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Use of Ca-bentonite to ameliorate moisture and nutrient limitations of sandy soils in drought stricken areas

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Abstract

Moisture shortage is a major factor limiting crop production in sandy soils. This study evaluated the potential for Ca-bentonite (2:1 clay mineral) as an amendment for increased moisture retention by sandy soils in drought stricken/prone areas. In the green house, maize was grown to sandy soil containing 0, 5, 10, 15 and 20% Ca-bentoniteby weight, replicated three times. The mixtures were watered to field capacity (30% water) then maize (Longe V) grown for 5 weeks without additional water. In the field, Ca-bentonite was applied on sandy soils in the drought-prone Lwabiyata sub-county, Nakasongola district, Central Uganda. Treatments included: Ca-bentonite at 0, 1.25 and 2.5 t ha^{-1}; DAP at 0, 62.5 and 125 kg ha^{-1}; urea at 0 and 60 kg ha^{-1}; and farmyard manure (FYM) at 0, 1.25 and 2.5 t ha^{-1}, arranged in arandomized block design with three replicates. Under greenhouse conditions, Ca-bentonite significantly ($P<0.05$) increased soil moisture retention, pH, N, P, Ca and Mg content, and subsequently, maize dry matter yield. Under field conditions, Ca-bentonitesignificantly ($P<0.05$) increased maize grain yield by 40%. Yields were even higher (65 to 108% above the control) where bentonite was combined with FYM and/or DAP. Results suggest that Ca-bentonite has potential asa soil amendmentfor moisture conservation, neutralizing acidity, and improving N, P, Ca and Mg contentin sandy soils, and consequently support crop growth and yield, and therefore presents a possible option for amelioration of sandy soils in drought stressed environments, hence climate change adaptation.

Key words: Climate change adaptation, drought mitigation, moisture stress, soil fertility management, soil moisture conservation

Introduction

Calcium bentonite is a naturally occurring 2:1 clay mineral which is known to hold water many times its own weight. When applied to a sandy soil, bentonite particles bond with those of sand and thus improve the structure and water holding properties of sand. The improved structure holds nutrients, air and water in a structure that is ideally suited to plant roots (greenlifesoil.com.au/sandremedy.htm). Previous studies suggest that to be effective, calcium bentonite should be dug into the root zone (greenlifesoil.com.au/sandremedy.htm). The recommended application rate is 10% of the soil volume. For field application, 5kg of calcium bentonite treats 16 m^2 in soils with a reasonable amount of organic matter. For new garden beds in very poor, sandy soil, a much higher application rate of 1-4 kg per m^2 is recommended, dug into a depth of 10 to 30 cm.

The benefits of using calcium bentonite in agriculture have been reported in

Thailand, China, Australia and South Africa among others. Noble *et al*. (2004) and Suzuki *et al*. (2007) demonstrated that introducing clay-based materials such as bentonite significantly and persistently improves the productivity of degraded, light–textured soils, more so in presence of an organic amendment. In Thailand, bentonite use significantly increased rice grain yields and reduced the risk of crop failure during drought (IWMI, 2010). Sorghum forage biomass yields increased by six-fold following bentonite application. The increased soil quality persisted for at least 3 years.

Berthelsen *et al*. (2005) reported significant increase in crop biomass and yields following bentonite application on light textured soils. The yield increase was attributed to increased water holding capacity, nutrient availability and reduced nutrient loss. In Australia, Sacchi (2010) observed increased soil cation exchange capacity, exchangeable Ca, Mg, K and plant available water following bentonite application. Sacchi also observed that application of bentonite at rates of above 80 t ha^{-1} bentonite had a detrimental impact on soil structure leading to reduced yields.

Despite the reported promising results, scanty information on bentonite use exists for sub Saharan Africa and yet limitations due to moisture stress and soil fertility decline to crop performance are widespread in this region. In Uganda, calcium bentonite is mined in Hoima district and marketed by the Knights Mining Company and most of it is exported. However, there is inadequate information about its potential for supporting crop growth in Uganda.

Therefore, the objectives of this study were: to assess the effect of calcium bentonite application on soil moisture and other soil properties, and in addition, evaluate its effect on maize growth and yield following its application on sandy soils in the drought prone cattle corridor area of Uganda.

Materials and methods

The study was carried out in both a greenhouse and field. The greenhouse experiment was conducted at the National Agricultural Research Laboratories (NARL) of the National Agricultural Research Organization (NARO), Uganda. Treatments included finely ground calcium bentonite which was obtained from Knights Mining Company in Hoima district. The material was tested for pH, organic matter (OM), phosphorus, Ca, Mg, K and total N using standard methods (Okalebo *et al*., 1993).

About 100 kg of a medium textured, low fertility soil was sampled at 0 to 30cm depth from Mbale district. Sand (about 100 kg) was also collected from Tororo district. The soil and sand samples were dried for 3 days at 47^{o}C and ground to pass 2 mm sieve. They were analysed for moisture content, pH, organic matter (OM), phosphorus, exchangeable Ca, Mg, K, total N and particle size distribution using standard methods as specified by Okalebo *et al*. (1993).

The greenhouse experiment consisted of an incubation study and a maize growth experiment, both conducted under the same conditions (27 to 32^{o}C). In the soil incubation study, twenty, 3 kg samples of both the air-dried soil and sand were weighed in polythene bags. Calcium bentonite was added to the soil/sand samples at0, 150, 300, 450 and 600 g bentonite per 3 kg soil, representing 0, 5%, 10%, 15% and 20% calcium bentonite. The soil-bentonite and sand-bentonite mixtures were mixed thoroughly then transferred to plastic buckets, perforated at the bottom.Water (1 L) was added to each bucket containing the soil-bentonite and sand–bentonite mixtures, representing approximately 30% moisture (wt). The mixtures were stirred and left to stand in a greenhouse at 27 to 32°C, for 3 days. They were then stirred and sampled using soil cores measuring 5.0 cm diameter and 5.1cm height or 100.18 cm^3. This first sampling corresponded to the time when maize in the parallel maize growth experiment was planted.

The mixtures were left in a greenhouse at 27 to 32°C for 28 days, and sampled every after one week (7 days). No more water was added to the mixtures during the entire 4-week incubation period. The samples were dried at 105°C for moisture determination. After the 4 week incubationperiod, a sample of the mixtures was collected for determination of pH, OM, phosphorus, exchangeable Ca, Mg, K and total N (Okalebo *et al*., 1993).

In the maize growth experiment. A total 23 kg samples of the soil/bentonite and sand/bentonite mixtures were prepared and watered. The mixtures were left to stand in a greenhouse (27 to 32°C) for 3 days. Maize (Longe V, 2 seeds) was planted in each bucket and at one week after planting (WAP) maize had germinated. Water (50 mls) was added to each bucket and the maize left to grow for 35 days (5 weeks) under greenhouse conditions. No additional water was added to the maize plants.

This was intended to assess the extent to which bentonite addition could improve water retention by soil or sand and support maize growth under moisture stress. Data on maize height and leaf width was taken. The maize plants were harvested at 5 WAP, weighed and oven dried at 78°C for dry matter (biomass) determination.

For the field experiments, trials were planted in Lwabiyata sub county, located 1°30’20"N and 32°22’41"E in the northern part of Nakasongola district (Mugisha *et al*., 2011). Nakasongola district lies in the central plateau of Uganda at an altitude between 1,000 and 1,400 m above sea level (Rwabwogo, 2002). It is characterized by undulating landscape with most low lying areas found towards L. Kyoga in the north. The vegetation type is characterized by open deciduous savannah woodland with short grasses. The district experiences high temperatures ranging from 25°C to 35°C during the dry season. It receives low and unreliable rainfall that ranges from 500 mm to 1000 mm per annum.

There are two rainy seasons: the main season from March to May with peak in April and a second season from September to December with a modest peak in November. Evaporation exceeds rainfall by a factor of about 6 during the dry months from June to August (Republic of Uganda, 2004).

The district lies in the pastoral rangelands agro-ecological zone within the cattle corridor area. Lwabiyata sub-county is located near L. Kyoga, and is characterised by sandy soils with moderate to poor fertility. Crop yields in the area are frequently affected by drought.

Experimental treatments included: a control (where nothing was applied), bentonite at 2.5 t ha^{-1}, bentonite (2.5 t ha^{-1}) + DAP (62.5 kg ha^{-1}), bentonite (2.5 t ha^{-1}) + FYM (2.5 t ha^{-1}), bentonite (1.25 t ha^{-1}) + DAP (62.5 kg ha^{-1}) + FYM (1.25 t ha^{-1}) and DAP (125 kg ha^{-1}) + urea (60 kg ha^{-1}). These treatments were applied randomly and replicated three times plot sizes of 10m by 10 m. Bentonite, farmyard manure and DAP were surface broadcast and incorporated into the 0 to 10 cm soil layer using a hand rake. Urea was top dressed when maize was knee high. Maize (Longe V) was grown during the March-June (2013A) then September - December (2013B) seasons and harvested for grain yield.

Data analysis

Data were processed using Microsoft Excel and statistically analysed using Genstat package version 3.2. Significant differences between means were determined at a 95% Confidence level and means separated using the standard error of difference (sed) procedure. Two means were declared as significantly different when the difference between them was greater than twice the sed value.

Results

Characteristics of the bentonite and soils used in the studies

Table 1 presents the characteristics of calcium bentonite and the soils used in the study. Bentonite had a clay texture with a neutral pH (pH 6.9), low in organic matter (OM) and N content, high in Ca and Mg, with moderate P and K contents. All the three soils were high in sand, but the soil from Mbale contained less sand compared to others. Soil from Mbale had a slightly lower pH than the sand from Tororo (5.3 vs 6.0) but both values were above the critical level. Organic matter (OM) was lower than the critical value in three soils, with values lowest in the Tororos and. Nitrogen and P were deficient in both materials, more so in sand. Calcium, Mg and K were higher in Mbale soil than Tororo sand.

Table 1. Selected characteristics of the soil materials used in the greenhouse study

	pH	OM	N	P	Ca	Mg	K	Sand	Clay	Silt	Textural class
		%		mg/kg				%			
Bentonite	6.9	2.7	0.17	44.1	4539	1615	358	7.7	78.3	14.0	Clay
Soil from Mbale	5.3	1.5	0.12	0.90	560	243	154	70.4	21.0	8.6	Sandy clay loam
Sand from Tororo	6.0	0.7	0.09	0.45	183	87	31	88.4	5.0	6.6	Sand
Soil from Nakasongola	6.4	2.2	0.15	23.9	566	141	59.6	80.7	9.3	10.0	Sandy loam
Critical values	5.2	3	0.2	45	330	17	55				

In addition to the sandy texture, soil from Nakasongola (Lwabiyatasub County) was slightly acidic, low in OM, N, Ca, Mg and K, but moderate in P. The sandy nature and low available nutrients present management challenges, some of which could be addressed through use of bentonite.

Effect of bentonite application on soil moisture content

Moisture content of the mixtures increased with amount of calcium bentonite added, levelling off between 10 to 15% bentonite application for both the soil and sand materials (Fig. 1). At 1 week after planting (WAP), both the soil and sand amended with 0, 5 and 10% calcium bentonite contained equivalent moisture (o/o). Moisture content of soil amended with 15 to 20% bentonite was higher than that of sand amended with the same amount of bentonite.

At 4 WAP, the un-amended soil (0% bentonite) had a higher moisture content than sand (2.6% vs 0.6%, $P<0.05$). Moisture content of the soil and sand amended with 5% bentonite were not significantly different. Sand amended with 10% or more bentonite contained significantly ($P<0.05$) higher moisture, than soil amended with the same amount of bentonite (i.e. 9.3 vs 3.6, 10.4 vs 7.9 and 11.0 vs 7.8 % moisture for the 10, 15 and 20% bentonite treated sand mixtures, respectively).

Effect of bentonite application on selected soil chemical properties

Table 2 presents the effects of bentonite application on soil and sand materials as observed at 4 weeks incubation. At a given level of bentonite application, the pH for sand was significantly ($P<0.05$) higher than that of soil.

Application of 5% bentonite significantly ($P<0.05$) increased pH of both the soil and sand. The raised pH values were maintained at higher bentonite rates for sand but not for soil. Nitrogen was deficient in both the soil and sand, but with soil N slightly higher than that of sand at all levels of bentonite applied. Application of bentonite up to 10% had no significant effect on soil N content. Higher rates of bentonite (15 and 20%)

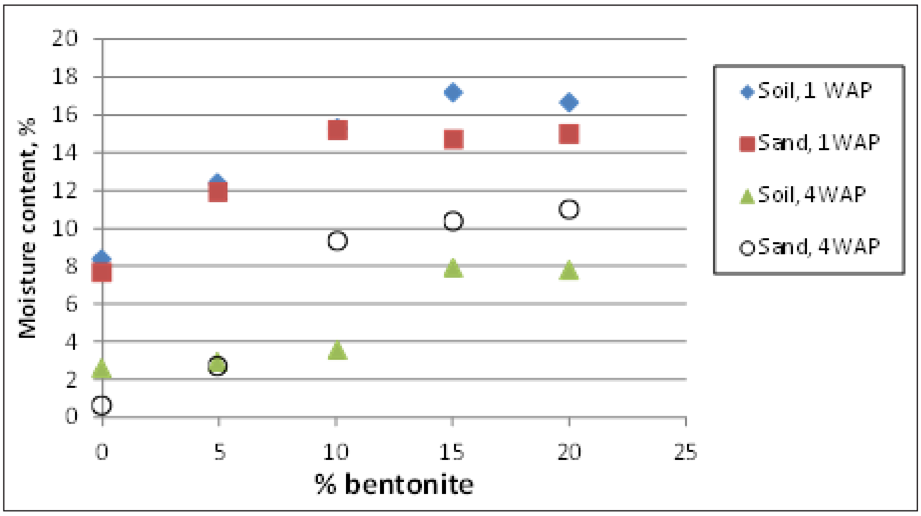

Figure 1. Effect of bentonite application on soil moisture content.

Table 2. Effect of bentonite application on selected soil and sand chemical properties

% bentonite	pH	OM	N	P	Ca	Mg	K	Ca/Mg ratio
				Soil at 4 weeks of incubation				
0	5.68	1.45	0.115	0.00	628.5	207.9	159.5	3.02
5	5.88	1.35	0.112	7.28	795.3	403.0	171.2	2.00
10	5.78	1.25	0.112	14.33	1000.2	611.6	167.3	1.63
15	5.63	1.15	0.107	23.52	1144.1	786.3	170.4	1.48
20	5.65	1.08	0.102	28.05	1238.1	873.6	186.1	1.40
				Sand at 4 weeks of incubation				
0	6.30	0.90	0.077	1.11	372.4	40.6	87.6	9.53
5	7.00	0.78	0.092	15.49	578.7	269.3	75.2	2.15
10	7.00	0.80	0.092	29.89	740.7	445.3	70.6	1.68
15	7.10	0.93	0.095	39.42	974.2	651.0	100.5	1.50
20	7.18	0.70	0.087	50.40	1078.6	782.0	84.9	1.40
sed	0.06	0.11	0.004	2.16	25.8	17.7	NS	0.42
cv, %	1.40	14.70	5.20	14.50	4.3	4.9	19.8	23.0

decreased soil nitrogen content significantly ($P<0.05$).On the other hand application of bentonite at 5% on the N-deficient sand significantly ($P<0.05$) increased the N content.

At higher rates of bentonite, the sand N content although significantly higher than the control did not significantly differ from that at 5% bentonite.

There was a significant ($P<0.05$) increase in Mehlich III (Mehlich, 1984) extractable P with addition of 5% bentonite for both the soil and sand. A further significant ($P<0.05$) increase in Mehlich III extractable P was observed for higher rates of bentonite applied. Potassium content was higher for soil than sand (170.9 vs 83.7 $mgkg^{-1}$). Bentonite application had no significant ($P>0.05$) effect on the K content of the soil and sand.There was a significant ($P<0.05$) increase in Mehlich III extractable Ca with addition of 5% bentonite for both the soil and sand.

A significant ($P<0.05$) progressive increase in Ca content of both soil and sand was observed for higher rates of bentonite applied. Mehlich III extractable Mg increased significantly ($P<0.05$) on addition of 5% bentonite for both the soil and sand. A significant ($P<0.05$) progressive increase Mg content of both soil and bentonite was observed at higher rates of bentonite applied. The Ca/Mg ratio for soil was lower than that of sand (3.02 vs 9.53). Bentonite application significantly ($P<0.05$) decreased the Ca/Mg ratio for both soil and sand. The decrease increased with increasing rates of bentonite.

Effect of bentonite application on maize dry matter yield

Dry matter yield increased significantly ($P<0.05$) with amount of bentonite applied (Fig. 2), with values peaking off at 10% bentonite for sand and at 15% for soil mixtures. The data show that for sand

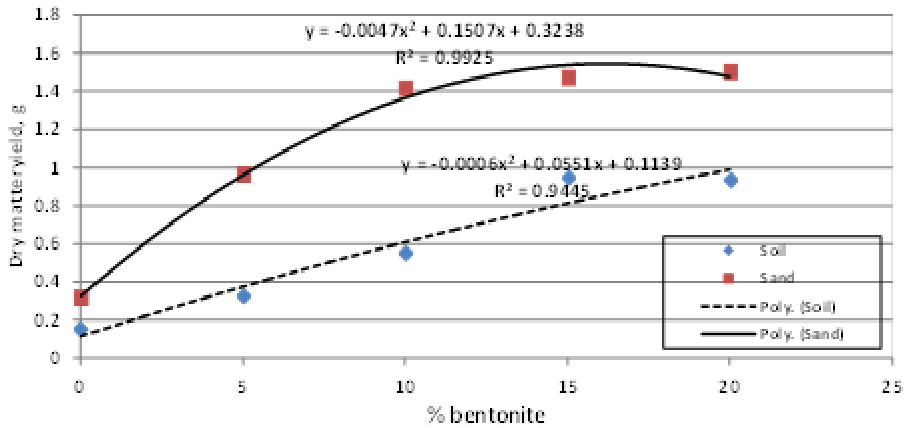

Figure 2. Effect of bentonite application on dry matter yield.

treated with 15% and 20% bentonite, dry matter yield was not different from that at 10% bentonite. For a given level of bentonite treatment, dry matter was significantly ($P<0.05$) higher for the sand than the soil mixtures (i.e. 0.92 vs 0.32g, 1.42 vs 0.55g, 1.47 vs 9.95 and 1.50 vs 0.93g respectively for the 5, 10, 15 and 20% bentonite treated mixtures).

Effect of bentonite application on maize grain yield

Results for the field evaluation of calcium bentonite on maize are presented in Table 3. During 2013A season, application of calcium bentonite alone increased maize grain yield by 10% over the control. In 2013B which was a better season, maize grain yield increased by 40% following bentonite application alone.

The yield was much higher where bentonite was combined with either DAP or farmyard manure. Results for 2013B also show that yields for the (bentonite+DAP) or (bentonite+FYM) were equivalent to those for DAP (125 kg ha^{-1}) + urea (60 kg ha^{-1}), which is the recommended fertilizer rate for maize in the area.

Averaged over the two seasons, bentonite use resulted in 25% increase in grain yield over the control. Combining bentonite with DAP and/or FYM resulted in 43 to 53% increase in grain yield.

Discussion

The low organic matter (OM) and N, plus high Ca and Mg in bentonite suggests that this material could possibly supply Ca and Mg, but not OM or N. In fact bentonite had a much higher Ca, Mg and K content than all three soils materials. Amendment of such soils with bentonite would thus alleviate some the nutrient deficiencies. The neutral pH suggests that if used, bentonite will not acidify soil.

Compared to soil, sand materials amended with calcium bentonite had higher moisture content suggesting that amendment with bentonite improved the moisture retention of sand more than that of soil. Bentonite application on sand significantly increased the pH, N, P, Ca and Mg content.

As a result, higher dry matter yields were observed from sand-bentonite compared to soil-bentonite mixtures. The

Table 3. Effect of calcium bentonite application on maize grain yield, 2013

Treatment	Grain yield ($kg\ ha^{-1}$)	% increase	Grain yield ($kg\ ha^{-1}$)	% increase	2-season average	% increase
	2013A season		2013B season			
Control	982		931		956.5	
Bentonite, 2.5 t ha^{-1}	1086	10.6	1306	40.3	1196.0	25.0
Bentonite (2.5 t ha^{-1}) + DAP (62.5 kg ha^{-1})	1005	2.3	1822	95.7	1413.5	47.8
Bentonite (2.5 t ha^{-1}) + FYM (2.5 t ha^{-1})	985	0.3	1941	108.5	1463.0	53.0
Bentonite (1.25 t ha^{-1}) + DAP (62.5 kg ha^{-1}) + FYM (1.25 t ha^{-1})	1208	23	1541	65.5	1374.5	43.7
DAP (125 kg ha^{-1}) + urea (60 kg ha^{-1})	1193	21.5	2018	116.8	1605.5	67.9
Sed	284		352.1			
CV, %	29.5		21.7			

benefits were observed more on sand than on soil, suggesting that bentonite use could be more beneficial on highly sandy soils compared to medium textured soils. Sacchi, (2010) reported increased soil cation exchange capacity, exchangeable Ca, Mg, K and plant available water following bentonite application.

Table 3 also shows that bentonite addition resulted in a decrease in the Ca/Mg ratio of both soil and sand, the trend increased with increasing rates of bentonite. This observation suggests that if used at high rates, calcium bentonite could change the natural cationratio of the soil medium.

Furthermore, bentonite rates higher than 10% on sand did not result into any further increments in biomass yield.

In addition, with increasing time of incubation, caking was observed especially in the soil mixtures containing 15 and 20% bentonite making them hard and increasingly difficult to sample. This observation suggests increasing resistance to root penetration at higher rates of bentonite. Thus, it is possible that rates higher than 10% bentonite somehow affected the soil (e.g. reduced soil moisture, Ca/Mg ratio and increased soil caking which affected root development).

A combination of these factors possibly resulted in a decrease in dry matter yield. This finding suggests that bentonite should not be applied at rates higher than 10%. In Australia, Sacchi (2010) observed that application of bentonite at rates of above 80 t ha^{-1}bentonite had a detrimental impact on soil structure leading to reduced yields. The current study points to reduced soil moisture and changes in soil physical and chemical properties when high rates of bentonite are applied.

As a way of validating results from the greenhouse, the benefit of bentonite application on maize grain yields was tested for two seasons on a sandy soil located in a drought stricken/prone area. From the results reported in this study, it is clear that bentoniteuse increased maize grain yields but with visible seasonal variations in its benefits.

During the better 2013B season, applying bentonite alone resulted in up to 40% increase in maize grain yield. However, taking into account the seasonal variations, bentonite application resulted in 25% increase in grain yield, and up to 43 to 53% increase in grain yield where it was combined with DAP and/or FYM.

These results are consistent with those of Noble *et al.* (2004) and Suzuki *et al.* (2007) who demonstrated that introducing clay-based materials such as bentonite significantly and persistently improves the productivity of degraded, light–textured soils, more so in the presence of an organic amendment.

In similar experiments, application of 1.2 t ha^{-1}bentonite increased rice grain yields by 73% and reduced the risk of crop failure during drought (IWMI, 2010). In another experiment sorghum forage biomass yields increased by six-fold following bentonite application. The improved soil quality persisted for at least 3 years (IWMI, 2010).

From a review of results from field experiments to assess the efficacy of bentonite addition on crop productivity and soil nutrient status, Berthelsen *et al.* (2005) reported significant increase in crop biomass and yields following bentonite application on light textured soils. The yield increase was attributed to a combination of increased water holding capacity, nutrient availability and reduced nutrient loss.

Conclusion

This study demonstrated the benefits of using calcium bentonite on sandy soils in a drought prone area. Amendment of a sandy soil with calcium bentonite significantly increased soil moisture, pH, N, P, Ca and Mg content, and consequently, maize dry matter and grain yields. The grain yield benefits were higher where bentonite was combined with DAP and/or farmyard manure. Yields for the bentonite + DAP or bentonite + farmyard manure were equivalent to those for DAP + urea at recommended rates.

Results suggest increased chances of crop survival following bentonite use on sandy soils under drought/ moisture stressed environments. Thus bentonite use can be a promising technology for improving the productivity of sandy soils in drought stricken/prone areas. It is also a promising climate change adaptation technology. However, more studies could be conducted to determine the net economic benefit of the application of bentonite in the production of maize and other crops under similar soil conditions.

Acknowledgement

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