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Full Length Research Paper

Soil nutrient content, soil moisture and yield of Katumani maize in a semi-arid area of Kenya

Maina Muniafu[1] and J. I. Kinyamario[2]

[1]School of Arts and Sciences, United States International University, P.O. Box 14634 00800 Nairobi, Kenya.
[2]School of Biological Sciences, University of Nairobi, P.O. Box 30197-00100, Nairobi, Kenya.

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Many farmers in Kenya's semi arid lands cannot afford to purchase inorganic fertilisers to improve their crop yields. They thus rely on traditional agronomic practices such as addition of crop residues, animal manures or intercrops of cereals and legumes. This study investigated soil parameters and their influence on yield. It was carried out at the University of Nairobi's Dryland, Research and Utilisation Station located at Kibwezi. Soil parameters measured included soil organic carbon, total soil nitrogen, available phosphorus, soil moisture and soil texture and nitrogen mineralization rates. There was significant correlation ($p<0.05$) in the growing seasons, between soil moisture and soil organic carbon ($r = 0.66$, 0.81 and 0.65 for seasons 1, 2 and 3 respectively) as well as total soil nitrogen ($r = 0.73$, 0.79 and 0.70 for seasons 1, 2 and 3 respectively) and available phosphorus ($r = 0.55$ for season 1). Where rainfall was low, maize yield correlated negatively ($p<0.05$) with percent clay content ($r = -0.4$) in season one and showed no significant correlation ($r=0.21$) in season 3. Where rainfall amounts were high, (as in season 2), the correlation was significant ($r = 0.75$). Nitrogen mineralization rate did not seem to have a direct influence on yield but its effects were modified by soil moisture, soil texture and carbon to nitrogen ratios of the soil. Overall the organic inputs seemed to have minimal impact on yield though goat manure and pigeon pea intercropping had a melioration effect on the soil.

Key words: Soil nutrients, maize yield, semi-arid, Kenya.

INTRODUCTION

Farmers in semi-arid areas face a seasonal lottery of timing their crops to short rain periods and not surprisingly, crop failures and famines are common (Ewel, 1999). Efforts to increase yield from the land have led to a temptation by farmers to abandon traditional agronomic practices in favour of artificial fertilizer applications. However, despite access to fertilizers, many farmers lack sufficient funds and mainly rely on maize stover, goat manure and intercropping of maize with leguminous crops such as pigeon peas and cowpeas. Applied in appropriate quantities, such organic residues have an ameliorating effect on soil organic matter (Kapkiyai et al., 1999). Although the organic matter is not a requirement for crop growth per se, it contributes greatly to soil fertility through its effects on soil biota and properties (Sikora and Stott, 1994).

*Corresponding author. E-mail: mmuniafu@usiu.ac.k.

Yield integrates the effects of the underlying land characteristics and qualities (FAO, 1976) and will be maximal under certain soil conditions (Deckers et al., 1992).

In plants, nitrogen uptake is in the form of nitrate (NO^3-) and ammonium ions ($NH4^+$) from the microbial mineralization of organic matter or from biological nitrogen fixation by free-living bacteria and plant-bacteria symbiosis (Vermoesen et al., 1993). The mineralization rates of these two are thus very important and by breaking up of soil, as happens when land is cultivated, the resulting aeration leads to a lot of $NH4^-N$ being produced from the uncontrolled breakdown of organic matter. The amount of nitrogen mineralized can be estimated by measuring the amount of microbial activity using field or laboratory incubation either aerobically or non-aerobically. Mineralization rates very much depend on the carbon to nitrogen ratio of the organic residues applied with high ratios being proportional to mineralization rates (TSBF, 1996) and findings in this area may be useful for the purposes of advi-

Table 1. Correlations (r) of soil moisture content (SMC) and clay content (CC) with total soil organic carbon (TSOC), total soil nitrogen (TSN) and available phosphorus (AP) at the 0 – 20 cm depth.

Treatment	SMC (%)	Clay (%)	TSOC	r CC	rSMC	TSN	rCC	rSMC	AP	rCC	rSMC
	Season 1 (0 –20 cm) depth										
NE	4.6	29.3	1.88	0.84*	0.66*	0.20	0.64*	0.73*	16.62	0.70	0.55*
GM	4.9	24.0	1.77	0.84*	0.66*	0.18	0.64*	0.73*	21.34	0.70	0.55*
MS	3.0	24.3	1.56	0.84*	0.66*	0.15	0.64*	0.73*	17.36	0.70	0.55*
PP	6.0	23.0	1.58	0.84*	0.66*	0.17	0.64*	0.73*	14.82	0.70	0.55*
MA	7.6	26.0	2.22	0.84*	0.66*	0.21	0.64*	0.73*	22.48	0.70	0.55*
	Season 2 (0 –20 cm) depth										
NE	11.8	29.3	1.50	0.82*	0.81*	0.13	0.80*	0.79*	13.41	0.36	0.17
GM	7.7	24.0	1.40	0.82*	0.81*	0.10	0.80*	0.79*	21.30	0.36	0.17
MS	6.9	24.3	1.03	0.82*	0.81*	0.10	0.80*	0.79*	14.09	0.36	0.17
PP	9.0	23.0	1.34	0.82*	0.81*	0.11	0.80*	0.79*	11.75	0.36	0.17
MA	10.1	26.0	1.24	0.82*	0.81*	0.11	0.80*	0.79*	14.26	0.36	0.17
	Season 3 (0 –20 cm) depth										
NE	8.8	29.3	1.13	0.44	0.65*	0.11	0.53	0.70*	10.10	-0.2	-0.29
GM	5.5	24.0	1.06	0.44	0.65*	0.12	0.53	0.70*	24.70	-0.2	-0.29
MS	5.2	24.3	0.87	0.44	0.65*	0.08	0.53	0.70*	16.11	-0.2	-0.29
PP	13.6	23.0	1.39	0.44	0.65*	0.13	0.53	0.70*	11.27	-0.2	-0.29
MA	14.1	26.0	0.89	0.44	0.65*	0.12	0.53	0.70*	14.91	-0.2	-0.29

* Indicates significant difference at $p<0.05$. rCC – correlation with percent clay content rSMC – correlation with soil moisture content.

sing the local farmers. Maize growth and ultimately yield are the crucial parameters for the farmers. Yield will be influenced by a number of factors key being soil moisture and nutrient availability at critical stages of crop growth. It is a fact that crop yields in Kenya are low due to declining soil fertility as a result of continuous cropping and the lack of application of fertilizers by farmers. Establishing agronomic practices that enhance yields under local conditions is therefore imperative in research efforts in the arid and semiarid lands.

MATERIALS AND METHODS

The study was carried out in a semi-arid ecosystem at the University of Nairobi's Dryland, Research and Utilisation Station located at Kibwezi, about 220 km south-east of Nairobi. It lies at latitude 2^o 18' South, longitude 38^o 3" East with an elevation of about 915 m above sea level. It is in Zone V of Kenya's agro-climatic regions (Sombroek et al., 1980) and is thus classified as semi-arid, with an average annual precipitation of 450-900 mm and an annual evapotranspiration of 1650 to 2300 mm. Mean annual temperature is between 24^o and 30^{o}C and is hot to very hot. The region receives long rains between March and June and short ones between Nov-ember and December (Touber, 1983). Work done in the area by Michieka and Van der Pouw (1977) showed that the soils are ulti-sols with an A horizon that extends for an average depth of 30 cm while a B horizon with higher clay content extends to a depth of more than 120 cm. This property is described as being important for semi-arid areas since it allows for enhanced water-holding capacity at deeper soil layers away from the hot surface (Eswaran, 1993).

Using a randomized complete block design with four treatments and a control, the Katumani cultivar of maize was sown at a spacing of 30 x 50 cm in plots measuring 20 x 20 m under four types of treatments. These were based on the local agronomic practices and included, maize sown with goat manure (GM), maize intercropped with pigeon peas (PP), maize sown with maize stover (MS), and maize sown alone without any organic residues (MA). The stover was cut down at the time of ploughing from standing maize stocks from the previous season's harvest and left lying on the ground. Each of these treatments was replicated three times and a further three treatments (in similar plots) which contained the natural ecosystem (NE) of the region were used as the control. Soil samples were collected, using a soil augur two weeks after sowing at various depths with those of the upper 0 – 20 cm being shown in the paper. From these samples, total soil organic carbon (wet oxidation), total soil nitrogen (modified Kjeldhal oxidation method), available phosphorus (Bray 2 method) and soil moisture content (dry weight basis) were obtained with those for soil moisture being sampled every fortnight thereafter. Clay content measurements were made in the replicate plots at the beginning of the experiment using the hydrometer method (Anderson and Ingram, 1993). At the end of the growing season, yield in each treatment replicate was measured after sun drying of the maize grain (following the local practice). The experiment was repeated over two more growing seasons during which, estimates of nitrogen mineralization were made in addition to those of soil organic carbon and other nutrients. This involved aerobic incubation of soils in the laboratory (Anderson and Ingram, 1993). Samples from the field were taken about two weeks after emergence (and thereafter once every four weeks) and transported to the laboratory at 4^{o}C, bulked and soil moisture estimated gravimetrically. They were then sorted out to remove stones and as much root material as possible without disrupting the gross aggregate structure and allowing the soil to dry. Net nitrogen mineralization was determined as the total of nitrate-nitrogen and ammonia-nitrogen amounts produced after a two-week incubation period.

RESULTS

Soil mineral content

In season 1, there was a significant correlation ($p< 0.05$)

Table 2. Maize yield (kg ha^{-1}) correlation with clay content, total soil organic carbon, total soil nitrogen and available phosphorus from soil samples taken at the 0 – 20 cm depth

Treatment	Y	C	corr	SMC	corr	TSOC	corr	TSN	corr	AP	corr
Season 1											
GM	209.2	24.0	-0.4	4.9	-0.2	1.77	-0.4	0.18	0.09	21.34	-0.2
MS	286.7	24.3	-0.4	3.0	-0.2	1.56	-0.4	0.15	0.09	17.36	-0.2
PP	217.5	23.0	-0.4	6.0	-0.2	1.58	-0.4	0.17	0.09	14.82	-0.2
MA	274.0	26.0	-0.4	7.6	-0.2	2.22	-0.4	0.21	0.09	22.48	-0.2
Season 2											
GM	993.3	24.0	0.75*	7.7	0.69*	1.40	0.70*	0.10	0.70*	21.30	0.36
MS	723.3	24.3	0.75*	6.9	0.69*	1.03	0.70*	0.10	0.70*	14.09	0.36
PP	848.3	23.0	0.75*	9.0	0.69*	1.34	0.70*	0.11	0.70*	11.75	0.36
MA	992.5	26.0	0.75*	10.1	0.69*	1.24	0.70*	0.11	0.70*	14.26	0.36
Season 3											
GM	117.5	24.0	0.21	5.5	0.08	1.06	-0.3	0.12	-0.2	24.70	0.53
MS	148.3	24.3	0.21	5.2	0.08	0.87	-0.3	0.08	-0.2	16.11	0.53
PP	0.0	23.0	0.21	13.6	0.08	1.39	-0.3	0.13	-0.2	11.27	0.53
MA	129.2	26.0	0.21	14.1	0.08	0.89	-0.3	0.12	-0.2	14.91	0.53

between total soil organic carbon and soil moisture content (r = 0.66). The same was the case with total soil nitrogen and available phosphorus (r = 0.81 and 65 for the two nutrients respectively) (Table 1). All the three nutrients also showed significant correlation with the clay content at the 0 – 20 cm depth (r = 0.84, 0.82 and 0.55 respectively).

Maize yield obtained in Season 1 showed a non-significant (p>0.05) correlation with clay content, soil moisture content, total soil organic carbon, total soil nitrogen and available phosphorus (r = -0.4, 0.02, -0.4, 0.09 and - 0.02 respectively) (Table 2). The highest yield in this season was obtained in maize stover and maize alone without any residues treatments. In season 2 the area experienced the El Niño rainfall and the total amount of rainfall over this season was 1,150.9 mm compared to the 215.5 mm received in season 1. Therefore, correlations between soil moisture and total soil organic carbon, total soil nitrogen were significant at p<0.05 (r = 0.81 and 0.79, 0.70 and 0.70) but were non-significant with available phosphorous (r = 0.17) (Table 1). The same was the case in the correlations between clay content and total soil organic carbon as well as total soil nitrogen (r = 0.82 and 0.80 respectively). Clay content had a non-significant correlation with available phosphorus (r = 0.36) (Table 1). Maize yield was relatively high in season 2 and correlated significantly (p<0.05) with clay content, soil moisture, total soil organic carbon and total soil nitrogen (r = 0.75, 0.69, 0.70 and 0.70 respectively). It showed non-significant correlation with available phosphorus (r = 0.36). During season 3 total soil organic carbon and total soil nitrogen showed significant correlation (p<0.05) with soil moisture at the measured depth (r = 0.65 and 0.70 respectively), available phosphorous did not show significant correlation (p>0.05) at this depth (r = -0.29). Maize yields obtained during season 3 were the lowest for the entire experimental period. There were non-significant correlations (p>0.05) between yield and clay content, soil moisture content, total soil organic carbon, total soil nitrogen and available phosphorus (r = 0.21, 0.08, -0.3, -0.2 and 0.53 respectively) (Table 2). However, highest yields were obtained in the plots under maize stover and maize alone without any residues treatments. The pigeon peas treatment had a zero maize yield due to the shading effect of the pigeon pea plants on the maize. The latter had overgrown from the heavy rains caused by the El Niño rainfall of the previous season. The total amount of rainfall over season 3 was only 221.8 mm.

During season 2, mean net nitrogen mineralization values were highest for maize alone without any residues treatment (11.23 mg $kg^{-1}$of soil) followed by pigeon peas treatment (10.90 mg kg^{-1}) and by natural ecosystem treatment (10.34 mg kg^{-1}) (**Table 3**). Net nitrogen mineralization was highest in the 79 DAS samples in all the treatments except for maize alone without any residues treatment (Table 3). The amounts of nitrate-nitrogen (NO_3-N) mineralised were in most cases higher than those for ammonium-nitrogen (NH_4-N) except early in season 2 maize stover treatment (8.02 mg $kg^{-1}$of soil) followed by maize alone without any residues (5.55 mg Kg^{-1}) and natural ecosystem (4.94 mg kg^{-1}) treatments (Table 3).

DISCUSSION

The high rainfall received in season 2 translated into high yields especially for the goat manure and maize alone without any residues treatment plots. The former had received more organic inputs while the other had not. The possibility was that in addition to the positive contribution

Table 3. Nitrogen mineralization (mg N kg^{-1})s.

	Season 2								
	22 DAS			59 DAS			79 DAS		
Treatment	NO_3^-	NH_4^+	Net N	NO_3^-	NH_4^+	Net N	NO_3^-	NH_4^+	Net N
NE	7.48	2.27	9.75	1.02	-3.10	-2.08	7.46	2.88	10.34
GM	1.61	4.50	6.11	0.32	-0.58	-0.26	3.97	3.97	7.94
MS	3.91	4.00	7.91	0.70	-1.39	-0.69	5.36	3.83	9.19
PP	3.44	5.29	8.73	0.57	0.28	0.85	7.83	3.08	10.90
MA	4.53	6.70	11.23	3.41	-1.46	1.95	3.90	3.69	7.59
	Season 3								
	17 DAS			59 DAS			Carbon to nitrogen ratios		
	NO_3	NH_4	Net N	NO_3	NH_4	Net N	Season 2	Season 3	
NE	-2.85	2.87	0.02	4.54	0.40	4.94	11.1	11.9	
GM	-2.33	1.77	-0.56	3.23	-0.94	2.29	14.0	10.2	
MS	-2.43	1.92	-0.51	6.17	1.85	8.02	11.2	11.3	
PP	2.13	2.71	4.84	3.35	-0.19	3.16	12.7	11.2	
MA	-2.85	-0.78	-3.63	4.73	0.82	5.55	10.8	7.7	

of the goat manure to yield (in the case of goat manure treatment), the high clay content of the maize alone without any residues treatment (hence high total soil organic carbon and total soil nitrogen) was another contributing factor to high yields in this treatment.

With the lower rainfall amounts received in season 3, the lack of significant correlation ($p<0.05$) of yield with percent clay content ($r = 0.21$) implied a larger influence on yield for sandy soils due to their tendency to release soil moisture more easily than clay soils. Thus maize stover treatment had a higher yield than maize alone without any residues treatment.

The low values of net nitrogen mineralization in season 2 on 59 DAS represented a period of nitrate depression which is usually short or long depending on prevailing soil conditions (such as soil moisture levels and carbon to nitrogen ratios) during which the soil microfauna use nitrogen for themselves (Brady, 1984). Weier and Macrae (1993) also attributed a lack of mineralization in laboratory incubated soil obtained beneath roots of pasture plants to an immobilisation of mineralised NH_4-N from high microbial activity associated with organic carbon decomposition.

There were high values of mean net mineralization for the treatments in soil samples taken on 22 days after sowing for the maize alone without any residues and natural ecosystem treatments. This was an indication of the low organic carbon to soil nitrogen (C: N) ratios in these treatments (Table 3). The maize stover treatment in this season had the lowest ratio of 10.8 at depth 0 – 20 cm and hence the highest net mineralization rate while the goat manure treatment with a ratio of 14.0 had the lowest net nitrogen mineralization rate of 6.11 mg $kg^{-1,}$ which was the highest. These findings are in line with those of Risasi et al. (1999) who observed that initial C:N ratios of roots appeared to be the main factor controlling net nitrogen mineralization in the absence of soil fauna and that the correlation between the two was negative and significant. Ajwa et al. (1998), however, obtained higher net mineralization values for a natural ecosystem consisting of pristine tall grass prairie (after a 40 week incubation period) of 220 mg kg^{-1} compared to a value of 67 mg kg^{-1} for agricultural lands due to reduced organic matter levels in the latter. Luna-Suarez et al. (1998) found significantly higher NO_3-N in incubated soils of a natural ecosystem of mesquite trees than in arable fields of maize and beans in the central highlands of Mexico. They attributed this to the higher inorganic nitrogen content of such ecosystems. This was also the case in our study for the samples taken 22 days after sowing where the NO_3-N value for the NE treatment was higher than those for the cultivation treatments and total soil nitrogen value for this treatment was also higher than for those in the cultivation treatments.

In the soil samples taken 79 days after sowing net nitrogen mineralised was lower in the cultivation treatments compared to the natural ecosystem treatment except in the pigeon pea treatment where it was higher. This was probably due to nitrogen fixation by the pigeon pea plants and the higher NO_3-N produced showed that there was more nitrogen available (Luna-Suarez et al., 1998).

The correlation of C:N ratio with net nitrogen mineralization, which was evident in season 2, was absent in soil samples taken 17 days after sowing in season 3. Thus the treatments such as goat manure and maize stover, which had the lowest ratios, did not show significant mineralization rates. This may have been due to the stimulation of microbial activity by presence of surface residue of maize stover together with the relatively lower soil moisture at this sampling time. The mean net nitrogen mineralization values of the soil samples taken 59 days after sowing were all thus negative or close to zero apart from pigeon peas treatment.

Conclusion

The main influencing factors for yield in the experiment seem to have been rainfall received in the growing season (soil moisture content) and soil texture (percent clay). The maize alone without any residues treatment consistently was among the highest maize yielding plots in all the growing seasons. This was a reflection of the high clay content of the treatment site. When rainfall amounts were lower, yields were better in treatments sites of lower clay content.

In regions such as Kibwezi, where farmers rely sorely on organic inputs, there seems to be a minimal impact on these residues on yield. An indicator of this is the lack of significant differences between the yields of the various treatments. However, goat manure improved yields in the treatments in which it was applied. Yield in the pigeon peas treatment was also compared favourably with that of the other treatments (apart from season 3) despite the fact that there was less maize in these plots due to the greater spacing to accommodate the pigeon pea plants.

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