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SOIL SCIENCE

Response of Gadam Sorghum (*Sorghum bicolor*) to Farmyard Manure and Inorganic Fertilizer Application

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ABSTRACT

This study aimed to evaluate the effect of Farm Yard Manure (FYM), mineral fertilizers (nitrogen and phosphorus), and their combination on the production of Gadam sorghum in a Kenya Semi-arid region of Makueni and Machakos counties. The first experiment evaluated the response of sorghum to N and P application at four levels (0, 25, 50, 75 kg ha^{-1}) whereas the second evaluated the response of sorghum to the combined application of FYM (0, 5, and 10 tons ha^{-1}) and N and P fertilizer (0 and 50 kg ha^{-1}). Nitrogen application enhanced sorghum yields more than phosphorus addition. Combining N at 75 kg ha^{-1} and P at 50 kg ha^{-1} gave the highest sorghum grain yield in Kampi ya Mawe which was 135% higher than the control. In Katumani, combining 50 kg ha^{-1} N and 25 kg ha^{-1} P gave the highest mean grain yield, which was 68.3% more than the untreated control. In the follow-up experiment (Kampi ya Mawe), combining FYM with NP fertilizer (50 kg ha^{-1} N & P and 10 t ha^{-1} FYM) gave the highest yield; 13.7% more than the control. At Katumani, however, combining FYM at 10 t ha^{-1} and 50 kg of N and P resulted in insignificant differences in grain yield compared to the untreated control. Nitrogen use efficiency (NUE) was optimal at 50 kg ha^{-1} N and declined at 75 kg N ha^{-1}. Similarly, phosphorus use efficiency (PUE) was highest at 50 kg P ha^{-1}. Based on the results, it's evident that the integration of organic and inorganic nutrient sources enhances sorghum yield.

HIGHLIGHTS

- Nitrogen application enhanced sorghum yields more than phosphorus addition.
- Sorghum grain yield increased by 135% after combining N at 75 kg ha^{-1} and P at 50 kg ha^{-1} at Kampi ya Mawe.
- Nitrogen and phosphorus use efficiency was optimal at 50 kg ha^{-1} application rate.
- Integration of organic and inorganic nutrient sources enhanced sorghum grain yield.

Keywords: ASALs, soil fertility, sorghum, nutrient use efficiency

Agriculture will remain the driver of Kenya's economic and social development for the foreseeable future. The sector directly contributes 33% of GDP with an additional 27% through linkages to agro-based industries (Mwangi *et al*. 2010; FAO, 2020; USAID, 2022). The agriculture sector employs more than 40% of the total population and 70% of those living in rural areas (USAID, 2022). About 80% of Kenya's population live in rural areas and most of them are dependent on agriculture for a large part of their livelihood. However, the emerging adverse effects of climate change have in the recent past led to massive crop failures especially in the

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ASALs (Huho and Mugalavai, 2010; Ochieng *et al*. 2016; Nyawade *et al*. 2020). Approximately 84% of the country is arid or semi-arid (ASAL) and is not suitable for rain-fed farming due to low and erratic rainfall, though there is limited cultivation of some crops (GoK, 2010). The ASALs of Kenya have a population of about 10 million people, 70% of the livestock herd, and 75% of the wildlife in the country. Over 60% of ASAL inhabitants live below the poverty line, subsisting on less than 1.90 US dollars per day (NEPAD & GoK, 2016; UNDP, 2018).

In Kenya, the agricultural sector is dominated by smallholder farming systems, with 75% of national food production being primarily for household-level subsistence (FAO, 2020). Food insecurity in Kenya is also most severe in the ASALs. Approximately 1.3 million people in Kenya are currently facing food insecurity. In 2019, an estimated 2.6 million people needed food relief (GoK, 2019; USAID, 2021). Between 2000 and 2005, the Kenya government spent about £40-60 million annually on famine relief with NGOs spending an equivalent amount. As climate change continues to unfold, the frequency of climate extremes such as severe droughts and floods is expected to increase (Huho and Mugalavai 2010). The major constraint to crop productivity in the semi-arid regions is inadequate, unreliable, and poorly distributed rainfall (Nikus *et al*. 2004). This calls for the adoption of climate-smart agriculture technologies to ensure crop failure is minimized. Good soil fertility and water management and the use of drought-tolerant crop varieties are necessary to better cope with the current and anticipated challenges to sustain agricultural production in drylands (Raza *et al*. 2021; Seleman *et al*. 2021).

Sorghum (Sorghum bicolor L. Moench), one of the drought-tolerant crops, is the fifth most important cereal crop grown for human consumption in the world, is surpassed only by maize, wheat, rice and barley (Akram *et al*., 2007). It is most widely grown in the semi-arid tropics where water availability is limited and frequently subjected to drought. It is one of the main staple food crops for the world's poorest and food-insecure people (Timu *et al*. 2012). In Kenya, the Gadam sorghum variety was introduced by the Kenya Agricultural and Livestock Research Organization (KALRO) to the semi-arid Eastern Kenya in 2009 as a technology to improve food security and generate income from the marginal land. The hardy high-yielding variety has thrived in the harsh conditions and has been widely adopted by smallholder farmers in the region. The grain is high in starch and low in protein which makes it suitable for malting and offers a good alternative source of starch (Esipisu 2011). In 2017, it was estimated that sorghum production in Kenya was approximately 150,000 metric tons due to the high demand from East African Breweries Limited (EABL), the region's brewing giant (KASAL, 2010; KALRO, 2016; FarmBiz Africa 2018).

Application of nutrients to the soil is necessary to replenish nutrients lost through crop harvest or leaching. However, due to scarcity and the high cost of fertilizers, most smallholder farmers in Africa rarely use inorganic fertilizer on food crops including sorghum (Buah and Mwinkaara 2009). The use of resources available on the farms to enhance soil fertility is gaining importance among smallholder farmers. Such resources include crop residues, green manure, and FYM (Achieng *et al*. 2010). Farmyard manure is the most commonly used because of its availability and the fact that it contains most of the nutrients needed for plant growth including trace elements. However, FYM alone cannot satisfy the crop requirements because of low nutrient contents, slow decomposition rates, and high C/N ratio which hinder the mineralization process (Tolessa and Friesen 2001). Integrated nutrient management through the combined use of mineral and organic fertilizer sources is of great potential in sustainably improving soil productivity in intensive cropping systems (Alemu and Bayo 2005). The objectives of this study were to evaluate the effect of farmyard manure and mineral fertilizer on sorghum grain yield and to assess the nutrient use efficiency of sorghum under different fertilizer rates.

MATERIALS AND METHODS

Study sites description

The study was conducted at Kampi ya Mawe KALRO sub-station in Makueni County and KALRO Station at Katumani in Machakos County, from October 2012 to April 2013. Makueni County covers an area of 8009 km^2 and lies at latitudes 1°35′S and longitude 37°10′ to 38°30′E. The County has a population of 989,653 people according to the

2019 census (KNBS, 2019) and a poverty index of 60%. Agro-ecologically, the area lies between lower highland zone LH2 and lowland zone L6 where the risk of maize production is 25-75% (Muchena 1975). It lies at an altitude of 1600m above sea level with an annual mean day temperature of 24°C and rainfall ranging 200-1200mm. The rainfall is bimodal with long rains (LR) lasting from March to June and short rains (SR) from October to December. The soils are mainly Orthic Acrisols (Muchena 1975) which are moderate to slightly acidic. The area is characterized by rapid population growth, low agricultural productivity, and high poverty index (FAO, 2007).

Machakos County on the other hand has a population of 1,421,932 (KNBS, 2019). The local climate is semi-arid; the terrain is hilly with altitudes ranging from 1000 to 1600 m above sea level. It stretches from latitudes 0°45´S to 1°31´S and longitudes 36°45´ E to 37°45´E, covering an area of 6281.4 Km^2, most of which is semi-arid. High potential areas in the County where rain-fed agriculture is carried out account for 1574 Km^2 or 26% of the total area. The majority (60%) of the population lives below the poverty line and the County accounts for 4.4% of national poverty (GoK, 2011). The dominant soil groups are Alfisols, Ultisols, Oxisols, and lithic soils (FAO/UNESCO, 1970). The soils are generally of low fertility, highly erodible and less than 20% are well-drained. Farming in the County is mainly subsistence-oriented with the cultivation of crops such as maize, millet, pigeon peas, and sorghum.

Experimental Design

Two experiments were conducted concurrently at both sites. Experiment 1 was a 2 by 4 factorial where Nitrogen was applied at 0, 25, 50, and 75 kg N ha^{-1} and Phosphorus at 0, 25, 50, and 75 kg P ha^{-1}. Nitrogen was applied as Calcium Ammonium Nitrate (CAN) at the top-dressing stage (30-40 cm) plant height, while P was applied as Triple Super Phosphate (TSP) at planting. In a separate trial, the effects of nitrogen and phosphorus fertilizer and farmyard manure were tested in a 2 by 3 factorial experiment (Experiment 2). Nitrogen and Phosphorus fertilizer was applied at a rate of 0 and 50 kg ha^{-1} while FYM was applied at 0, 5, and 10 t ha^{-1}. Each experiment was arranged in a Randomized Complete Block Design (RCBD) replicated 3 times in plots measuring 4.5 m by 4.5m. Sorghum variety Gadam was used as the test crop. The crop was planted at two seeds per hill and spaced at 0.75 m by 0.2m. Soil characterization was done before setting up the experiments and soil analysis was conducted using standard analysis procedures (Okalebo *et al*. 2002; Savoy 2009). The samples were analyzed for soil pH, Magnesium (Mg), Calcium (Ca), Sodium (Na), total Nitrogen (N), available phosphorus (P), extractable Potassium (K), total Carbon (C), and microbial population (bacteria and fungi).

Agronomic nutrient use efficiency was determined to assess the efficiency of sorghum in utilizing nutrients. The formula used to determine Agronomic Efficiency (AE) was as described by Rajendra (2009).

$$AE = \frac{yf - yc}{Na}$$

AE = kg grain obtained/ kg of nutrient applied

Where:

yf = yields in fertilized plots (kg ha^{-1})

yc = yields in control plots (kg ha^{-1})

Na = amount of nutrient applied (kg ha^{-1})

AE = is the same as crop response ratio or Agronomic Efficiency

Data recording and analysis

Data was captured in an excel spreadsheet and analyzed using SAS software for Windows (version 9.0). After testing for normality, the yield data were subjected to analysis of variance (ANOVA) and tested for significant differences among treatments by the Least Significant Difference (LSD) method at $p \leq 0.05$.

RESULTS

Initial soil fertility status at Kampi ya Mawe and Katumani

The initial soil analysis results of the two sites; Kampi ya Mawe and Katumani are shown in Table 1. The soils were poor in nitrogen and phosphorus. The pH ranged from slightly to strongly acidic (6.17-4.88). Organic carbon in both soils was extremely low and ranged between 0.3 and 0.89% against the optimal range of 2.7%. The bacteria population which was estimated in colony-forming units (CFUs) was higher in the soil at both sites than the fungi population and the microbial population generally decreased with depth.

Table 1: Soil biochemical properties at Kampi ya Mawe and Katumani at the beginning of the experiment

Parameter	Katumani			Kampi ya Mawe		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
pH	5.90	6.00	6.17	4.88	4.88	4.80
$N\text{-}NO_3$- mg/kg	12.63	10.38	6.49	11.39	12.57	4.17
Available P- mg/kg	12.0	6.0	6.0	24.57	10.59	12.26
Na (mg/kg)	7.35	9.15	8.55	9.82	8.17	9.36
Mg (mg/kg)	17.6	25.6	30.6	1.45	1.62	1.55
Ca (mg/kg)	48.0	32.0	36.0	35.0	34.0	48.0
K (mg/kg)	39.8	22.6	14.8	66.2	52.2	43.3
Total N (%)	0.09	0.05	0.06	0.06	0.05	0.05
Total C (%)	0.59	0.30	0.38	0.67	0.89	0.84
Fungi (CFUs* 10^2)	6.7	4.5	3.0	4.3	3.6	2.6
Bacteria (CFUs*10^2)	20.4	11.7	8.9	10.9	5.1	5.0
Bulk density (g/cm^3)	1.37	1.32	1.22	1.34	1.34	1.32

Response of sorghum to nitrogen and phosphorus mineral fertilizer application

The grain yields of the Gadam sorghum variety at Kampi ya Mawe were significantly different in the various treatments applied ($p<0.02$) as shown in Table 2.

Table 2: Response of sorghum grain yield to N and P application at Kampi ya Mawe and Katumani during 2012/2013 short rains season

Fertilizer rates (kg ha^{-1})	Yield (kg ha^{-1})	
	Kampi ya Mawe	Katumani
N0 - P0	2059.62^{e}	1476.97^{e}
N0 - P25	2273.71^{de}	1552.85^{de}
N0 - P50	2628.73^{bcde}	2129.51^{cde}
N0 - P75	2886.18^{bcde}	2032.52^{abcd}
N25 -P0	2276.42^{de}	1799.46^{bcde}
N25-P25	2569.11^{cde}	1997.29^{abcde}
N25-P50	2601.63^{cde}	2040.65^{abcd}
N25-P75	3710.03^{abc}	2186.99^{abc}
N50-P0	2913.28^{bcde}	2149.05^{abc}
N50-P25	3514.91^{bc}	2485.10^{a}
N50-P50	3804.89^{ab}	2460.70^{a}
N50-P75	3685.64^{abc}	2214.18^{abc}
N75-P0	3542.01^{bc}	2257.45^{ab}
N75-P25	3821.14^{a}	2121.95^{abc}
N75-P50	4859.08^{a}	2257.45^{ab}
N75-P75	3279.13^{bcd}	2102.98^{abc}
$p \le 0.05$	0.02	0.04
N	0.001	0.0006
P	0.12	0.43
N*P	0.51	0.70
LSD	1198.6	549.5

Means denoted by the same letter along the column are not significantly different at p ≤ 0.05. N means nitrogen and P means phosphorus; the number appearing after the letter N and P are the corresponding fertilizer rates applied.

The combined application of N at 75 kg ha^{-1} and P at 50 kg ha^{-1} gave the highest grain yield of 4859.1 kg ha^{-1} followed by N at 75 kg ha^{-1} and P at 25 kg ha^{-1} (3821.1 kg ha^{-1}). The unamended control gave the lowest mean grain yield of 2059.6 kg ha^{-1}, a decline of 57.6% compared to the highest yield realized. Grain yields increased with increased fertilizer application (both sole N and P and their combination) except for the combined application of highest N and P doses (75 kg ha^{-1}) which gave low yields of 3279.1 kg ha^{-1}. Sole application of N and P also increased grain yield above the control but only the increase as a result of N application was significant ($p<0.001$). In comparison, the combination of nitrogen and phosphorus increased grain yield significantly from 2569 to 3804 kg ha^{-1} with an increase from 25 to 50 kg of N and P ha^{-1} combinations. The sole application of nitrogen and phosphorus gradually enhanced sorghum yields with increasing application rates. Grain yields at Kampi ya Mawe responded better to N application than P as shown in Fig. 1.

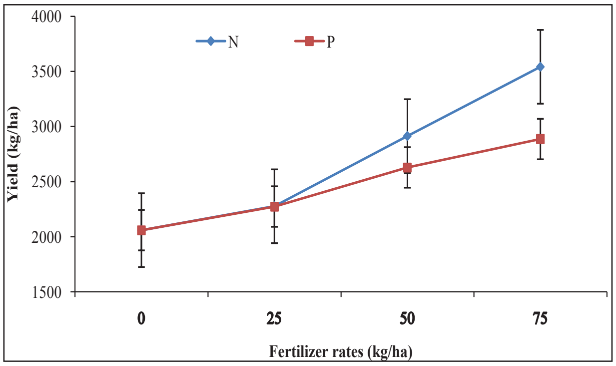

Fig. 1: Response of sorghum grain yield to N and P fertilizer at Kampi ya Mawe during 2012/13 short rains

The grain yields at Katumani were significantly different (*p* <*0.04*) between treatments (Table 2). At this site, the highest grain yields (2485.1 kg ha^{-1}) were obtained with the combination of 50 kg N and 25 kg P ha^{-1}, which resulted in a 68.3% increase above the control (1477.0 kg ha^{-1}). This was followed closely by treatment with the combination of 50 kg N and 50 kg P ha^{-1} which yielded 2460.7 kg ha^{-1}. Sorghum grain yield responded better to Nitrogen (*p*<*0.0006*) than to P addition (*p*<*0.43*). Yield due to N input increased from 1476 kg to 2257 kg ha^{-1} at 75 kg N dose while for P, the increase was only up to 2130 kg ha^{-1} obtained at 50 kg P ha^{-1}; at the higher dose of 75 kg ha^{-1} P, there were no significant yield differences recorded. Fig. 2 highlights the response of sorghum to nitrogen and phosphorus application at Katumani during the 2012/2013 short rains.

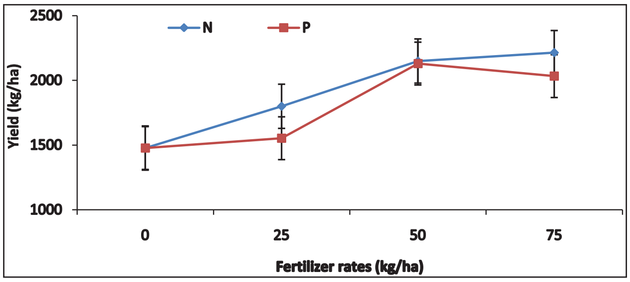

Fig. 2: Response of sorghum grain to N, and P at Katumani during 2012/2013 short rains

Response of sorghum to combined application of N and P mineral fertilizer; and farmyard manure

In the second experiment at Kampi ya Mawe where manure, and N and P fertilizer were used, the combination of nitrogen and phosphorus at 50 kg ha^{-1} and manure at 10 tons ha^{-1} gave the highest grain yield of 5393 kg ha^{-1} followed by N and P at 50 kg ha^{-1} and manure at 5 tons ha^{-1} (5187 kg ha^{-1}). The untreated control (NP0-M0) gave the lowest yield of 4233 kg ha^{-1} (Table 3). Grain yields slightly increased with increasing rates of fertilizer application. The application of N and P fertilizer without manure increased sorghum grain yield significantly (*p*<*0.006*), while sole FYM did not lead to significant changes in sorghum grain yield (*p*<*0.18*). This could have been as a result of the slow decomposition rate of FYM which delayed the nutrient release process thus affecting sorghum grain yields. Application of FYM alone at 10 tons ha^{-1} yielded the lowest sorghum yield increase of 5.4%, followed by that of FYM 5 tons ha^{-1} with an 11% grain increase over the control. In comparison, sorghum yields due to manure application alone were lower than sole mineral fertilizer application and the combination of both manure and mineral fertilizer. Application of N and P fertilizer at 50 kg ha^{-1} had a 14% yield increase over the control with the highest yield advantage obtained from combining N and P fertilizer at 50 kg ha^{-1} and manure at 10 tons ha^{-1}.

Table 3: Effect of farmyard manure and N and P fertilizer on sorghum yields at Kampi ya Mawe and Katumani during the 2012/13 short rains

Treatments	**Yield (Kg/ha)**	
	Kampi Ya Mawe	**Katumani**
NP0 - M0	4233.062^{c}	1669.38^{a}
NP0 - M5	4715.447^{abc}	1970.19^{a}
NP0 - M10	4463.414^{abc}	1886.18^{a}
NP50 - M0	4813.008^{abc}	1994.58^{a}
NP50 - M5	5186.992^{ab}	1864.50^{a}
NP50 - M10	5392.954^{a}	1566.40^{a}
p≤0.05	0.04	0.69
NP	0.006	0.85
M	0.18	0.69
NP*M	0.62	0.35
LSD	817.9	553.4

Means denoted by the same letter along the column are not significantly different at p ≤ 0.05. N means nitrogen, P means phosphorus and M means manure; the number appearing after the letter N and P are the corresponding fertilizer rates in kg/ha applied while the number appearing after the letter M are manure rates in ton/ha.

In general, therefore, the yields realized with manure alone were lower than those obtained under sole mineral fertilizer and even with the combination of both manure and mineral fertilizer. The potential yield of Gadam sorghum as reported by KARI is approximately 4800 kg ha^{-1} with the application of 50 kg ha^{-1} of N and P fertilizer (KARI, 2006), however, the integration of manure with N and P fertilizer greatly improved Gadam sorghum yields above the documented potential.

At the Katumani site, the application of mineral fertilizer and manure did not lead to significant differences in sorghum grain yield as shown in table 3 (*p*<*0.69*). The application of N and P fertilizer at 50 kg ha^{-1} resulted in the highest grain yield of 1995 kg ha^{-1} which was 19.5% above the control (1670 kg ha^{-1}). This was followed by FYM at 5 t ha^{-1} with a grain yield of 1970 kg ha^{-1}; this was 18% higher than the unamended treatment. Generally, sorghum yields were lower at Katumani compared to Kampi ya Mawe.

Comparison of sorghum growth performance at Kampi ya Mawe and Katumani

The variability and differences in rainfall patterns during the growing season at the two sites might have led to the differences in sorghum yields at Kampi ya Mawe and Katumani (Figs. 1 and 2). While Kampi ya Mawe received >540 mm of rainfall during the season, Katumani received <200mm. Moisture stress which was experienced at Katumani during the grain milk filling stage (Plate 1) might have greatly contributed to low grain yield. Plate 1(b) shows the effect of dry spells in crop development especially at Katumani during the seed milk filling stage which is an important stage in sorghum crop development. Leaf drooping at Katumani due to water stress adversely affected the grain yields during this season.

Effect of mineral fertilizer on sorghum agronomic nutrient use efficiency

Agronomic fertilizer use efficiency was determined to assess the efficiency of sorghum in utilizing nitrogen and phosphorus for grain production (Roberts 2008; Nduwimana *et al*. 2021; Nasar *et al*. 2021). Nitrogen use efficiency (NUE) averaged 8.7, 17.1 and 20 kg of grain for each kilogram of N applied with the application of 25, 50, and 75 Kg ha^{-1}, respectively, at Kampi ya Mawe (Table 4).

Table 4: Agronomic nutrient use efficiency of sorghum at Kampi ya Mawe and Katumani (kg grain/ kg of fertilizer applied) during 2012/13 short rains

Attribute	**Nitrogen use efficiency**		**Phosphorus use efficiency**	
Fertilizer Rates (kg ha^{-1})	**KYM**	**KAT**	**KYM**	**KAT**
25	8.67	12.9	8.56	3.04
50	17.07	13.44	11.38	13.05
75	19.77	10.41	11.02	7.41

Note: *KYM and KAT denote Kampi ya Mawe and Katumani, respectively.*

In Katumani nitrogen use efficiency was 12.9, 13.4, and 10 kg of sorghum grain for every kilogram of nitrogen applied at 25, 50 and 75 kg ha^{-1} N applied respectively. Phosphorus use efficiency (PUE) was lower than that of nitrogen at Kampi ya Mawe averaging 8.6, 11.4 and 11.0 kilogram of sorghum grain for every kilogram of P applied at 25, 50, and 75 kg ha^{-1} P_2O_5, respectively. Katumani site recorded

(a) **(b)**

Plate 1: Sorghum at the seed filling stage at Kampi ya Mawe **(a)** and Katumani **(b)** during the 2012/13 short rains

slightly lower PUE than that of Kampi ya Mawe averaging 3, 13.1 and 7.4 kilograms of sorghum grain for each kilogram of P_2O_5 applied at 25, 50, and 75 kg ha^{-1} P_2O_5, respectively.

DISCUSSION

Response of sorghum to nitrogen and phosphorus mineral fertilizer application

Application of both nitrogen and phosphorus fertilizer generally enhanced sorghum grain yield as the application rates increased in the present study similar to the findings of Tayebeh *et al*. (2010). Combining nitrogen and phosphorus fertilizer was found to be better in improving sorghum grain yield than either sole nitrogen or phosphorus application. This conforms to the report by Shuaibu *et al*. (2018) who revealed that balanced application of nutrients enhanced sorghum grain yield since most crops require N at the early stages to ensure optimum vegetative growth and later for the synthesis of proteins in the grains while P is often required by plants for root development to enhance nutrient uptake (Mahmoud *et al*. 2009; Gitari *et al*. 2020). Application of P at 50 kg ha^{-1} was determined to be optimal since the yields did not differ significantly when the P dose was increased to 7.5 kg ha^{-1}. Comparable findings were also reported by Zenter *et al*. (1987). Kagwiria (2018) further revealed that the application of N fertilizer enhanced sorghum grain yield and other yield characteristics.

Response of sorghum to a combination of N and P mineral fertilizer; and farmyard manure application

It is evident from the findings of this study that the application of both FYM and mineral fertilizer gave higher grain yields than the sole application of mineral fertilizer at Kampi ya Mawe. This could be attributed to the positive effect of FYM on soil properties through both physical (water holding capacity of the soil) and chemical (nutrients released through the mineralization process). Studies by Ouedrago and Mando (2010), and Maitra and Gitari (2020) concluded that combining organic resources with mineral fertilizer was better in increasing yields than the application of mineral fertilizer alone. Alemu and Bayo (2005) further reported a significant sorghum grain yield increase of up to 3.23 t ha^{-1} due to N and P fertilizer application compared to the untreated control. Gitari *et al*. (2015) and Mwangi *et al*. (2010) observed increased growth and yields of maize, respectively as a result of the integration of FYM and mineral fertilizer. Kagwiria (2018) equally observed increased sorghum grain yield with the integration of FYM and inorganic N fertilizer. The studies attributed the changes to enhanced soil fertility through the addition of nutrients and enhanced soil physical attributes resulting from organic matter added through FYM.

Interestingly, the combination of FYM and N and P fertilizer at 10 tons ha^{-1} and 50 kg ha^{-1} respectively recorded the lowest grain yield at Katumani (1566 kg ha^{-1}) which was 6.2% below the control treatment. This was not expected for a combined application of manure and mineral fertilizers since numerous studies have reported the benefits accrued to combined application of organic and inorganic nutrient sources (Mochoge *et al*. 1997; Achieng' *et al*. 2010; Mohsin *et al*. 2010; Mwangi *et al*. 2010; Oedrago and Mando 2010; Kagwiria 2018; Shuaibu *et al*. 2018; Faridvand *et al*. 2021; Heydarzadeh *et al*. 2021a, b). This response could be due to low moisture content in the soil as a result of low and erratic rainfall experienced at the site during the season, and probably due to low dynamic changes in soil microbial activities. Microbial activities and hence nutrient turnover and uptake by crops are affected by moisture stress in soils (Birch and Friend 1956b; Bharambe and Joshi 1993; Igbadan *et al*. 2008; Seleiman *et al*. 2021).

Achieng *et al*. (2010) reported that FYM had a 108% grain yield advantage over mineral fertilizer in a study conducted in Western Kenya to assess the effects of FYM and inorganic fertilizer on maize production in Alfisols and Ultisols. The study revealed that FYM had a 4% grain advantage over mineral fertilizer on Ultisols during the dry season because of its ability to improve the water holding capacity of the soil. These findings are in tandem with Tasneem *et al*. (2004) who reported the significant influence of organic and inorganic fertilizer on the number of grains per cob in a study conducted to determine the effectiveness of FYM, poultry manure, and N for corn productivity.

Effect of mineral fertilizer on sorghum Gadam nutrient use efficiency

In terms of nutrient use efficiency, the results of this study concur with the findings of other researchers. Berral *et al*. (2002) reported that at 50 kg N ha^{-1} the improved genotype of sorghum had the highest nutrient use efficiency. The study concluded that simultaneous improvement of yield and N utilization efficiency was possible in sorghum. The results of this study also concur with Kayuki *et al*. (2012) and Ochieng' *et al*. (2021) who reported that at a very high N application rate the NUE declined despite the slight increase in grain yield. This was attributed to the luxury consumption of nitrogen by most crops which is not utilized by the crop. This trend of declining NUE at a very high N application rate was also emphasized by Kogbe and Adediran (2003). Oikeh *et al*. (2007) reported NUE was lowest for sorghum with 12 to 19 kg grain per kg N applied. Maranville *et al*. (2002) further revealed that nitrogen use efficiency (grain weight per unit of N supplied from soil and/or fertilizer) is reduced due to poor crop cultural practices, sub-optimal yields, and N losses or deficiency of other nutrients.

The efficiency of fertilizer P use by crops ranges from 10 to 30% in the year that is applied. The remaining 70 to 90% becomes part of the P pool which is released to the crop over the following months and years (Malhi *et al*. 2002; Syres *et al*. 2009; Cheptoek *et al*. 2021). In the present study, PUE was optimum at 50 kg P ha^{-1} and declined at 75 kg P ha^{-1} applied. This trend where yields reduced at higher doses of P was also observed by Kogbe and Adediran (2003) who reported that PUE increased until 40 kg ha^{-1} but declined as P application rate increased; application of 40 kg P_2O_5 appeared to be the optimum since, at higher rates, the yields were depressed.

CONCLUSION AND RECOMMENDATIONS

The current study revealed that organic and inorganic nutrient sources enhanced sorghum grain yield. From the findings of this study, it can be recommended that farmers growing sorghum in semi-arid eastern Kenya be encouraged to combine both mineral fertilizer (N and P) at 50 kg ha^{-1} and organic resources (FYM at 5 t ha^{-1}) for optimal sorghum production. As a result of the low and erratic rainfall in Katumani, further studies should be undertaken to evaluate the potential of soil moisture conservation technologies in enhancing growth and crop yield.

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