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Research Application Summary

Effect of organic and inorganic ammendments on soil chemical and maize yield characteristics in Zimbabwe

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Abstract

Performance evaluation of five treatments on soil chemical characteristics and yield of maize was carried out in Lower Gweru, Zimbabwe. The treatments were gypsum, mopane ash, green manure, combined gypsum and green manure (green manure + gypysum) and an unamended control treatment. The treatments were set up in a complete Randomised Block Design (CRBD) with five blocks and slope was used as the blocking factor. Results indicate that a combination of gypsum and green manure and gypsum do not differ significantly in reducing excessive sodium (Na^+), pH, sodium absorption rate (SAR) and exhangeable sodium percentage (ESP). The combination of green manure and gypsum was the most effective in reducing Na^+ (36%), SAR (79%), ESP (37%) and increased maize yield to 2 t/ha (122%). Green manure reduced Na^+, pH, SAR and ESP by 15, 7, 68 and 15%, respectively and increased electrical conductivity (EC) and yields by 147 and 100%, respectively. Mopane ash significantly reduced SAR and ESP by 65 and 12%, respectively whilst increasing EC and yield by 166 and 55%. Although Mopane ash reduced Na^+ to 8.1 and pH value to 8, the reduction was not significantly different from the control. A combination of gypsum and green manure, and green manure and Mopane ash cost effectively improved some soil characteristic and yield of maize when used to amend sodic soils in lower Gweru Zimbabwe. Amongst these amendments, a combination of gypsum and green manure outperformed the other amendments in improving maize yield.

Keywords: Green manure, gypsum, Mopane ash, sodic soil, sodium adsorption rate

Résumé

L'évaluation de la performance de cinq traitements sur les caractéristiques chimiques du sol et le rendement du maïs a été effectuée dans le Lower Gweru, au Zimbabwe. Les traitements étaient le gypse, la cendre de mopane, le fumier vert, le gypse combiné avec du fumier vert (fumier vert + gypysum) et un traitement témoin n'ayant reçu aucun amendement. Les traitements ont été mis en place dans un dispositif de blocs aléatoire complets (CRBD) avec cinq blocs et la pente a été utilisée comme facteur de blocage. Les résultats indiquent qu'une combinaison de gypse et de fumier vert et de gypse ne diffèrent pas de manière significative dans la réduction du sodium (Na +), du pH, du taux d'absorption du sodium (SAR) et du pourcentage de sodium échangeable (ESP). La combinaison de fumier vert et de gypse a été la plus efficace dans la réduction du Na+ (36%), de la SAR (79%), et du ESP (37%) et a augmenté le rendement de maïs de 2 t / ha (122%). Le fumier vert a réduit le Na+, le pH, la SAR et l'ESP respectivement de 15, 7, 68 et 15%, et augmenté la conductivité électrique (EC) et les rendements respectivement de 147 et 100%. Les cendres de Mopane ont considérablement réduit la SAR et l'ESP respectivement de 65 et 12%, tout en augmentant la CE et le rendement de 166 et 55%. Bien que les cendres de Mopane aient réduit le Na+ à 8,1 et la valeur de pH à 8, la réduction n'était pas significativement différente de celle du témoin. Une combinaison de gypse et de fumier vert, de fumier vert et de cendre de Mopane a amélioré efficacement certaines caractéristiques du sol et le rendement du maïs lorsqu'il a été utilisé comme amendement sur les sols sodiques dans le bas Gweru au Zimbabwe. Parmi ces amendements, une combinaison de gypse et de fumier vert a surpassé les autres amendements visant à améliorer le rendement du maïs.

Mots-clés: Fumier vert, gypse, cendres de Mopane, sol sodique, taux d'adsorption de sodium

Background

In Zimbabwe, sodic soils account for approximately 20% of the total land area and its spatial distribution is high in low rainfall areas (Thompson, 1965; Nyamaphene, 1992). Resource-poor farmers in these areas, including in Lower Gweru, Zimbabwe are faced with complex environments, apart from the lack of water and capital resources, they struggle with managing the sodic soils. The Na^+ affected soils, in comparison to soils in the same natural region with similar climatic conditions, yield approximately 40-55% lower maize yields.

Confronted with prohibitive costs of inorganic amendments like gypsum, farmers have resorted to locally available organic materials (Mopane ash and green manure) to ameliorate sodic soils. In using green manure, farmers indicated that its availability is limited by the dual use as a soil amendment and livestock feed. Generally, farmers have reported that the organic amendments significantly improve maize yields. In addition, they suggest blending of green manure with inorganic amendments to balance the competing uses of the former as well as the financial implications of using the later as a sole amendment. However, it is not clear as to which economically improved soil characteristics the yield increase is attributed to and how mixed organic manure and the inorganic amendment would perform in improving the soil quality. Consquently, this study evaluated the effect of mopane tree ash, green manure and a combination of gypsum and green manure on soil and maize yield characteristics on sodic soils in Zimbabwe.

Literature summary

Sodic soils are soils with excessive sodium (Na^+) in their cation exchange sites as a result of natural and anthropogenic activities (Qadir *et al*., 2001; Hasanuzzaman *et al.,* 2014). The excess Na^+ affects soil structure, reduce hydraulic conductivity and availability of nutrients and water for plants leading to crop wilt, stunted growth and low yields (Qadir *et al.,* 2001). These effects can be reduced by both organic and inorganic amendments to the soil. Ammendments work through isomorphous substitution where Na^+ ions are displaced by Ca^{++} from the soil exchange sites. The Na+ together with other salts are then leached and drained beyond the root zone using excess irrigation water of good quality (Qadir and Schubert, 2002).

Gypsum, one of the widely used inorganic amendments is reported to improve soil physical and chemical properties at a faster rate (Chaudhry and Warkentin, 1968; Gorbunov *et al.,* 1980). It is known to reduce Na+ ions on the cation exchange sites, improve electrical conductivity (EC) (Ardakani and Zahirnia, 2006) and reduce sodium adsorption ratio (SAR) of the soil (Levy, 2000). Organic materials, such as wheat straw has been reported, though at a lower rate, to also reduce SAR, exchangeable sodium percentage (ESP), pH and improve EC, bulk density, infiltration rate and hydraulic conductivity in amelioration of sodic soils (Mahdy, 2011; Singh *et al*., 2013).

Traditionally, amelioration of sodic soils has been through chemicals, however, in developing countries such as Zimbabwe, the use of chemicals in subsistence holdings is not so popular. This is attributed to the prohibitive cost of chemical amendments (Qadir *et al*., 2001). The majority of the rural population, for example, in Zimbabwe survive on less than 1 US$ per day, and cannot afford the high prices of gypsum or other chemical amendments.

Study Description

The study was undertaken in Lower Gweru is a communal settlement in the Midlands province of Zimbabwe and is located about 20km North West of Gweru urban. The geographical coordinates of the area are 19° 14' south, 29° 15' east at an altitude of 1200m above mean sea level. This area is semi-arid and lies in Natural Region IV which receives rainfall ranging from 450 to 600 mm per year (Vincent and Thomas, 1962). High temperatures (maximum 32^0C) are responsible for high evaporation from the soil surface and sodicity problem. The vegetation is predominantly dry deciduous savanna dominated by two tree species: *Colophospermum mopane* (Mopani) and Acacia varieties.

To evaluate the effect of organic and inorganic ammendments, five treatments were evaluated: gypsum, mopane ash, green manure, combined greenmanure and gypsum and a control (unamended treatment). These treatments were evaluated on five blocks, each treatment on a plot size of 10 m^2 arranged in a Complete Randomized Block Design (CRBD) and the slope was used as the blocking factor. Treatments were randomly assigned to the experimental units and the randomisation was independent between the blocks.

Mopane ash from mopane wood used as firewood by local farmers was applied to the plots at a rate of 4 t/ha, green manure prepared from maize at tasselling stage, dried and ground to powder was applied at a rate of 20 t/ha, gypsum was applied at a standard rate of 5 t/ha, a combination of gypsum and green manure was applied at a ratio of 1: 4, that is, 2.5 and 10 t/ha and a control, without any amendment. All the amendments were incorporated into the soil by broadcasting followed by disking to a depth of 20 cm. All the application rates, with the exception of gypsum and a combination of gypsum and green manure, were determined using standard farmer practice. Gypsum and a combination of gypsum and green manure application rates were determined using proportional equivalence. Soil characteristics improved by the amendments were evaluated using measured soil ions: Na^+, Ca^{++}, K^+, Mg^{++}, EC, CEC, pH and calculated Exchangeable Sodium Percentage (ESP) and Sodium Absorption Rate (SAR).

Table 1: Physical and chemical characteristics of soil, amendments, and water used in the study

Parameter / Samples	Na+	Mg++	Ca++	K+	pH	SAR	ESP	CEC	EC	C	N
Soil	9	0.3	0.5	0.9	8.2	14.2	66.7	13.5	2.1	-	-
Mopane Ash	0.6	1.8	2.9	4.2	5.9	0.4	6.7	9.5	0.9	46. 6	0.9
Green Manure	0.2	4.1	6	5	-	0.1	1.2	15.3	1.9	42.6	2.8
Irrigation water	3	0.8	1.2	0.9	8	3	26.6	11.2	4. 8	-	-

Na+, Mg++, K+ are measured in Cmol/dm3, ESP, C and N in %, EC (dS/m)

Maize variety SC403 was planted at a rate of 30,000 plants/ha and a basal application of compound D was applied at a rate of 200kg/ha before sowing. The experimental field was irrigated using flood irrigation applying the leaching requirement at every irrigation event following an average irrigation schedule of six days which was adjusted to cater for crop water requirements at different growth stages and time of the season. Crop management practices like weeding and fertiliser application was done uniformly on all plots. At maturity, maize in all the plots were harvested and mass of 100 seeds and yield per hectare was recorded for each treatment. Analysis of variance (ANOVA) was used to evaluate the treatments means and the least significant difference was used in the separation of means at 5% significant level ($p < 0.05$).

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There was a decrease in the Na^+ ion after amendment, the biggest drop of Na^+ ions was recorded in the gypsum+ green manure (5.9) treatment followed by gypsum (5.8), green manure (7.7), Mopane ash (8.1) and no change in the control (9.1) (Table 2). Compared to the control there was a drop of 36, 15, 35, and 11% in Na^+ ions on soil amended with gypsum + green manure, green manure, gypsum and Mopane ash, respectively. There were significant differences in the capacity of different amendments to reduce Na+ in the soil with the exception of Mopane ash which did not differ significantly from the control treatment.

Table 2: Soil chemical characteristic after amendments

Parameter / Amendments	Na+ Cmoldm^{-3}	Mg++ Cmoldm^{-3}	Ca++ Cmoldm^{-3}	K+ Cmoldm^{-3}	pH	SAR	ESP %	CEC	EC dSm-1
Control	9.1_a	0.28_c	0.5_b	0.8_c	8.2_a	14.6_a	15.1_a	60.6_a	2.1_b
Gypsum + Green Manure	5.8_b	5.0_a	2.1_a	1.4_a	7.2_b	3.1_b	9.5_b	60.8_a	5.0_a
Green Manure	7.7_c	3.8_b	1.8_c	1_b	7.6_c	4.6_c	12.8_c	61.2_a	5.2_a
Gypsum	5.9_b	4.7_a	1.3_b	0.9_b	6.8b	3.7_b	9.7_b	60.6_a	4.7_b
Mopani Ash	8.1_a	3.4_a	1.8_c	2.1_a	8.0_a	5.0_c	13.3_c	61.3_a	5.6_a

Means with the same subscript letter within the same column do not differ significantly according to a least significant difference test at 5% significance level

The highest improvement in pH of the soil was observed in the gypsum treatment followed by gypsum + green manure combination, although they were numerically different, statistically, they did not differ from each other (Table 2). This performance of gypsum + green manure treatment can be attributed to the fact that, in addition to gypsum, the green manure contributed CO_3^{2-} and CO_2 produced during the decomposition of the green manure (Qadir *et al*., 2006) . These anions can combine with other ions to produce organic acids which lower the pH. The weak acids which can be formed increase the solubility the sodium salts formed hence increase the effectiveness of leaching and hydraulic conductivity (Qadir *et al*., 2001). The carbon dioxide produced during decomposition of green manure, after dissolution in water, also aids in the dissolution of Calcium carbonate into Ca^{2+} and $CO3^{2-}$ this ensures supply of Ca^{2+} to replace Na+ on the exchange site of the soil (Qadir *et al*., 2000; Ardakani and Zahirnia, 2006). These results are comparable to findings by Hanay *et al.* (2004), who reported improvement soil pH by combined gypsum + organic manure amendments.

In addition, the contribution of Ca^{2+} from the interaction of organic matter and calcium carbonate explain the highest reduction in Na^+ by the gypsum + green manure amendment. A comparable performance for Mopane ash to the control was recorded, which was the least effective in reducing the pH and N^+ in the soil. This can be attributed to the nature of mopane tree from which the ash came from. Mopane tree is a salt excreting halophyte. It contains some Na^+ in its biomass and these were added to the soil with the ash (Hasanuzzaman *et al*., 2014). The removal of Na^+ from the soil contributed to the reduced SAR. These amendments supply more Ca^{2+} and reduce Na^+ concentrations in the soil (Qadir and Schubert, 2002). During the decomposition of green manure, cations like Ca^{2+}, Mg^{2+} and K^+ are released into the soil which help to reduce the SAR. Green manure encourages granulation and increases the adsorbing power of soils as well as cation exchange capacity.

The best yield of 2 t/ha was recorded in the combination of gypsum and green manure treatment, giving a 122% increase in yield compared to the control where yields of 0.9 t/ha were recorded (Table 3). This was followed by green manure with a yield of 1.8 t/ha corresponding to 100% yield increase and the least yield was recorded in the gypsum treatment with 1.3 t/ha (44% yield increase).

Table 3: Yield components after sodic soil amendment with different treatments

Treatment	100 grain-weight (g)	Yield (t/ha)
Control	36.3_c	0.9_c
Gypsum +green manure	43.1_a	2.0_a
Green manure	40.7_a	1.8_a
Gypsum	38.6_b	1.3_b
Mopane ash	38.1_b	1.4_b

Means with the same subscript letter within the same column do not differ significantly according to a least significant difference test carried out at 5% significance level.

The improvement in yield can be attributed to reduced Na^+ concentrations (improved soil quality). Reduced Na^+ concentrations in the soil reduce nutrition imbalances in plant cells, trace elements toxicity and improve the rate of nutrient and water uptake by the plants (Qadir and Schubert, 2002). The comparatively high yields recorded in the gypsum + green manure and green manure can be attributed to the additional N from the green manure. The green manure had a high C: N ratio (Table 1) and the nutrients compensated the superior Na^+ removal by gypsum and green manure amendment. The C: N ratio, though, lower than the ideal 10:14, is relatively high in the green manure and hence its decomposition and nitrogen mineralisation is expected to be faster (Misra *et al*., 2007; Larney and Angers, 2012).

Conclusion

This study has established that Mopane ash, green manure and a combination of gypsum + green manure cost effectively improved soil characteristics by reducing Na+ by 10-36%, pH (2-12%), SAR (6-79%), ESP (12-37%) and by increasing the EC by 138-166%. In Addition, these amendments improved the maize yield by upto 122%, from 0.9 to 2 t/ha. Comparatively, the combination of gypsum + green manure was more cost effective than the other amendments under investigation. Although the soil and maize yield characteristics improved significantly and at lower cost, more research needs to be done to ascertain the effect, if any, of these amendments on the soil physical properties and also to determine the sustainable application rates for recommendation to farmers.

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