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Full Length Research Paper

Reclamation of sodic soils in northern Tanzania, using locally available organic and inorganic resources

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Sodic soils could produce useful maize (*Zea mays* L.) crop yields if reclaimed by appropriate techniques. A field experiment was conducted on the selected lowlands of northern Tanzania using a randomised complete block design to study the effectiveness of supplying gypsum ($CaSO_4.2H_2O$) or farmyard manure (FMY) alone or both mixtures on the reclamation of a sodic soil. Sodic soil and FYM were characterised to establish their quality status before any intervention was introduced. The treatment used included: control, FYM alone (25 t ha^{-1}), FYM (25 t ha^{-1}) combined with gypsum (12.5 t ha^{-1}) and gypsum alone (12.5 t ha^{-1}). The treatments were replicated four times. Selected numbers of soil physical and chemical properties were then investigated. Results from our study revealed that regardless of the amendments used, maize yield and all soil physical and chemical properties tested were improved in Year 2 (Y2) relative to Year 1 (Y1). Our results also showed that combining FYM with gypsum significantly ($p \leq 0.05$) improved pH, electrical conductivity of the saturated paste (ECe), exchangeable sodium percentage (ESP), infiltration rate (IR), osmotic potential (OP) and available water capacity (AWC) of sodic soils. The FYM was the second-best treatment in the improvement of pH, ESP and EC whereas gypsum was second in the improvement of ESP, IR and maize yield.

Key words: Available water capacity, electrical conductivity, exchangeable sodium percentage, farm yard manure, gypsum, infiltration rate, maize, osmotic potential, salts, sodium.

INTRODUCTION

Soil degradation caused by salinisation and sodification is of great concern in the modern world because it reduces potential agricultural lands (Tanji, 1990; Maas and Grattan, 1999; Sadiq et al., 2007). Suitable land areas for food production in Tanzania and particularly in the lowlands of Kilimanjaro region remain fixed and are decreasing because of human activities. Owing to the problems of land shortage, some farmers in this area have resolved to utilise sodic soils located in the semi-arid zone regardless of very low yields reported from such soils (Alexander et al., 2006). In such semi-arid zones there is intense evaporation which tends to accumulate salts in the upper soil profile, especially when it is associated with an insufficient leaching or where soluble salts move upward in the soil profile from a water table instead of downward (Isabelo and Jack, 1993). Such accumulation of salts in the soils may alter its physical and chemical properties, including soil structure and hydraulic conductivity (Rengasamy et al., 1984; Mullins et al., 1990). Excessive exchangeable sodium (Na_{exch}) and high pH decrease soil permeability, available water capacity and infiltration rates through swelling and dispersion of clays as well as slaking of soil aggregates (Läuchli and Epstein, 1990). These modifications may further compromise the yield of crops growing on such soils (Voorhees, 1992).

The main source of salt in arid and semi-arid areas includes rainfall (Rengasamy and Olsson, 1993), mineral weathering (Lindsay, 1979; Gunn and Richardson, 1979; Macumber, 1991), irrigation and various surface waters (Mehanni and Chalmers, 1986; Rengasamy and Olsson,

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1993; SPORE, 1995), groundwater which redistributes accumulated salts during evaporation (Macumber, 1991), chemical applications (Rengasamy and Olsson, 1993) and man activities (Dregne, 1976). These sources, coupled with environmental modifications, lead to three different classes of salinisation and sodification that are grouped so for management purposes. These classes include: saline (EC_e>4dSm^{-1}, ESP<15%, pH<8.5); saline sodic (EC_e>4dSm^{-1}, ESP>15%, pH<8.5) and sodic soils (EC_e<4dSm^{-1}, ESP>15%, pH>8.5) (Richards, 1954).

The maintenance of adequate soil physical chemical properties in sodic environments may be achieved by using good quality water, proper choice of and/or combination of soil ameliorants, good drainage and appropriate cultural practices (Grattan and Oster, 2003). In this respect, the development of the most suitable reclamation technology or a combination of technologies may be critical to optimise farm management and better crop yields in a sodic soil. Although several reclamation techniques have been researched, including physical, biological and chemical treatment, limited literature is available on the application of different technologies on the amelioration of a sodic soil in Tanzania. The aim of this study was, therefore, to assess the effect of locally available ameliorants on the physical chemical properties of sodic soils and yields of maize with a view to their possible management and yield improvement.

MATERIALS AND METHODS

Experimental sites and material preparation

The field experiment was conducted in year 2002 (Y1) and 2003 (Y2) on sodic soils of the Rundugai traditional irrigation scheme in Hai District, Kilimanjaro Region. Rundugai village is bordered by Longoi village in the east, Tanganyika Planting Company sugar estate in the south, Shiri Mgungani in the north and lower Hai in the west. The scheme is about 15 km south of Moshi town. The most predominant soil types in the study area are loam, silt clay and clay formed on the recent alluvium, both calcareous and non-calcareous. The colours of the soils range from black to dark brown. Soils in the study area were classified as sodic. The investigations were carried out on four plots of 10 x 15 m separated by drains of 0.6 m wide x 0.6 m deep from each side of the plots. All drains were connected to one outlet. The plots were ploughed following the farmers' practice using animal traction, hand hoe and spades before the onset of the main rainy season. Gypsum at 98% purity was sieved to pass through a <0.2 mm sieve since these are the particles with the maximum surface area and uniformity to ensure high solubility. Whereas gypsum material was obtained locally from Makanya (in the same District, Kilimanjaro region) gypsum reserves, FYM was obtained from farmers' homesteads.

Experimentation

The experiment was carried in farmers' fields for two years on the same plots. A randomised complete block design was employed with four treatments and four replications. These treatments were 1) control, 2) FYM, 3) gypsum and 4) FYM combined with gypsum. The gypsum requirement was calculated prior to application following the methods described in Makoi (1995). Gypsum and FYM were applied at a rate of 12.5 and 50 t ha^{-1}, respectively, in both Y1 and Y2. Before their application in the respective plots, gypsum and FYM were thoroughly mixed and then applied within the 20 cm soil depth (plough layer) before the onset of the rainy season and before planting to ensure homogeneity. Maize hybrid C 4141 purchased from seed stockist Kibo Trading Company was planted as a test crop at a spacing of 90 x 25 cm to give a population density of 44,444 plants ha^{-1} just at the onset of the main rainy season.

Soil sampling and analysis

Soil samples were collected within a soil depth of 0 – 20 cm each year before planting season and the application of the ameliorants. Another set of soil samples was collected from each plot after harvesting maize. These samples were air dried and ground to pass through a <2 mm sieve. The available water capacity (AWC), electrical conductivity of the saturated paste (EC_e), exchangeable sodium percentage (ESP) and pH were determined following the methods outlined in the USDA Handbook No 60 (Richards, 1954). Infiltration rate (IR) was measured by a double ring infiltrometer (Bouwer, 1986). Soil and fresh organic manure were analysed at the National Soil Service laboratory in Tanga, Tanzania. Maize yields were recorded after the harvesting period and yield of maize was measured in kg ha^{-1} and later converted to t ha^{-1}.

Climatic conditions at the experimental sites

The climate in the experimental site was classified as hot semi-arid according to Köppen's classification. There are two rainy seasons. The short rainy season starts from November and ends in December, while the long rainy season starts in mid-March and ends in May. Generally, the area receives unreliable and poorly distributed rainfall of less than 600 mm per annum with 60 - 65% of the total rains falling in the months of March through May. February and March are the hottest (mean monthly temperatures of between 27 - 28°C). July and August are the coolest months (with mean monthly temperatures of between 22 - 23°C). Day and night temperatures differ by 10 - 15°C, depending on the season. The temperature difference is lowest at the end of the main rainy season in May-June. Relative humidity ranges between 65% (February) to 78% (May). Potential evapotranspiration as computed by the Penman Montieth equation is in the range of 106 mm month^{-1} (July) to 242 mm month^{-1} (March) or 1900 mm per annum.

Statistical analysis

Data collected were analysed statistically using a one-way ANOVA, performed with the STATISTICA software programme 2007 (Stat Soft Inc., Tulsa, OK, USA). Fisher's least significant difference (LSD) was used to compare treatment means at $p \leq 0.05$ level of significance (Steel and Torrie, 1980).

RESULTS

Characterisation of soil and organic manure

Results of soil physical and chemical characteristics from the experimental sites show that the electrical conductivity of the saturated paste (EC_e) = 1.62 dSm^{-1}, pH (KCl) = 9.3, bulk density (BD) = 1.9 gcm^{-3}, infiltration rate (IR) = 0.4 cm hr^{-1}, hydraulic conductivity (HC) = 7.7 mmday^{-1}, osmotic potential (OP) = 22.1 Kpa, available water capa-

Table 1. Effect of different ameliorants on maize yield and physical-chemical properties of soils in 2002.

Treatment	pH (KCl)	EC_e (dSm^{-1})	ESP (%)	IR ($cm\ h^{-1}$)	AWC ($mm\ m^{-1}$)	Yield ($t\ ha^{-1}$)	Osmotic potential (Kpa)
Control	9.30±0.0a	1.62±0.0a	19.4±0.0a	0.4±0.0d	72.0±0.0d	1.0±0.0d	22.1±0.3a
FYM	8.41±0.0b	1.61±0.0a	13.5±0.0b	1.4±0.0b	73.6±0.1b	1.5±0.0c	21.8±0.4a
Gypsum	8.94±0.0a	1.60±0.0a	13.5±0.0b	1.1±0.0c	73.2±0.1c	1.8±0.0b	21.7±0.4a
Gypsum+FYM	7.93±0.0c	1.59±0.0a	13.5±0.0b	1.6±0.0a	74.4±0.1a	2.0±0.0a	21.3±0.3a
One-Way ANOVA (F-statistic)							
F-Statistic	932.1***	0.9	89629.9**	2210.5**	105.0***	278.8***	0.9
% Change relative to control							
FYM	9.5±0.1b	0.9±0.3a	30.4±0.0a	112.9±3.3a	2.2±0.1b	54.1±1.8c	2.4±0.8a
Gypsum	3.9±0.3c	1.1±0.3a	30.3±0.1a	42.5±2.4a	1.7±0.2c	82.2±4.7b	2.9±0.8a
FYM+Gypsum	14.7±0.3a	1.4±1.0a	30.4±0.0a	160.2±4.0a	3.3±0.2a	104.2±6.2a	3.6±2.5a
One-Way ANOVA (F-statistic)							
F-statistic	977.3***	1.2	90582.1**	637.2***	90.7***	126.6***	1.3

***: $p \leq 0.01$; ***: $p \leq 0.001$.
Means followed by dissimilar letters in the same column are significantly different at $p \leq 0.05$ according to Fischer LSD.

city (AWC) = 72 mmm^{-1}, OC = 3 g kg^{-1}, exchangeable sodium (Na_{exch}) = 5.1 cmol (+) kg^{-1} soil, cation exchange capacity (CEC) = 26.3 cmol (+) kg^{-1} soil, exchangeable sodium percentage (ESP) = 19.4%. The FYM had a pH (KCl) of = 6.5, BD = 0.97 gcm^{-3}, saturation capacity (% v/v) = 71.0, organic matter = 28.7 g kg^{-1}, and C/N ratio = 16.8.

Effect of amelioration over years on the physical chemical characteristics of the sodic soils

Results from our study revealed that regardless of the amendments used, all physical and chemical properties tested were improved in Y2 relative to Y1 (Tables 1 and 2). For example, in Y1, the soil pH, ESP and IR significantly ($p \leq 0.05$) decreased while AWC was significantly increased (Table 1). In Y2, soil pH, EC, ESP and OP were decreased significantly with the amendments relative to control. However, the IR and AWC were significantly increased (Table 2). The percentage changes in both physical and chemical properties of soils in Y2 due to amendments were significantly greater, ranging from 10.6 % in soil pH to 928.4% in infiltration rate (Table 2).

Effect of different ameliorant on the physical and chemical characteristics of the sodic soils

The soil physical and chemical characteristics measured in YI and Y2 were relatively consistent. The mean values were generally more positive for data collected in Y2 relative to those in Y1 (Tables 1 and 2). In Y1, relative to control, applying FYM or gypsum alone or in combination decreased ($p \leq 0.05$) the soil pH, exchangeable sodium percentage (ESP), and IR in the order of FYM+gypsum>FYM>gypsum (Table 1). On the contrary, application of these ameliorants in Y1 led to the increase ($p \leq 0.05$) of soil-available water capacity (AWC) in the order of FYM+gypsum>FYM>gypsum (Table 1). In Y2 similar results were achieved, and in addition the EC and OP were significantly decreased by the amendments in the order FYM+gypsum>FYM>gypsum (Table 2). The combination of FYM+gypsum was superior to either one alone in all the parameters measured. The mean values of all parameters measured were generally better in Y2 as compared with Y1. This is clearly reflected in the higher values of percentage changes in measured soil physical and chemical properties in Y2 compared with Y1 (Table 1 and 2).

Effect of different ameliorants on the maize yield

Compared to the control treatments, the amendments used significantly ($p \leq 0.05$) increased maize yield in both Y1 and Y2 (Table 1 and 2). In Y1, combining FYM and gypsum was found to increase maize yield significantly more compared with all other treatments (Table 1). This was followed by FYM and gypsum supplied alone respectively.

DISCUSSION

Studies on salt-affected soils have been carried out in different parts of the world in a range of crops using different techniques (Oster, 1982; Swarup, 1994; Hyas et al., 1997; Wahid et al., 1998; Madejon et al., 2001; Sharma et al., 2001; Sahin et al., 2002; Hanay et al., 2004; Sharma and Minhas, 2004). However, few studies, if any, have assessed such techniques in Tanzania. As a result, most areas affected by this problem are neglected and

Table 2. Effect of different ameliorants on maize yield and physical-chemical properties of soils in 2003.

Treatment	pH (KCl)	EC_e (dSm^{-1})	ESP (%)	IR ($cm\ h^{-1}$)	AWC ($mm\ m^{-1}$)	Yield ($t\ ha^{-1}$)	Osmotic potential (Kpa)
Control	9.3±0.0a	1.61±0.0a	19.4±0.0a	0.42±0.0d	72.0±0.0d	1.01±0.0d	22.1±0.3a
FYM	6.8±0.0c	1.29±0.0b	3.9±0.5c	2.24±0.0b	142.4±0.9b	3.82±0.0c	10.5±0.1b
Gypsum	8.0±0.0b	1.14±0.0c	6.0±0.0b	1.96±0.0c	136.9±0.0c	4.50±0.0b	5.0±0.2c
Gypsum+FYM	6.5±0.1d	1.11±0.0d	2.6±0.0d	3.10±0.0a	243.0±0.0a	7.05±0.0a	3.9±0.1d
One-Way ANOVA (F-statistic)							
F-Statistic	**614.9*****	**2066.3*****	**1077.8*****	**59786.8****	**24325.2****	**34447.9****	**2066.3*****
% Change relative to control							
FYM	26.9±0.4b	20.0±0.5c	79.8±2.4b	429.9±7.8b	97.8±1.2b	280.9±9.9c	52.4±1.0c
Gypsum	14.2±0.1c	29.4±0.4b	69.1±0.0c	362.5±7.7c	90.3±0.0c	348.1±11.3b	77.2±0.7b
FYM+Gypsum	29.8±1.0a	31.4±0.3a	86.6±0.0a	633.3±10.6a	237.7±0.2a	602.9±18.5a	82.5±0.3a
One-Way ANOVA (F-statistic)							
F-statistic	**613.2*****	**1547.1*****	**1076.4*****	**1195.4*****	**25545.1****	**434.2*****	**3853.2****
				Years			
Y1	8.6±0.1a	1.60±0.0a	15.0±0.7a	0.8±0.1b	73.3±0.2	1.6±0.1b	21.7±0.2a
Y2	7.6±0.3b	1.29±0.1b	8.0±1.7b	1.9±0.2a	148.6±15.8	4.1±0.6a	10.4±1.9b
One-Way ANOVA (F-statistic)							
F-Statistic	10.0**	36.5***	14.2***	20.6***	22.7***	19.4***	36.5***
% Change in Y2 relative to Y1							
	11.5	19.6	46.7	155.1	103.2	154.7	52.2

***: $p \leq 0.01$; ***: $p \leq 0.001$.
Means followed by dissimilar letters in the same column are significantly different at $p \leq 0.05$ according to Fischer LSD.

underutilised. Our study has compared the effect of different locally available sodic soil ameliorants on soil pH, EC_e, ESP, IR, AWC, OP and yield of maize in Tanzania. Results indicated that all amendments significantly ($p \leq 0.05$) improved some of the soil properties in the two years of experimentation when compared with the control treatment (Tables 1 and 2). The greater improvement observed in Y2 is an indication that the treatments were more effective by their repeated application in the same plots.

Our present results show that in Y1, FYM decreased the ESP by 30.4%, gypsum by 30.3% and by 30.4% when the two amendments were combined (Table 1). This indicates that the treatments' effects were almost similar and not very significantly effective in reducing the ESP in Y1. In the second year, the treatments were significantly more effective and FYM decreased the ESP by 79.8%, gypsum by 69.1% and by 86.6% when the two amendments were combined (Table 2). The critical limit between sodic and non-sodic soil is established at an ESP value of 15 (Richards, 1954). Compared with control, addition of ameliorants in Y1 reduced the ESP values below the proposed limits (Table 1), and the repeated applications on the same plots in Y2 further reduced the values to single digits (Table 2) making the soil non-sodic. Combined FYM and gypsum was superior to all other ameliorants in reducing the ESP in the soil. Similarly, FYM decreased the OP by 52.4%, gypsum by 77.2% and by 82.5% when the two amendments were combined (Table 2). This suggests that a repeated combination of inorganic and organic ameliorants was more effective in the reduction of ESP and osmotic potential in Year 2. This work is consistent with the results reported by Madejon et al. (2001); Sharma et al. (2001); Sharma and Minhas, (2004).

There was an increase in IR and AWC in response to the application of different ameliorants (Table 1). FYM, gypsum, or their combination increased the IR by 112.9, 42.5 and 160.2% in Y1 and 429.9, 362.5 and 633.3% in Y2 respectively (Tables 1 and 2). Similarly, FYM increased the AWC by 2.2%, gypsum by 1.7% and by 3.3% when the two amendments were combined in Y1 (Table 1), whereas in Y2, FYM increased the AWC by 97.8%, gypsum by 90.3% and by 237.7% when the two amendments were combined (Table 2). The increased IR and AWC in Y2 as compared with Y1 in this experiment suggests improved soil physical properties, probably due to desodification that resulted in increased water permeability in plots receiving the amendments. Similar findings have also been reported (Hyas et al., 1997; Wahid et al., 1998 and Sahin et al., 2002) in related studies involving the use of organic and inorganic amendments on salt-affected soils.

Our data also show that the effect of these ameliorants to decrease pH was in the order of FYM+gypsum>FYM>gypsum (Table 1). For example, whereas FYM decreased pH by 9.5%, gypsum by 3.9%, pH was lowered by 14.7% when the two amendments were combined in Y1 (Table 1). In Y2, FYM decreased pH by 26.9%, gypsum by 14.2%, and by 29.8% when the two amendments were combined. The observed decline in soil pH suggests desodification of the sodic soil as a result of beneficial effects of FYM and gypsum. The possible mechanism involved is that when FYM is applied in the soil, the ongoing microbial activity causes reduction of pH owing to production of organic acids or increased CO_2 partial pressure leading to the development of reducing conditions. The lowered pH increases the solubility of gypsum, thus, removing some of the Na^+ ions (Wahid et al., 1998).

FYM decreased the EC_e by 20.0%; gypsum by 29.4% and combining FYM+gypsum by 31.4% (Tables 2). These results suggest that combined ameliorants were superior to either one alone in their effect to decrease EC_e. The reduction of EC_e may probably be due to leaching of soluble salts into the drainage systems or into the deeper layers of the profile. Consistent with the results observed in this study, Niazi et al. (2001) also reported that a combination of gypsum+FYM reduced the EC_e more than the other ameliorants used.

In this study, maize yield increased by 54.1 and 82.2% when FYM and gypsum were applied alone respectively. However, combining the two amendments increased maize yield by 104.2% in Y1 (Table 1). In Y2, maize yield increased by 281, 348 and 601% by applying FYM, gypsum and combined FYM and gypsum, respectively. These results suggest that combined amendments were superior to either one alone in their effect on increased maize yield. Although gypsum has been reported extensively to improve cereal yields (Oster, 1982; Swarup, 1994; Wahid et al., 1998; Hanay et al., 2004), in our study, it was found to be more effective when combined with FYM. It is possible that the observed changes in physical and chemical soil properties due to addition of FYM and gypsum (Tables 1 and 2) were responsible for increased maize yields.

Clearly, in this study, the application of FYM, gypsum or their combination was important for increased maize yield in the salt-affected soils in northern Tanzania. However, in these areas, where most small-scale farmers are resource-poor and unaware of this technology, the promotion of gypsum use in crop production systems is likely to remain a challenge for quite some time.

Conclusion

In conclusion, our findings demonstrated that combining farmyard manure with gypsum (FYM + gypsum) as ameliorants is probably the best choice in the improvement of the physical-chemical properties and yield of maize in sodic soils of Rundugai. More beneficial influences were noticed by extending the applications to Y2. These amendments are locally available and hence could probably be the most effective tools for maintaining soil productivity and sustaining crop yields in such salt-affected areas. However, the economic, social, and environmental factors must also be considered before the scaling up of such technology. A holistic approach should consider the cost and availability of the inputs, the soil depth, the level to which sodicity needs to be reduced to allow cropping, and the options available for drainage-water disposal or reuse.

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