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Groundnut yield response to single superphosphate, calcitic lime and gypsum on acid granitic sandy soil

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Abstract

Phosphorus and calcium are the major nutrients limiting groundnut production. The objectives were to determine (a) optimum application levels of P and Ca, and (b) compare the effectiveness of calcitic lime (40% Ca, 4.5% Mg) and gypsum (22% Ca, 17% S) as sources of Ca for groundnut grown on sandy soils. Field experiments were established in smallholder farming areas using four levels of P (0, 8.5, 17 and 34 kg ha^{-1}) combined factorially with calcitic lime (0, 200, 400 and 800 kg ha^{-1}) to give 16 treatments. Similar levels of P were combined factorially with gypsum (0, 100, 200 and 400 kg ha^{-1}) to give sixteen treatments. Experiments were laid in a randomized complete block design with three replications. Phosphorus had a significant effect on groundnut yield at the majority of the experimental sites. Application of P at 8.5 kg ha^{-1} gave the optimum groundnut yield response. The optimum application rates for calcitic lime and gypsum were 200 and 100 kg ha^{-1}. Gypsum and calcitic lime were not significantly different as sources of Ca for groundnut. Soil chemical properties were significantly improved following application of P and Ca sources.

Introduction

Soil fertility decline is a major problem facing smallholder farmers in sub-Saharan Africa (Murwira et al. 2002). The majority of smallholder farming is taking place on weakly buffered acid sandy soils. Current levels of fertilizer use under the existing farming system promote nutrient mining and the development of soil acidity (Dhliwayo et al. 1998). Application of insufficient nutrients is widespread in the smallholder farming sector of Sub-Saharan Africa (Murwira et al. 2002). Groundnut is one of the few crops that can be grown on the light textured acid soils of the smallholder farming sector (Nyakanda and Hildebrand 1999). Work done by Chikowo et al. (1999) showed that Ca and P were limiting groundnut production in the smallholder farming sector. Phosphorus is one of the major limiting plant nutrient (Nandwa 1998; Rao et al. 2004) in the tropical and sub-tropical soils. Studies by Tagwira et al. (1991) showed that P availability increases with liming in some Southern African soils. Chikowo et al. (1999) observed significant groundnut yield responses to P at some sites in the smallholder farming areas. However, at other sites with soil P below critical levels there were no yield responses to P application. In Malawi, Ngwira

(1984) also observed erratic groundnut yield responses to P application. Makombe (1991) reported that groundnut yield response to P depends on the amount of rainfall received during the season. Manure, the major source of P in the smallholder farming sector, has been shown to be low in nutrient concentration including P (Murwira and Kirchman 1993; Nyamangara et al. 1999; Chivenge 2003) and this cannot, therefore, be applied as the only source of P to crops. Mapfumo and Giller (2001) reported that manure from smallholder farming sector is deficient in P. The concentration of P in smallholder manure ranges between 0.10 and 0.16% (Mapfumo and Giller 2001). Studies by Dhliwayo (2000) and Nhamo (2001) showed that smallholder manure can supply adequate nutrients such as P and N when it is supplemented with inorganic fertilizers. Application of inorganic P fertilizers would enable smallholder farmers to benefit from increased groundnut yields and the 2–3 year residual effect of P.

Gypsum is widely used as a source of Ca for groundnut worldwide. Groundnut response to gypsum, as with any other fertilizer, depends on the fertility status of the soil. The dissolution of gypsum is fairly rapid and therefore readily adds Ca to the podding zone. However, the major disadvantage of gypsum is its vulnerability to leaching especially on light textured soils. Positive responses have been observed on sandy soils with pH less than 5.0 (0.01 M $CaCl_2$). Survey data from the smallholder farming sector has shown that the majority of the farmers do not apply gypsum or any other basal fertilizer to groundnut (Chikowo 1998).

The use of lime instead of gypsum can provide not only Ca for the groundnut crop but also improves the availability of other plant nutrients. Proper incorporation of lime into the soil ensures availability of Ca in the podding zone (Cox et al. 1982). The crop following limed groundnut benefits from the residual effect of lime in addition to N contributed through fixation by the legume. The low solubility of lime makes the Ca and/or Mg less prone to leaching which is one of the most common modes of nutrient loss from sandy soils of the smallholder areas. Liming decreases the phytotoxic levels of Al and reduces nutrient imbalance (Belkacem and Nys 1997).

This study was designed to (a) determine the optimum application levels of Ca and P for the sandy soils of the smallholder farming sector (b) compare the effectiveness of calcitic lime and gypsum as sources of Ca for groundnut grown on sandy soils and (c) determine the effect of the P and Ca sources on soil chemical properties.

Materials and methods

The experiments were conducted in Marange (18°52′ S, 32°24′ E) and Nyamazura (18°52′ S, 32°26′ E) smallholder farming areas. The two areas have a unimodal rainfall pattern, receiving an average of 550–800 mm annually between November and March. The mean annual temperature is 22 °C and the soils are predominantly alfisols (USDA classification), derived from granitic parent material.

Two experiments were conducted to determine the effect of single superphosphate (SSP) (9% P, 20% Ca, 11% S), calcitic lime (40% Ca, 4.5% Mg) and gypsum (22% Ca, 17% S) on groundnut yield. The soil fertility ameliorants were applied in the following quantities; 0, 8.5, 17 and 34 kg ha^{-1} P as SSP; 0, 200, 400 and 800 kg ha^{-1} calcitic lime and 0, 100, 200 and 400 kg ha^{-1} gypsum. In Experiment 1 the above P application rates were combined factorially with calcitic lime rates to give 16 treatments. In Experiment 2 the P application rates were combined factorially with the 4 gypsum rates to give 16 treatments. The quantities of SSP used in the experiments supplied 21–83 kg Ca ha^{-1} and 11–46 kg S ha^{-1}. Calcitic lime supplied 80–320 kg Ca ha^{-1} and 9–36 kg Mg ha^{-1}. Total amount of Ca from SSP and calcitic lime ranged from 101 to 403 kg ha^{-1}. Single superphosphate and calcitic lime were applied at planting by broadcasting uniformly in the plots receiving the treatments. The soil ameliorants were incorporated into soil using hand hoes before opening planting furrows. The gypsum was applied at early flowering by dusting on the plants.

An early maturing bunch variety, falcon, was sown in plots measuring 6×6 m in gross area. The spacing adopted was 0.45 m inter-row and 0.075 m in-row. Planting of the groundnuts was done with the onset of the rains. The experiment was laid out in a randomized complete block design with 3 replications. The experiments were established between 21 and 29 November across the two seasons, 1998/1999 and 1999/2000. Starter nitrogen was applied at 18 kg N ha^{-1} a week after crop emergence. Weeding was done at 2, 5 and 9 weeks after crop emergence. In the P × lime experiment soil samples were collected at flowering, pod filling and physiological maturity. In the P × gypsum experiment soil samples were collected at pod filling and harvest stages. At sampling intervals soil was collected from 15 cm depth using an auger. At harvest groundnut plants were collected from a netplot of 25 m^2 and, grain yields were measured at 12.5% moisture content and converted to a ha^{-1} basis. The net-plot comprised 7 middle rows, each 5 m long. The harvested plants were air-dried to constant moisture content before determining kernel yield.

Characterization of soil from the experimental sites was done before planting. From the collected soil the following were measured; pH, extractable P (Mehlich 3 Extraction), exchangeable Ca, Mg, K and available Zn. The exchangeable cations were extracted by the Mehlich 3 method Mehlich (1984) and pH was determined using 0.01 M $CaCl_2$ (1:5 soil:suspension). The exchangeable cations were determined by the atomic absorption spectrophotometry. The Murphy and Riley (1962) solution was used for colour development in the determination of extractable P by the spectrophotometer. Soil texture was determined by the hydrometer method.

Analysis of variance was performed to determine treatment differences on groundnut yield using Genstat Version 3.2 (Lane and Payne 1996) and treatment means were compared by least significant difference (LSD). Regression analysis was conducted to determine the relationship between groundnut yield and P, lime and gypsum quantities applied. Basic economic analysis was performed to determine the rate of economic returns for each rate of soil amendment applied (CIMMYT 1988).

Results

Soil properties of experimental sites

Table 1 shows the chemical and textural properties of soils from the experimental sites used during the 1998/1999 and 1999/2000 cropping seasons. The soils were acid and low in available plant nutrients. The inherent soil Ca and P concentrations were below the critical levels for groundnut as reported in literature.

Kernel yield

Figure 1 shows the effect of P on groundnut yield at varying calcitic lime application rates across the seasons in Experiment 1. Phosphorus significantly ($p < 0.001$) increased kernel yield across the seasons. Application of 8.5, 17 and 34 kg ha^{-1} P increased kernel yield by 39, 40 and 51% over the zero P treatment. Increasing P application rate from 8.5 to 17 and 34 kg ha^{-1} had no significant effect on groundnut yield. Application of calcitic lime at 800 kg ha^{-1} gave significantly ($p < 0.01$) higher yield than 200 and 400 kg ha^{-1}. Analysis of variance indicated no significant P × calcitic lime interaction effect on groundnut yield. The relationship between yield and P applied was significantly ($p < 0.01$) linear. Regression analysis showed that the equation relating kernel yield (KY, kg ha^{-1}) to the amount of P (P, kg ha^{-1}) is $KY = 539 + 10.5P$ ($r = 0.71$, s.e. of regression coefficient = 51.4). The relationship between lime applied and groundnut yield was not significantly ($p > 0.05$) linear.

The effects of P and gypsum on groundnut yield in Experiment 2 are shown in Figure 2. Phosphorus had a significant ($p < 0.05$) effect on kernel yield across the seasons. Analysis of variance showed that gypsum and the interaction effect of P and gypsum on groundnut yield were negligible ($p > 0.05$). Regression analysis indicated that the relationship between groundnut yield and either P or gypsum was not linear ($p > 0.05$).

Figure 3 shows the effect of calcitic lime and gypsum on kernel yield at varying P rates across the 1998/1999 and 1999/2000 seasons. The effects of calcitic lime and gypsum on groundnut yield were not significantly ($p = 0.11$) different across the two seasons. At 0 kg P ha^{-1} there was an increase in groundnut yield with application of either calcitic lime or gypsum. At 0 kg P ha^{-1}, application of calcitic lime at 200, 400 and 800 kg ha^{-1} significantly ($p < 0.05$) increased groundnut yield by 57, 75 and 81% over the control treatment. At 0 kg P ha^{-1} P, gypsum applied at 100, 200 and 400 kg ha^{-1} increased yields by 50, 58 and 90% over the control treatment.

Table 1. Chemical and textural properties of soils from the experimental sites.

Site	Ca	Mg	K	P	Zn	pH	Texture
	Cmol$_c$/kg			mg kg^{-1}		0.01 M $CaCl_2$	
Kodza	0.95	0.28	0.14	9.7	0.14	4.2	Sandy loam
Kwira	0.97	0.32	0.23	14	0.16	4.2	Sandy loam
Maenza	1.15	0.36	0.09	17	0.13	4.3	Loamy sand
Mashizha	1.54	0.31	0.14	11	0.20	4.6	Loamy sand
Matara	0.95	0.40	0.21	9.0	0.10	4.4	Sandy loam
Matowe	1.36	0.48	0.23	14	0.16	4.5	Loamy sand
Mvuru	1.64	0.38	0.24	10	0.14	4.4	Loamy sand

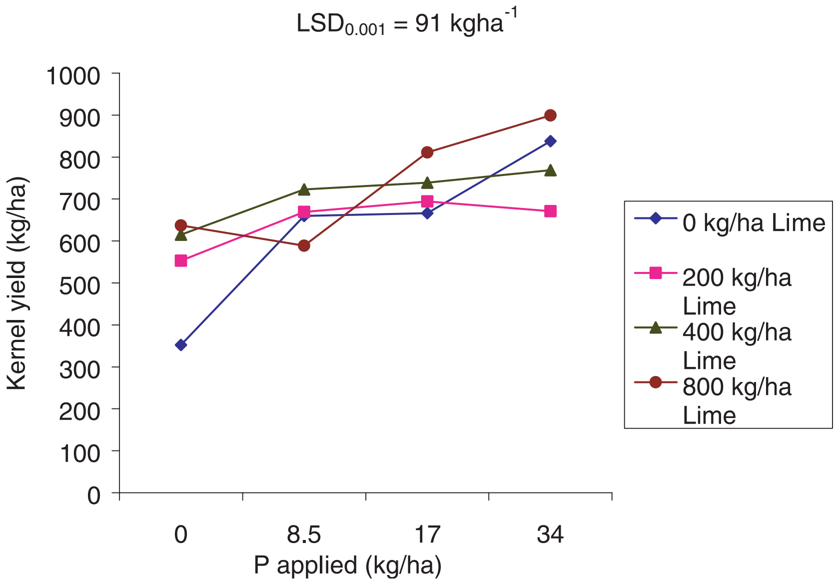

Figure 1. Groundnut yield response to P application at varying calcitic lime rates.

Effects of P, calcitic lime and gypsum on soil chemical properties.

At every soil sampling stage plots which received single superphosphate had higher ($p < 0.01$) soil P and Ca concentrations than the control plot (Table 2). Liming significantly ($p < 0.01$) increased soil pH, Ca and Mg concentrations (Table 3). Soils collected from limed plots at flowering and pod filling indicated an increase in solution P with increase in liming rate. Soil collected from plots that had received gypsum had significantly higher ($p < 0.05$) Ca concentration than the control (Table 4). Soil Ca, Mg and pH decreased between flowering and harvest sampling stages while K content increased.

Figure 4 below shows the net benefits derived from the application of P across the experimental sites. All treatments produced positive net benefits including the zero P treatment. Application of 8.5 kg ha^{-1} gave the highest rate of economic returns. Higher rates of P (>8.5 kg ha^{-1}) offered lower returns per hectare.

Net benefits increased with the first 200 kg calcitic lime per hectare but declined with successive additions of lime (Figure 5). Similarly with gypsum, net benefits increased with the first 100 kg ha^{-1} (Figure 6). Further increases in gypsum application rate beyond 100 kg ha^{-1} gave no significant increase in the rate of returns.

Discussion

The soils used in this study were low in available plant nutrients. Soil Ca concentration at

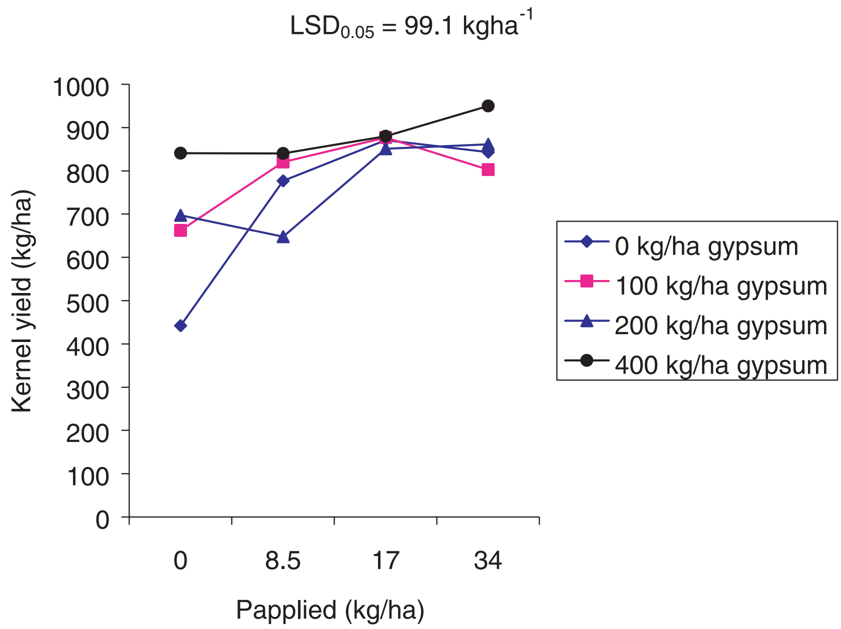

Figure 2. Groundnut yield response to P application at varying gypsum rates.

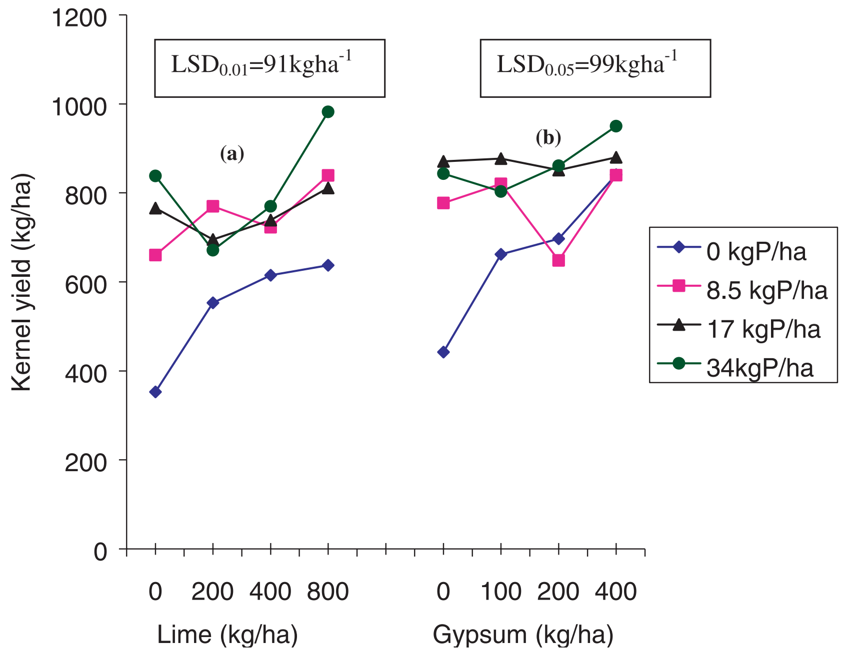

Figure 3. Groundnut yield response to calcitic lime (a) and gypsum (b) application at varying P rates.

all experimental sites was below 3 $Cmol_c\ kg^{-1}$ (Mehlich 3 Extraction) reported by Parischa and Tandon (1993) as the critical level required in the groundnut podding zone. There were significant kernel yield responses to P application across the sites and seasons. The positive yield response to P was due to the low P levels in the soil. The soil P was less than 30 ppm (Mehlich 3) reported as the

Table 2. Effect of P application on exchangeable cations (Cmol$_c$ kg^{-1}), extractable P (mg kg^{-1}) (Mehlich 3 Extraction) and pH (0.01 M $CaCl_2$) across the experimental sites.

P applied (kg ha^{-1})	Flowering					Pod filling					Harvest				
	Ca	Mg	K	P	pH	Ca	Mg	K	P	pH	Ca	Mg	K	P	pH
0	1.2	0.84	0.19	12	4.6	1.4	0.79	0.19	13	4.5	1.3	0.69	0.19	13	4.5
8.5	1.5	0.82	0.18	15	4.6	1.6	0.82	0.15	16	4.5	1.3	0.73	0.17	16	4.6
17	1.6	0.82	0.15	19	4.6	1.6	0.80	0.19	21	4.5	1.4	0.67	0.20	19	4.5
34	1.7	0.84	0.16	29	4.8	1.6	0.81	0.21	28	4.6	1.5	0.74	0.20	26	4.5
$Lsd_{0.01}$	0.2	0.1	0.04	1.7	0.08	0.2	0.09	0.04	1.1	0.09	0.1	0.07	0.04	1.0	0.07
CV (%)	19	14	30	12	2.2	13	13	27	7.1	2.4	22	14	6.8	8.2	1.9

Table 3. Effects of calcitic lime application on soil pH (0.01 M $CaCl_2$), extractable P (mg kg^{-1}) (Mehlich 3 extraction) and exchangeable cations (Cmol$_c$ kg^{-1}) across experimental sites.

Lime (kg ha^{-1})	Flowering					Pod filling					Harvest				
	Ca	Mg	K	P	pH	Ca	Mg	K	P	pH	Ca	Mg	K	P	pH
0	1.2	0.75	0.17	18	4.2	1.4	0.71	0.19	18	4.1	1.3	0.60	0.18	18	4.2
200	1.3	0.83	0.18	19	4.5	1.4	0.86	0.18	19	4.4	1.3	0.70	0.17	18	4.3
400	1.6	0.86	0.16	19	4.8	1.6	0.86	0.19	20	4.7	1.4	0.76	0.21	18	4.6
800	1.9	0.87	0.17	20	5.2	1.8	0.78	0.18	21	4.9	1.5	0.77	0.19	19	4.8
$Lsd_{0.01}$	0.2	0.1	0.04	1.7	0.08	0.2	0.09	0.04	1.1	0.09	0.1	0.07	0.04	1.0	0.07
CV (%)	19	14	30	12	2.2	13	13	27	7.1	2.4	22	14	6.8	8.2	1.9

critical level for groundnut (Jones and Piha 1989). Generally soils in the smallholder sector are inherently low in P. Data from this study showed that 8.5 kg P ha^{-1} gives the highest rate of return from groundnut grown in acid sandy soils. Lack of kernel yield responses to P at a few sites could have been a result of other soil limiting factors. The lack of kernel yield response to P when soil P was in deficient range for groundnut is consistent with the findings of Ngwira (1984) in Malawi and Chikowo

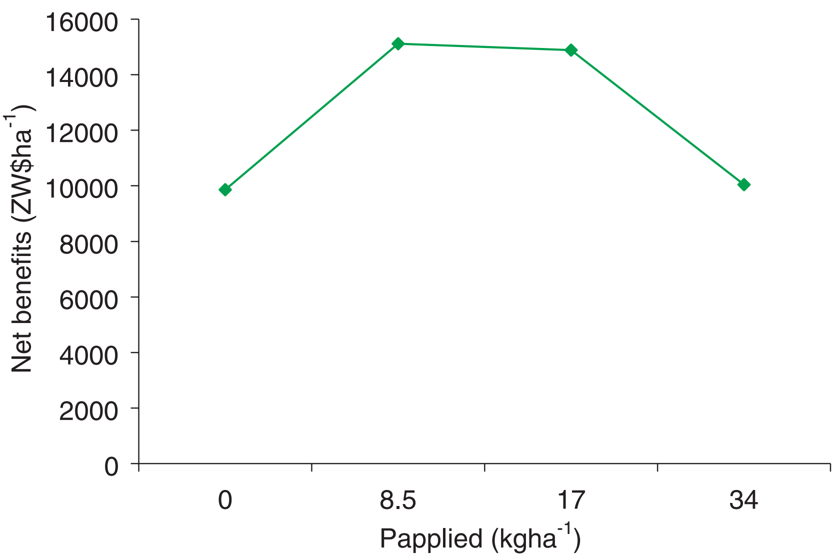

Figure 4. Net benefits derived from the application of P across the experimental sites.

Table 4. Effect of gypsum on exchangeable cations ($Cmol_c\ kg^{-1}$), extractable P ($mg\ kg^{-1}$) (Mehlich 3 extraction) and pH (0.01 M $CaCl_2$) across experimental sites.

Gypsum ($kg\ ha^{-1}$)	Pod filling					Harvest				
	Ca	Mg	K	P	pH	Ca	Mg	K	P	pH
0	1.3	0.65	0.16	17	4.3	1.3	0.56	0.16	15	4.2
100	1.5	0.62	0.17	17	4.3	1.4	0.58	0.15	16	4.2
200	1.5	0.67	0.14	17	4.4	1.4	0.58	0.16	16	4.1
400	1.5	0.66	0.15	17	4.3	1.5	0.55	0.18	17	4.2
$Lsd_{0.05}$	0.2	0.10	0.05	1.1	0.08	0.1	0.09	0.04	1.1	0.07
CV(%)	16	18	31	7.9	2.1	14	14	31	8.4	2.0

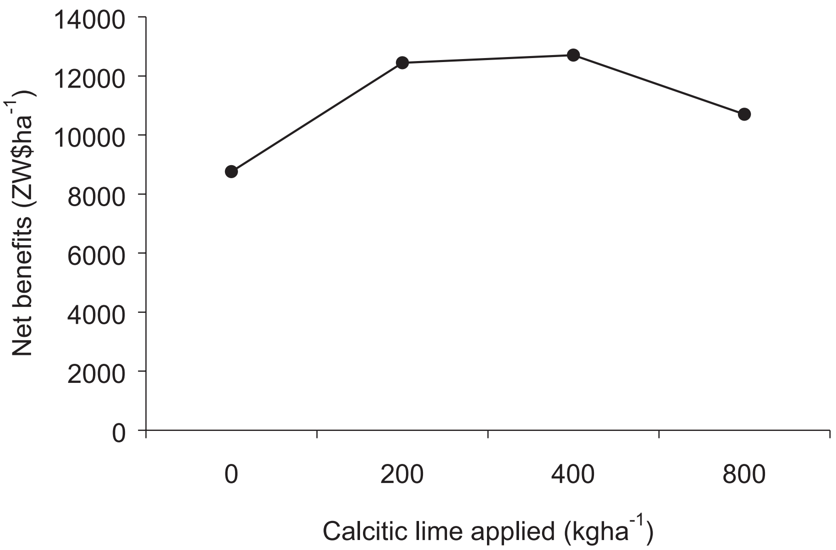

Figure 5. Net benefits derived from the application of calcitic lime across the experimental sites.

(1998) in Zimbabwe. Field and greenhouse studies by Otani and Ae (1996) showed that groundnut took up more P from low P soils than other crops such as sorghum. Ae et al. (1996) also attributed lack of yield response to P by groundnut to the exceptional ability of the legume to extract P from low P soils. The same authors reported that groundnut releases relatively high exudates which solubilize Al-bound P.

The response to Ca applied as calcitic lime and gypsum was variable. Positive yield responses to calcitic lime and gypsum observed could have been a result of the applied Ca being available within the top 10 cm where most pods are concentrated. Cox et al. (1982) reported that groundnut has a higher Ca requirement at pod filling. Adequate Ca supply in the podding zone is critical for the production of quality kernels. The Ca requirement for kernel development is taken up directly by the pod from the soil (Zharare et al. 1993; Zharare 1996). However, pods are poor absorbers of Ca and hence require that the soil has significant Ca levels. Calcium absorbed by the roots is not channeled to the developing pods because of the subterranean nature of groundnut.

Calcitic lime provided Ca and Mg which were inherently low in the acid sandy soils of the smallholder sector. Cox et al. (1982) reported that incorporating lime to a depth of 10 cm ensures availability of Ca in the podding zone. Desai et al. (1999) reported that on acid soils, topdressed gypsum at flowering and preplant broadcast lime gave similar groundnut yield responses. Smith (1995) also reported that lime is a more suitable source of Ca than gypsum for groundnut grown on acid light textured soils because of the slow release of Ca.

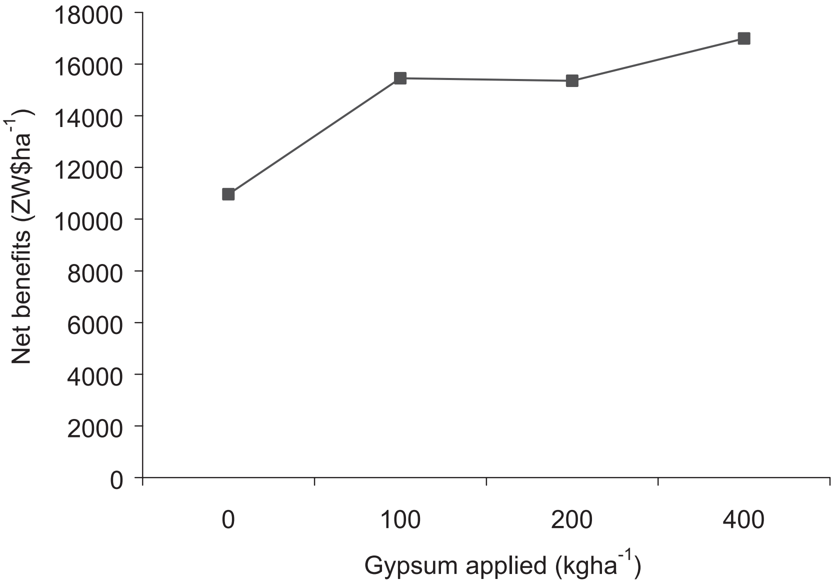

Figure 6. Net benefits derived from the application of gypsum across the experimental sites.

Gypsum is subject to leaching and this could be one of the reasons why insignificant yield responses were observed at the sites used in this study.

Soil moisture is critical to the availability of Ca to groundnut. The rainfall for the two seasons was adequate and fairly distributed during the season. This could have improved the solubility of calcitic lime and hence the supply of Ca from this source. Smith (1995) reported that soil moisture is very critical in the pegging zone during peak periods of Ca uptake by pods. Hartzog and Adams (1973) reported that groundnut growing in dry topsoil but with roots in moist subsoil show poor pod development and kernel abortion because Ca absorbed by the roots is not channeled to the developing pod. The increase in soil solution P with liming between flowering and pod filling stages of groundnut is consistent with results observed by Tagwira et al. (1991).

Conclusion

The study showed that P significantly increases groundnut yields on acid granitic sandy soils. Application of 8.5 kg P ha^{-1} gave the economically viable benefits and yield response to P at this rate was not significantly different from higher application rates. Optimum calcitic lime and gypsum application rates were 200 and 100 kg ha^{-1} respectively. The study also showed that application of calcitic lime and gypsum as Ca sources for groundnut gave no significant yield differences. Single superphosphate, calcitic lime and gypsum significantly improved P, Ca, Mg and pH levels of granitic sandy soils.

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