76	75ab	82
N2P3	50	100	61	76	83	94	60	76	75ab	82
N3P1	75	0	62	76	84	94	63	78	79c	84
N3P2	75	50	60	77	84	94	61	80	77bc	82
N3P3	75	100	62	77	82	94	60	81	76ab	81
N4P1	100	0	60	78	84	94	61	77	79c	84
N4P2	100	50	62	78	84	93	62	76	76ab	81
N4P3	100	100	63	77	83	95	61	78	74a	83
Significance			NS	NS	NS	NS	NS	NS	**	NS

*Means with different unit weight letters in a column significantly differ from each other at p = 0.05. Expt. 1 = April-August growing season 2014; Expt. 2 = October-February growing season 2014; Expt. 3 = April-August growing season 2015; Expt. 4 = October-February growing season 2015; G = Gadam; S = Seredo; NS = Non-significant; *, ** = Significant at 95% and 99%, respectively*

Table 4: Effects of Cultivar and Fertilizer Rates (N and P) on days to 50% flowering at Katumani

Effects	Expt. 1	Expt. 2	Expt. 3	Expt.4
	F- Probability			
Cultivar	*	*	*	*
N	NS	NS	NS	NS
P	NS	NS	NS	**
N*P	NS	NS	NS	NS
N*Cultivar	NS	NS	NS	NS
P*Cultivar	*	NS	NS	NS
N*P*Cultivar	NS	NS	NS	NS

*Expt. 1 = April-August growing season 2014; Expt. 2 = October-February growing season 2014; Expt. 3 = April-August growing season 2015; Expt. 4 = October-February growing season 2015; NS = Non-significant; *, ** = Significant at 95% and 99%, respectively.*

3.4 Effect of N and P on Days to Physiological Maturity

Significant difference ($p < 0.05$) among the different rates of fertilizer in the number of days to physiological maturity was not present (Table 5) except for the gadam cultivar in Experiment 2. In Experiment 2, approximately two more days were required by the Gadam cultivar for the 100N kgha^{-1} treatment in comparison to the control which took 115 days to attain physiological maturity (Table 5). On the other hand, phosphorus affected days to physiological maturity in an opposite way to nitrogen (Table 5). Days to physiological maturity reduced with increasing rate of P fertilizer at the same level of N fertilizer.

The yearly effect on days to maturity of sorghum was significant. The crop took lesser days to mature (116days) during the year 2015, which was 6.9% lower as compared to the year 2014 (124 days). Sorghum took an average of one (1) extra day to mature during the April to August growing season (121days) compared to the October- February growing season (120 days). Seredo variety had the highest numbers of days to maturity in all the four experiments.

Seasonal effect revealed faster crop development by decreasing days to physiological maturity by an average of 12 and 15 days during the October to February growing season (114 and 120 days) compared to the April-August growing season (126 and 135days) for gadam and seredo cultivars, respectively (Table 5). On the other hand, experiments 3 and 4 also depicted the opposite trend with increased days to maturity between the two growing seasons (12 days and 13 days) for gadam and seredo cultivar, respectively.

The effect of cultivar differences on number of days to physiological maturity was statistically significant ($p < 0.05$ and $p < 0.01$) in experiments 1 and 2 (Table 6), with seredo taking on the average more days (128 days) to mature compared to gadam (120 days). There was no significant difference between days to physiological maturity at different N and P rates except for experiment 2. A significant interactive effect between N, P and cultivar was noted in experiment 4 (P < 0.05) (Table 6).

Table 5: Duration of Gadam and Seredo growth from sowing to maturity expressed in calendar days after treatment with fertilizer

Treatment Combinations	N applied	P applied	Expt. 1		Expt. 2		Expt. 3		Expt. 4	
			G	S	G	S	G	S	G	S
			Calendar days							
N1P1	0	0	125	135	115e	121	108	114	115	127
N1P2	0	50	125	136	111b	120	106	112	115	125
N1P3	0	100	124	136	114d	119	105	112	117	125
N2P1	50	0	129	134	115e	119	106	113	121	125
N2P2	50	50	127	135	113c	119	107	113	119	127
N2P3	50	100	126	135	116f	119	108	114	119	127
N3P1	75	0	123	135	116f	122	105	114	119	127
N3P2	75	50	123	134	109a	121	106	112	120	123
N3P3	75	100	128	134	113c	119	109	110	116	125
N4P1	100	0	128	136	117g	120	107	112	119	126
N4P2	100	50	129	135	115e	120	109	112	118	126
N4P3	100	100	126	134	115e	122	106	112	118	126
Significance			NS	NS	**	NS	NS	NS	NS	NS

*Means with different unit weight letters in a column significantly differ from each other at p = 0.05. Expt. 1 = April-August growing season 2014; Expt. 2 = October-February growing season 2014; Expt. 3 = April-August growing season 2015; Expt. 4 = October-February growing season 2015; G = Gadam; S = Seredo; NS = Non-significant; *, ** = Significant at 95% and 99%, respectively*

Table 6: Effects of Cultivar and Fertilizer Rates (N and P) on days to maturity at Katumani

Effects	Expt. 1	Expt. 2	Expt. 3	Expt.4
	F- Probability			
Cultivar	**	*	NS	NS
N	NS	**	NS	NS
P	NS	**	NS	NS
N*P	NS	**	NS	NS
N*Cultivar	NS	**	NS	NS
P*Cultivar	NS	**	NS	NS
N*P*Cultivar	NS	NS	NS	*

*Expt. 1 = April-August growing season 2014; Expt. 2 = October-February growing season 2014; Expt. 3 = April-August growing season 2015; Expt. 4 = October-February growing season 2015; NS = Non-significant; *, ** = Significant at 95% and 99%, respectively.*

3.5 Effect of N and P on Above Ground Total Biomass Accumulation

The effects of different treatments on biomass accumulation at harvest in all the four experiments are presented in (Table 7). Biomass responded insignificantly to the different rates of fertilizer application rates in both cultivars except for experiment 2. Biomass accumulation of sorghum at harvest was 74.9% higher during the October to February growing season (5585kgha^{-1}) compared to the April-August growing season (3193kgha^{-1}) for the two years.

The ANOVA (Table 8) showed significant cultivar effect in experiments 2 and 4. Seredo had significantly higher biomass than gadam with percentage difference of 84.1% and 39.9% in Experiments 2 and 4, respectively. Generally, seredo produced a higher average biomass (37.5 %) than gadam in all the four experiments. Significant effects were also noted with N and P application rates for both cultivars in Experiment 2.

N application significantly increased biomass accumulation in seredo by 12.3 and 12.2% with application of 50Nkgha^{-1} over the control for Experiments 1 and 4, respectively (Table 7). However, the accumulation of biomass started decreasing at higher levels of N (100kgha^{-1}). Significant differences in biomass accumulation at harvest were observed between 0, 50 and 100 Pkg ha^{-1} at similar levels of N within Experiment 2. Experiment 1 showed the lowest biomass accumulation ranging from 2072 kgha^{-1} in N1P1 to 3326kgha^{-1} in N3P2. Hence, biomass accumulation was categorized (Table 8) in the increasing order of Expt. 1 < Expt. 3 < Expt. 2 < Expt. 4.

Comparable observations were made for the gadam cultivar biomass accumulation at harvest. Experiment 4, had a large amount biomass accumulation of 7660$kgha^{-1}$ in N4P2 while the lowest of 1448$kgha^{-1}$ in N1P3 was recorded in experiment 1 (Table 7).

Significant yearly effect on biomass accumulation of sorghum was observed. The crop accumulated more biomass during 2015 (5614$kgha^{-1}$) as compared to 2014 (3164$kgha^{-1}$).

Table 7: Biomass accumulation of Gadam and Seredo cultivars at harvest at Katumani

Treatment Combinations	N applied	P applied	Expt. 1		Expt. 2		Expt. 3		Expt. 4	
			G	S	G	S	G	S	G	S
			Calendar days							
N1P1	0	0	2773	2072	2274e	4183f	3014	4107	5929	8448
N1P2	0	50	4151	3228	2400g	3543a	2596	5121	6511	8084
N1P3	0	100	1448	2859	3531k	3917b	3697	3766	6539	8659
N2P1	50	0	2476	2326	3441j	4424h	2959	3921	5429	9486
N2P2	50	50	3361	2631	2426h	4382g	3119	3298	6020	8694
N2P3	50	100	3465	2994	3367i	4104e	3522	4571	6955	8392
N3P1	75	0	4126	2775	1287a	4055d	2391	4089	6230	9038
N3P2	75	50	1956	3326	1522c	4002c	2992	4026	6002	8102
N3P3	75	100	2591	2694	1438b	6027l	2771	3523	6622	11002
N4P1	100	0	3107	2600	1711d	5575k	3043	4270	5598	7553
N4P2	100	50	2006	2455	2397f	5276i	3532	4579	7660	10121
N4P3	100	100	2608	3291	3963l	5298j	3473	3565	7000	9440
Significance			NS	NS	**	**	NS	NS	NS	NS

*Means with different unit weight letters in a column significantly differ from each other at p = 0.05. Expt. 1 = April-August growing season 2014; Expt. 2 = October-February growing season 2014; Expt. 3 = April-August growing season 2015; Expt. 4 = October-February growing season 2015; G = Gadam; S = Seredo; NS = Non-significant; *, ** = Significant at 95% and 99%, respectively*

Table 8: Effects of Cultivar and Fertilizer Rates (N and P) on biomass accumulation at Katumani

Effects	Expt. 1	Expt. 2	Expt. 3	Expt.4
	F- Probability			
Cultivar	NS	**	NS	**
N	NS	**	NS	NS
P	NS	**	NS	NS
N*P	NS	**	NS	NS
N*Cultivar	NS	**	NS	NS
P*Cultivar	NS	**	NS	NS
N*P*Cultivar	NS	**	NS	NS

*Expt. 1 = April-August growing season 2014; Expt. 2 = October-February growing season 2014; Expt. 3 = April-August growing season 2015; Expt. 4 = October-February growing season 2015; NS = Non-significant; *, ** = Significant at 95% and 99%, respectively.*

3.6 Effect of N and P on Grain Yield

Sorghum grain yields at harvest for both cultivars are presented in (Table 9). The ANOVA showed a significant response of seredo cultivar among the different rates of fertilizer ($p < 0.05$ and $p < 0.01$, Table 10) in experiment 2. There was approximately 1261kgha^{-1} sorghum grain yield in 2014 compared to 2593kgha^{-1}in 2015 (Table 9).

The seasonal effect on grain yield was also evident with a 69.7 % higher grain yield in October-February growing season (2425kgha^{-1}) than in the April-August growing season (1429kgha^{-1}). On average sorghum cultivar effect on grain yield was insignificant (Table 10), with seredo producing 17.1 % more grain yield than gadam. The seredo cultivar produced 1.7 %, 22.6 % and 32.8% more grain than gadam in Experiments 1, 2 and 4, respectively..

In general, N insignificantly increased grain yield of seredo cultivar in Experiments 1, 2 and 4 at 0, 50 and 75kgha^{-1} levels of N with no P application. The sole application of P upto 50kgha^{-1} also increased grain yield for seredo (Experiment 1 and 3). Seredo grain yield in Experiments 1, 2 and 4 responded positively to application of nitrogen with yields ranging from 952kgha^{-1}, 1203kgha^{-1} and 4332kgha^{-1} in N1P1 (control) to yield maximum of 1337kgha^{-1}, 1397kgha^{-1} and 5088kgha^{-1} in N3P1, representing an increase of 40.4%, 16.1% and 17.5%, respectively.

The effect of Gadam cultivar to N, P and their interactive effects was insignificant in the majority of experiments. In general, grain yield was categorized (Table 9) in the decreasing order of Expt. 4 > Expt. 3 > Expt. 2 > Expt. 1 for both cultivars.

Table 9: Effect of nitrogen and phosphorus fertilizer on Gadam and Seredo cultivars grain yield at Katumani

Treatment Combinations	**N applied**	**P applied**	**Expt. 1**		**Expt. 2**		**Expt. 3**		**Expt. 4**	
			G	**S**	**G**	**S**	**G**	**S**	**G**	**S**
			Calendar days							
N1P1	0	0	1047	952	960	1203d	1637	1569	3225	4332
N1P2	0	50	1964	1613	1117	1011a	1126	1818	3119	3506
N1P3	0	100	546	1412	1001	1146c	1906	1411	3284	3566
N2P1	50	0	1046	1190	1530	1275f	1576	1703	2820	4391
N2P2	50	50	1533	1291	1276	1307g	1583	1244	2783	4079
N2P3	50	100	1615	1323	1488	1344h	1894	1805	3007	4289
N3P1	75	0	1984	1337	599	1258e	1651	1397	3139	5088
N3P2	75	50	939	1582	739	1056b	1540	1318	2790	3396
N3P3	75	100	1264	1284	729	1798l	1230	1125	3540	5210
N4P1	100	0	1370	1184	1030	1598j	1593	1532	2794	3625
N4P2	100	50	1005	1177	1122	1661k	1523	1699	3524	4104
N4P3	100	100	1220	1458	1522	1416i	1863	1531	3435	4176
Significance			NS	NS	NS	**	NS	NS	NS	NS

*Means with different unit weight letters in a column significantly differ from each other at p = 0.05. Expt. 1 = April-August growing season 2014; Expt. 2 = October-February growing season 2014; Expt. 3 = April-August growing season 2015; Expt. 4 = October-February growing season 2015; G = Gadam; S = Seredo; NS = Non-significant; *, ** = Significant at 95% and 99%, respectively*

Table 10: Effects of Cultivar and Fertilizer Rates (N and P) on sorghum grain yield at Katumani

Effects	Expt. 1	Expt. 2	Expt. 3	Expt.4
	F- Probability			
Cultivar	NS	NS	NS	NS
N	NS	*	NS	NS
P	NS	NS	NS	NS
N*P	NS	NS	NS	*
N*Cultivar	NS	NS	NS	NS
P*Cultivar	NS	NS	NS	NS
N*P*Cultivar	NS	NS	NS	NS

*Expt. 1 = April-August growing season 2014; Expt. 2 = October-February growing season 2014; Expt. 3 = April-August growing season 2015; Expt. 4 = October-February growing season 2015; NS = Non-significant; *, ** = Significant at 95% and 99%, respectively.*

4. DISCUSSIONS

The optimum temperature range for sorghum during vegetative growth and development is 26 to 34°C [37, 38] and during the reproductive phase is 25 to 28°C [38, 39, 40]. The observed temperatures during the short rainfall growing seasons for the year 2014 and 2015 approximated the optimum temperature ranges during the vegetative phase and reproductive phase as suggested by [37, 39], thus sorghum could perform relatively better in the study area during the short rainy seasons as compared to the long rainy seasons. Increase in temperature beyond the optimum range especially during the reproductive phase often result in decreased sorghum yield potential due to withering of the sorghum plants brought about by the scorching effect of the sun.

Sorghum crop water requirement increases from sowing to flowering and subsequently decreases during grain filling until the crop matures [41]. Thus, higher amounts of rainfall received during October to December in 2015 (which corresponded to the time of flowering) contributed to higher yields in 2015 compared to 2014. The relatively higher amounts of rainfall (68.9mm) received in February 2015 (Figure 1) during the short rainfall growing period (2014/2015) could have been the cause of the poor yields obtained since the month corresponded to the time of harvesting. High amounts rainfall at the time of harvesting affects the quality of the grain. In general distribution of rainfall observed for the two seasons in 2014 and 2015 denotes the continuing rainfall variability which strongly affects growth and development of sorghum and this contributed to the variability in the sorghum yield that were obtained from the four experimental seasons.

A decreasing trend in the bulk density is more beneficial to the growth of plants (Rowell, 1994) because of high porosity. The general rating of soils containing organic carbon is as follows > 20 % very high, 10 to 20 % high, 4 to 10 % medium, 2 to 4 % low and < 2 % very low [42]. On the other hand, the description of the percentage total Nitrogen content in soil is as follows > 1.0 very high, 0.5 – 1.0 % high, 0.2– 0.5 % medium, 0.1 – 0.2 % low and < 0.1 very low [42]. In reference to these ratings, the percentage of both Organic Carbon and total Nitrogen from the study area could be described as very low. The very low levels of Nitrogen in the soil could be ascribed to very low soil Organic Carbon levels depicted in the study area, thus indicating low fertility status of the soil. This could be due to continuous cultivation and lack of incorporation of crop residues and organic material in the field. The same observation could also be partially attributed to leaching and volatilization which results in Nitrogen losses. Application of crop residues and farmyard manure are reported to increase soil organic carbon [43]. Calcium content < 0.2 is rated very low, 0.2-0.5 low, 0.6-2.5 moderate, 2.6-5.0 high and > 5.0 very high. Magnesium content < 0.2 is rated very low, 0.2 – 0.5, 0.5-1.0 moderate, 1-2 high and >2 very high. Based on these ratings the soils in the study area have high and very high Calcium and Magnesium contents, respectively. The rating of soils containing sodium cations is as follows < 0.1 very low, 0.1-0.3 low, 0.3-0.7 moderate, 0.7-2 high and > 2 very high. Potassium content is rated as <0.05 very low, 0.05-0.1 low, 0.1-0.4 moderate, 0.4-0.7 high > 0.7 very high. Basing our results to these ratings the soils at Katumani have low and high sodium and potassium, respectively. Situations where by the estimated Sodium cations exceeds 1.0 cmol(+)kg^{-1} the soil is considered “sodic” and this has an impact on the yield of most cereals.

Owing to low content in organic carbon and the sandy characteristics of the soils, water infiltration is high resulting to poor water holding capacity. This is not favorable for crop production, particularly in this study area which is known to have low and irregular rainfall with frequent dry spells.

More days to 50% flowering noted in Experiment 2 (OND 2014), is attributed to the excess rainfall received during the month of November which led to water logging; hence removal of oxygen on which roots of the two sorghum cultivars could depend on for respiration. However, the number of days to 50% flowering improved during the year 2015 for the OND season since the amount of rainfall received in the month of December was enough to meet the increased water requirements during the flowering stage compared to 2014 where the rainfall decreased.

Early flowering in the year 2015 was attributed to increased amounts of rainfall in 2015. The differences in number of days to 50% flowering between the two cultivars at a particular N and P rates suggest that the effect of N and P stress on phenology vary among cultivars [44].

Delayed maturity in Experiment 2 at higher levels of nitrogen was attributed to the response of nitrogen fertilizers whereby they tend to increase vegetative growth of most crops thus delaying maturity time [45]. Because P is concentrated in the rapid growing parts of the plant thus hastening maturity in crops, days to physiological maturity reduced with increasing rate of P fertilizer at the same level of N fertilizer.

The delayed maturity for the Seredo cultivar in all the four experiments is attributed to the fact that long season variety produces more tillers and that they have an extended grain filling period [46]. Delayed flowering which had occurred in the year 2014 for both cultivars contributed to decreased number of days to maturity. (Expt. 1 vs. Expt.2).

The significant seasonal difference in biomass accumulation at harvest is attributed to the amount and distribution of rainfall between the two seasons. Higher biomass accumulated by the Seredo cultivar could be due to longer grain filling period and increased vegetative growth which was associated with seredo cultivar.

Both cultivars were responsive to both N and P rates and that an increase in N and P application resulted to an increase in the accumulation of biomass. These results are in conformity with [27] who also reported increase in sorghum biomass with application of nitrogen. The decrease in biomass accumulation at higher levels of N and P, indicate that other factors (environmental effects and other soil nutrients or both) could have been limiting to biomass accumulation.

Assessment of rainfall and yields in 2014 and 2015 shows the importance of rainfall distribution during the growing period and in particular during critical growth stages. Yields are influenced by rainfall in a moisture stress condition and that the yields were low in the April-August growing season due to moisture stress that was evident within the season. The low grain yields also obtained in 2014 was possibly due to water stress experienced during the same year.

The late cultivar attained higher yield because of the longer grain filling period and the increased vegetative growth. The yields of the Seredo cultivar increased with increased N rates. The findings of this study agree with [24, 25, 27] who reported that sorghum grain yield increased with increase in nitrogen rates.

5. CONCLUSIONS

Based on the results obtained, the following conclusions are drawn: The effect of different nitrogen and phosphorus application rates was observed on the phenological parameters, growth parameters and yield. The phenological parameters studied in this study were the days to 50% flowering and physiological maturity. The analysis of variance on these parameters indicated that the effect of different treatments was insignificant on phenological parameters. Both days to 50% flowering and physiological maturity in majority of the experiments was also influenced by cultivar effect, but the interactive effects of cultivar, N and P in the four experiments was non-significant. Gadam cultivar took around twelve (12) and seven days (7) earlier than the seredo in flowering and maturity, respectively. Above ground biomass weight was not influenced by the different nitrogen and phosphorus application rates except for Experiment 2. It was also not influenced by the interactive effect (nitrogen, phosphorus and cultivar). Regarding to the effect of cultivar on biomass, seredo produced a higher average biomass (37.5 %) than gadam in all the four experiments. Sorghum grain yield among various fertilizer application rates was related to general conditions of the soil and their photosynthetic activity. The sorghum plants responded more to N inorganic fertilizer. Presence of high amounts of soil P in the soil restricted the efficient use of P inorganic fertilizer by the plants. The interactive effect (nitrogen and phosphorus) was not significant on grain yield. While the cultivars were dissimilar, they responded uniformly to the application of N and P fertilizer. Seredo cultivar nonetheless, responded quickly to inorganic fertilizer because it produces higher biomass and grain yield than gadam.

Based on the findings of this study, it is recommended that efficient use of fertilizer could be enhanced by using techniques such as precision agriculture and micro-dosing. Effective implementation of this can be achieved by having on-farm demonstration trials in the study area and this could be funded by seed companies and agro-chemical companies within the country. In order to enhance the rate of inorganic fertilizer adoption, the government should subsidize the cost of purchasing fertilizer and extend the subsidy on a range of fertilizer types so as to make it affordable for small holder farmers to purchase so as to enhance crop productivity. In addition the effect of fertilizer application rates on seed quality of sorghum should be incorporated in future studies to acquire satisfactory evidence not only on the phenological parameters, growth parameters and yield, but also the planting value of the seed.

COMPETING INTERESTS

All authors declare that they have no competing interests.

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