# Effect of soil fertility management strategies and resource-endowment on spatial soil fertility gradients, plant nutrient uptake and maize growth at two smallholder areas, north-western Zimbabwe

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We investigate the effects of smallholder farmer resource-endowment and soil nutrient management strategies on plant nutrient uptake and growth across soil fertility gradients under semi-arid conditions. Soil fertility gradients as influenced by farmers' resource availability may affect the response of crops to fertilizer addition and therefore productivity. The study was conducted in Njelele and Nemangwe smallholder areas (450-800 mm per annum, unimodal) in north-western Zimbabwe. Soil and maize cobleaf samples were collected from fields of farmers (varying resource endowment) located near to (homefields) and far away (outfields) from the farmers' homesteads during the 2005-6 season. The samples were analysed for selected soil fertility indicators and soil samples were further used to test maize growth response to various nutrient applications under greenhouse conditions. Soil fertility (organic C, total N and available P) significantly ($P<0.05$) decreased from resource-endowed to resource-constrained farmers, and from outfields to homefields, but the latter differences were only significant for available P. Besides resource-endowment and field type, response to nutrient applications also depended on soil texture. In sandy soil, both N and P were limiting to MAIZE growth in outfields while N was most limiting in the homefield. It was concluded that resource-endowment and nutrient resource management strategies employed by farmers result in soil fertility gradients which affect response of crops to fertilisation and therefore need to be factored in the development of fertiliser recommendations.

**Keywords:** Homefields, outfields, semi-arid conditions, greenhouse experiments

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## Introduction

Maize (*Zea mays* L.) is the staple crop accounting for up to 85% of the calories consumed in eastern and southern Africa (Mugwira *et al.,* 2002). Consequently the crop is grown across different soil types and climatic conditions, and because of population pressure some of the agro-ecological environments cultivated are only marginally suitable for maize production. Therefore soil fertilisation technologies intended to increase productivity of maize, and other crops, under these conditions must be site-specific in order to be relevant. The majority of soils in Zimbabwe are inherently deficient in N, P and S (Grant, 1981), and deficiencies of secondary and micronutrients including Ca and Mg have also been reported on sandy soils in high potential smallholder areas (Mugwira & Nyamangara, 1998; Zingore *et al.*, 2007).

Soils derived from Kalahari sands cover vast expanses of land in western Zimbabwe, Botswana, parts of southern Namibia and north-western South Africa. Kalahari sands are of Aeolian origin and in Zimbabwe they cover 44 000 $km^2$ of land (Stagman, 1978), most of it under natural or commercial forests. The soils have fine-to-medium-grained sand particles, are low in cation exchange capacity as they are low in clay and organic matter. These soils are classified as regosols (Zimbabwe) or Arenosols (USDA) (Nyamapfene, 1991). Kalahari sands are productive during initial cultivation but quickly lose their fertility with time (Mapedza *et al.*, 2003) because the organic matter accumulated from natural vegetation is quickly mineralized due to lack of clay-induced physical protection from micro-organisms. According to Mapedza *et al.* (2003), most smallholder farmers in Gokwe historically countered this problem by expanding areas under cultivation, but this has become increasingly difficult due to the shortage of nearby virgin land as the population increases. Therefore, there is a need to increase and maintain crop productivity on soil already under cultivation through application of fertiliser.

Smallholder farmers rely on animal manure as a source of nutrients as mineral fertilisers are either unavailable or are unaffordable. Fertiliser recommendations developed according to agro-ecological regions have not been adopted by smallholder farmers because the fertiliser rates are too high and therefore unaffordable (Quiñones *et al.*, 1997; Nandwa *et al.*, 1998). Variable response to fertilisation is caused by differences in soil type and management history of different fields, and therefore varying nutrient requirements over short distances, a factor not considered in the development of the fertiliser recommendations for smallholder areas. At farm level, soil spatial variability large enough to affect crop response to applied nutrients has been reported (Zingore, *et al.*, 2007; Mtambanengwe & Mapfumo, 2005) and this was attributed to farmers applying the limiting nutrient inputs only to certain portions of their fields. Farmers tend to apply most of the nutrients to fields near their homesteads (homefields) resulting in higher soil fertility and balanced nutrition in these fields compared to fields further away from the homesteads (outfields) where limited or no nutrients are applied (Vanlauwe & Sanginga, 2004; Mtambanengwe &

Mapfumo, 2005; Tittonell *et al.*, 2005; Zingore *et al.*, 2007). However, cases of higher fertility in outfields compared to homefields have also been reported (Haileslassie, *et al.*, 2007). Therefore, in the development of fertiliser recommendations, these important soil fertility gradients, which affect crop response to fertilisation, should be considered in addition to general soil type and agro-ecology.

The aim of this study was to determine the effect of farmer resource-endowment and soil fertility management strategies on spatial soil fertility gradients across farms and the effect of the gradients, if present, on nutrient uptake and plant growth. It was assumed that soil fertility gradients do not exist on Kalahari sands because of the poor capacity of the soil to physically protect organic matter from microbial degradation.

## Material and methods

### Field site description

The field study was conducted in two wards each for Njelele and Nemangwe smallholder areas in Gokwe South District (18°-19° longitude; 28°-29° latitude), north-western Zimbabwe. Njelele is located in agro-ecological region III (rainfall 650-800 mm per annum) and Nemangwe in agro-ecological region IV (450-650 mm per annum) (Nyamapfene, 1991). The rainfall is unimodal (October-April), poorly distributed, highly variable and often inadequate for cropping. The farming system in the study area is characterised by mixed crop-livestock farming with maize as the main crop. In Nemangwe cotton is the main cash crop, while in Njelele maize and horticultural crops are key sources of income (Masvaya, 2007).

### Field soil and plant sampling

Thirty-four households, at least eight from each ward, were selected in 2005/06 cropping season to represent resourced (RG1), intermediate (RG2) and resource- constrained (RG3) households (Mtambanengwe & Mapfumo, 2005). At each household, two maize fields at different distances from the homestead were identified, one close to the homestead and the other further away from the homestead.

Ten soil sub-samples (0-20 cm layer) were randomly taken from a 50 $m^2$ sub-plot in the centre of each main plot using an auger and thoroughly mixed to make one composite sample. Ten maize cobleaf (at silking stage) samples were also randomly taken from the same plots to make a composite sample. Soil samples were air-dried and ground to pass through a 2 mm sieve whilst plant samples were oven-dried (60ºC) and milled (0.15 mm).

### Greenhouse experiment

After analysis of soil and plant samples from the four wards, two homesteads with soils representative of the medium wealth group (RG2) were selected from Njelele for greenhouse experiments. One homestead was on sandy clay loam soils whilst the other was on Kalahari sands. Sandy clay loam soils represent <2% of the soils in the district but are the most productive and therefore more intensively cultivated. The objective of the experiment was to determine maize growth responses to the addition of selected nutrients in home- and outfields of both soil types. Bulk soil samples (0-20 cm) were collected from the 50 $m^2$ plots where the original soil samples had been taken. Ten sub-samples were taken from randomly selected positions. The bulk soil samples were air-dried, ground to pass through a 4 mm sieve. Sub-samples of each soil were further ground (2 mm sieve) and analyzed for pH, texture, organic C, total N and P, and available P (Okalebo *et al.*, 2002). The bulk soils were weighed into 2 000 $cm^3$ free-draining pots according to their bulk density (sandy soil was 1.5 g $cm^{-3}$ and sandy clay loam soil 1.2 g $cm^{-3}$ and thus 3 kg and 2.4 kg were used to fill the pots, respectively). The experiment was a randomised complete block design with two factors: soil type (sandy clay loam and sand) and field type (homefield and outfield). The treatments were replicated three times. The treatments for the pot experiment are presented in Table 1. The nutrients were added at the following rates under field conditions; 100 kg N $ha^{-1}$, 30 kg P $ha^{-1}$, 30 kg K $ha^{-1}$, 20 kg Ca $ha^{-1}$, 5 kg Zn $ha^{-1}$, 5 kg Cu $ha^{-1}$ and 10 kg Mn $ha^{-1}$ (Zingore *et al.*, 2007). Three maize seeds were planted into each pot and then thinned to 2 seedlings after germination. The greenhouse temperature was not controlled but the mean temperature was 30°C.

Soil moisture content was maintained at 70% field capacity by weighing every second day and watering with de-ionized water. The maize plants were harvested five weeks after emergence by cutting at the soil surface.

**Table 1** Treatments used to assess limiting nutrients on homefields and outfields on a sandy and sandy clay loam soil from Gokwe South district, Zimbabwe.

| Treatment | Nutrients added |
|---|---|
| 1 | Control |
| 2 | N |
| 3 | N+P |
| 4 | N+P+Ca |
| 5 | N+P+Ca+Mg |
| 6 | N+P+Ca+Mg+Micronutrients (Zn, Cu, Mn, Fe, Co) |
| 7 | N+P+ Micronutrients(Zn, Cu, Mn, Fe, Co)+Lime(Calcitic) |

## Soil and plant analysis

Soil pH was determined in 1:5 soil suspension using distilled water and 0.01M $CaCl_2$ and organic C using the modified Walkley-Black method (Anderson & Ingram, 1993). Soil texture was determined using the hydrometer method, total N and P using semi-micro Kjeldahl digestion, and available P using $NaHCO_3$ (pH 8.5) extraction (Okalebo *et al.*, 2002). Exchangeable bases were determined by atomic absorption (emission for K) spectrophotometry after extraction with ammonium acetate (pH 7.0). Cation exchange capacity was determined by saturating the soil with 1M ammonium acetate buffered at pH at 5.2 (Okalebo *et al.*, 2002).

Cobleaf and whole plant shoots were oven dried (65°C), passed through a 0.15 mm sieve, and analysed according to standard methods (Okalebo *et al.*, 2002). Total N was determined using the semi-micro Kjeldahl digestion, total P by colorimetry after wet oxidation of organic forms using perchloric acid. Total Ca, Mg, K, Mn, Zn and Cu were determined by atomic absorption (emission for K) after digestion of the samples using aqua regia (Baker & Amacher, 1982). Maize cobleaf nutrient concentration adequacy was assessed according to standards suggested by Mengel and Kirby (2001) and Khiari *et al.* (2001) (Table 2).

**Table 2** Values used to interpret adequacy of nutrients in different fields in Gokwe South district, north-west Zimbabwe, using nutrient concentration values of maize cobleaves at silking and shoots at five weeks after emergence

(a) Maize cobleaves at silking

| Element | Deficient | Low | Adequate |
|---|---|---|---|
| N (%) | < 2.00 | 2.00 – 2.50 | 2.50 – 3.50 |
| P (%) | < 0.10 | 0.10 – 0.20 | 0.20 – 0.50 |
| K (%) | < 1.00 | 1.00 – 1.50 | 1.50 – 3.00 |
| Ca (%) | < 0.20 | 0.20 – 0.30 | 0.4 – 1.0 |
| Mg (%) | < 0.10 | 0.10 – 0.20 | 0.2 – 1.0 |
| Fe (mg $kg^{-1}$) | < 10 | 10 | 10 – 300 |
| Mn (mg $kg^{-1}$) | < 10 | 10 – 20 | 20 – 200 |
| Zn (mg $kg^{-1}$) | < 15 | 15 – 20 | 20 – 70 |
| Cu (mg $kg^{-1}$) | < 5 | _ | _ |

Mengel and Kirby, 2001

(b) Maize shoots

| | N | P | Ca | Mg | Zn | Fe | Mn | Cu |
|---|---|---|---|---|---|---|---|---|
| | | (%) | | | | (mg $kg^{-1}$) | | |
| Deficient[a] | - | <0.1 | <0.2 | <0.1 | <5 | <10 | <10 | - |
| Low[a] | - | 0.1-0.2 | 0.2-0.3 | 0.1-0.2 | 15-20 | 10 | 10-20 | - |
| Adequate[a] | - | 0.2-0.5 | 0.4-1.0 | 0.2-1.0 | 20-70 | 10-300 | 20-200 | - |
| High[a] | - | 0.5-0.8 | >1.0 | >1.0 | 70-150 | 300-550 | 200-250 | - |
| Critical concentrations | 3.0[b] | 0.2[b] | 0.3[b] | 0.2[b] | | | | |

[a] Mengel and Kirby 2001 (general values for maize); [b]Khiari *et al.* 2001

## Statistical analysis

Analysis of variance (ANOVA) was used to test the significance of differences between means of soil properties (home- and outfields) and cobleaf nutrient concentration in the field, and shoot biomass and nutrient composition in maize shoots in the greenhouse experiment. The statistical analysis was performed using the GENSTAT 5.0 statistical package (GENSTAT, 1997).

# Results

## Field study

There were significant ($P<0.05$) differences for total soil N and available P across resource-endowment classes, decreasing from resource-endowed to resource-constrained farmers (Figure 1). Although there were no significant differences between field types in each wealth category for soil N and

SOC, the parameters were higher in outfields compared to homefields. Soil P was significantly higher in outfields compared to homefields for RG1 and RG3 resource categories (Figure 1).

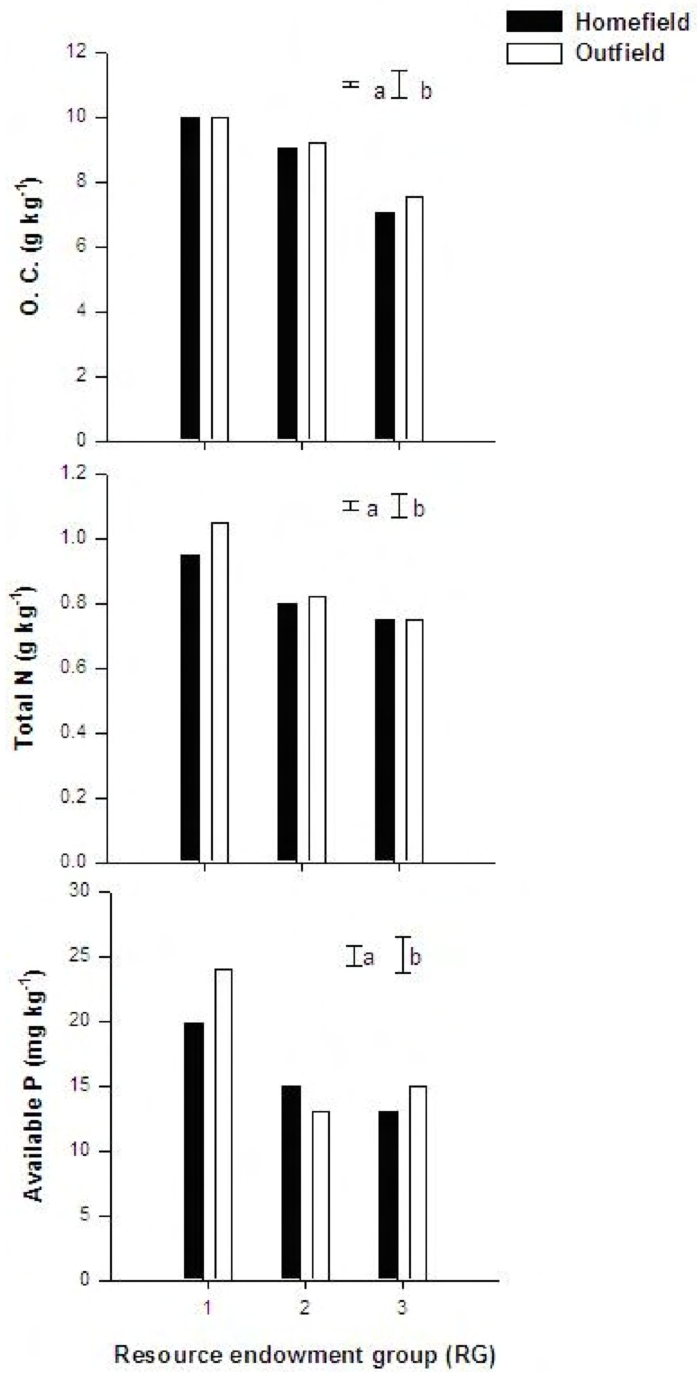


**Figure 1** Effect of resource group and field type on soil OC, total N and available P in Gokwe South District. Bars represent standard error of the mean for factors (a) Resource-endowment group and (b) field type.

In homefields soil pH and exchangeable bases, except Mg, showed no specific trend. Cation exchange capacity (CEC) decreased with decease in resource-endowment in both home and outfields, and the trend was similar for Mg in homefields (Table 3)

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**Table 3** Selected properties of soils across resource groups in sampled fields in four wards of Gokwe South District, Zimbabwe

| Resource group | % clay | | pH ($CaCl_2$) | | CEC ($cmol_c\ kg^{-1}$) | | Exch. Ca ($cmol_c\ kg^{-1}$) | | Exch. Mg ($cmol_c\ kg^{-1}$) | | Exch. Na ($cmol_c\ kg^{-1}$) | | Exch. K ($cmol_c\ kg^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *HF | *OF | HF | OF | HF | OF | HF | OF | HF | OF | HF | OF | HF | OF |
| 1 | 4.3 | 4.0 | 5.7 | 5.7 | 15.2 | 14.0 | 16.75 | 4.2 | 5.75 | 1.10 | 0.02 | 0.08 | 1.67 | 0.51 |
| 2 | 3.3 | 4.0 | 5.3 | 5.0 | 6.4 | 10.9 | 2.70 | 10.7 | 1.95 | 1.85 | 0.11 | 0.12 | 0.22 | 0.51 |
| 3 | 5.0 | 4.0 | 4.8 | 5.8 | 3.4 | 4.8 | 4.00 | 1.95 | 0.40 | 0.45 | 0.05 | 0.09 | 0.51 | 0.56 |
| +SE of mean | 0.35 | | 0.26 | | 3.15 | | 3.67 | | 1.16 | | 0.02 | | 0.31 | |

* HF represents Homefield and OF, Outfield. Values represent means of treatments.

+SE of mean is the standard error of the homefield and outfield mean

Maize cobleaf K, Ca, Mg, Zn, Cu, Fe contents varied across wealth classes but the differences were not significant (data not shown). Cobleaf N and P content decreased with decrease in resource-endowment, the largest decrease being from RG1 to RG2 (Figure 2). Field type effect was significant ($P<0.05$) for N in RG1 wealth group and P in RG2 wealth group. In both cases uptake was higher in the homefields compared to the outfields (Figure 2).

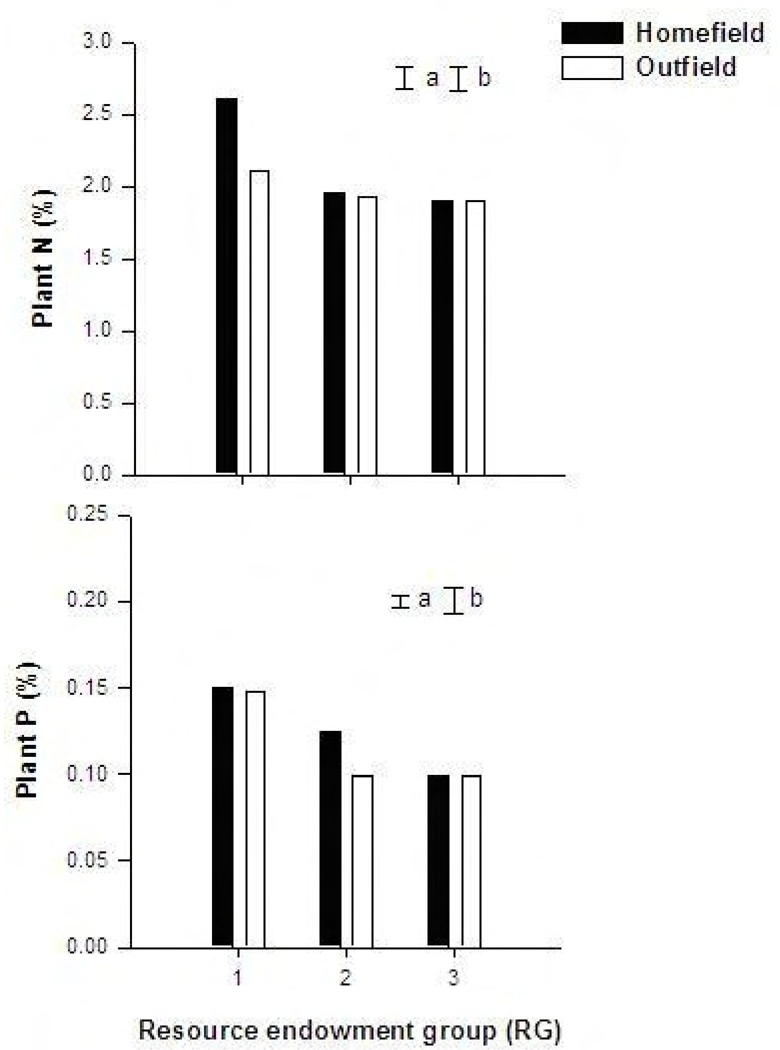


**Figure 2** Plant N and P concentrations of maize cob leaves at silking in Gokwe South District across resource-endowment groups. Bars show standard error of the mean for factors (a) resource endowment and (b) field type.

Nutrient uptake adequacy was assessed using cobleaf concentration limits developed by Mengel and Kirby (2001) (Table 2). The N status in the RG1 group was low (2.0-2.5%) while the rest were deficient (<2.0%) (Figure 2). Phosphorus status was deficient (<0.10%) in RG3 group and low (0.10-0.20%) in RG1 and RG2 groups.

### Greenhouse study

Aboveground dry matter yield across the two soil textures (sand, sandy clay loam) and between treatments within each soil type were significant (P<0.001) (Figure 3). In the sandy clay loam (SCL) soil, the highest response in dry matter yield compared to control occurred when N was added, especially in the outfield. Addition of micronutrients in addition to N+P+Ca+Mg increased dry matter yield in the outfield but had no effect in the homefield, while substitution of Ca with calcitic lime and Mg depressed yield (Figure 3).

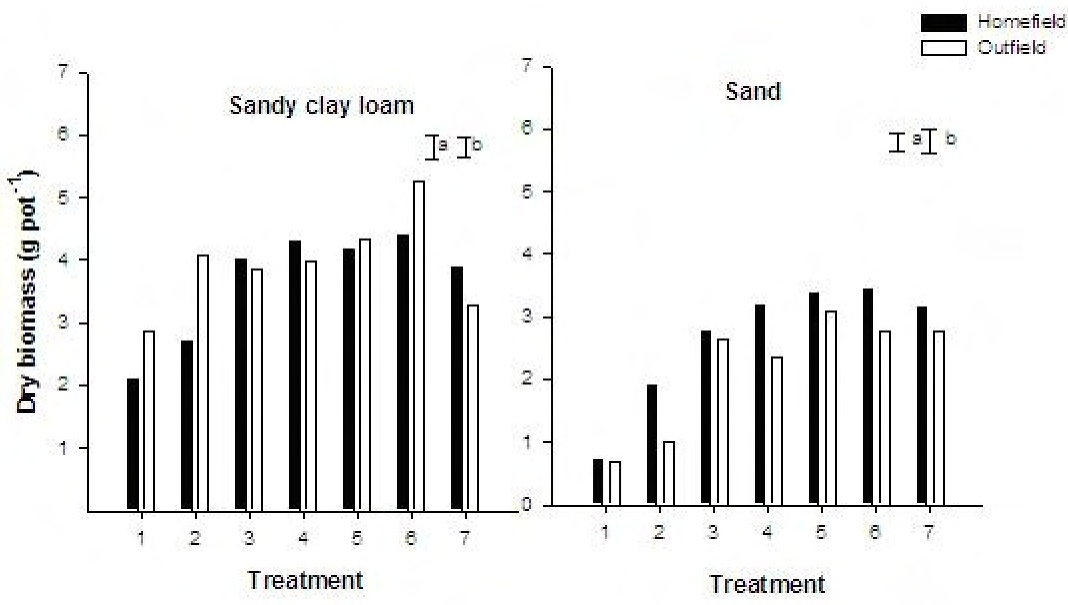


**Figure 3** Effect of field type and nutrient addition on the growth of the maize in a clayey and sandy soil. Bars represent standard error of the mean for factors (a) treatment and (b) field type.

In the sandy soil aboveground dry matter yield was generally higher in the homefield, in contrast with the sandy clay loam soil. While the highest growth response occurred when N was added in the homefield, in the outfield it occurred when N+P were added (Figure 3), indicating P was also limiting to growth in the latter. Compared to N+P, addition of Ca alone depressed dry matter yield in the outfield while in the homefield the yield was increased. However, addition of Ca+Mg to the N+P treatment increased yield in the outfield. Addition of micronutrients in addition to N+P+Ca+Mg depressed dry matter yield in the outfield but had no effect in the homefield (Figure 3).

**Table 4** Properties of soils from Gokwe South district used for the greenhouse experiment

| Soil type | Field type | Texture (C/S/S) (%) | pH ($CaCl_2/H_20$) | SOC (%) | N (%) | P (%) | Avail. P (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| | Homefield | 4/4/92 | 4.8/5.8 | 0.70 | 0.065 | 0.01 | 9.12 |
| Sandy soil | Outfield | 4/3/93 | 4.9/5.1 | 0.40 | 0.052 | 0.01 | 2.00 |
| | Homefield | 29/11/60 | 6.1/7.1 | 0.90 | 0.07 | 0.03 | 7.74 |
| Clay loam | Outfield | 29/15/56 | 6.1/7.3 | 0.90 | 0.05 | 0.03 | 6.05 |

Total N and P uptake significantly (P<0.05) varied across treatments and field types. Nitrogen uptake was highest when micronutrients were added to N+P+Ca+Mg across both field types in both the sandy and sandy clay loam soil (Figure 4). Total P uptake was highest when N was added to the control, and when micronutrients were added to N+P+Ca+Mg. Besides fertiliser effects, total P uptake was also influenced by field type, highest response occurred in the outfield in the sandy clay loam soil and in the homefield in the sandy soil (Figure 4).

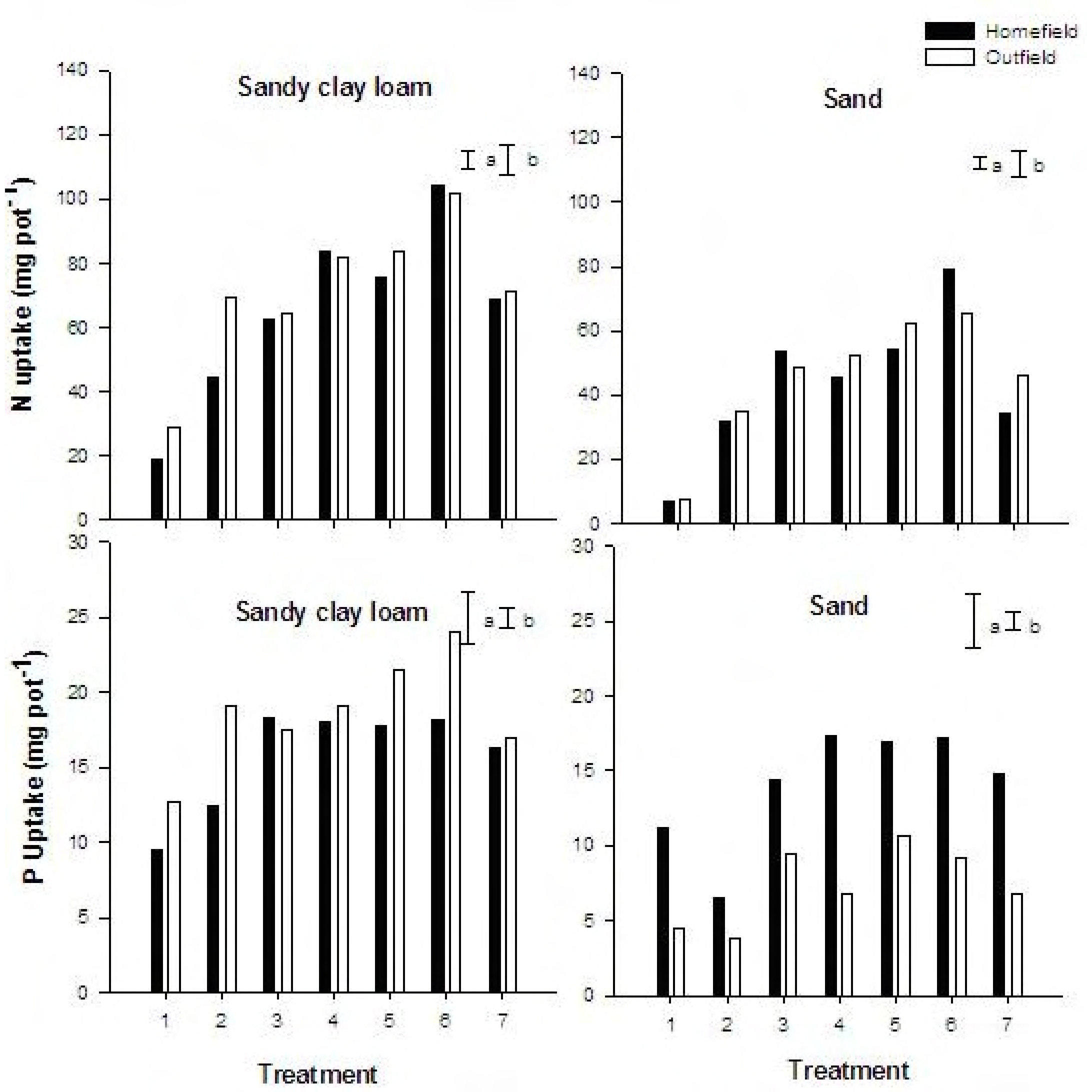


**Figure 4** Total N and P uptake as affected by soil and field type and nutrient application. Bars represent standard error of the mean for factors (a) treatment and (b) field type.

Nutrient concentrations in maize shoots were generally adequate across soil type and field types, except for N which was below the 3% critical limit across all treatments, soil types and field types (Tables 5 and 6). Phosphorus was adequate to high in both soil and field types, but was generally higher in the homefield of the sandy soil compared to the outfield (Table 6).

## Discussion

The significant differences in soil N, SOC and available P across farmer wealth classes (Figure 1) implied that the ability of farmers to invest in soil fertility was a function of resources available to the farmers. SOC is the most important indicator of soil fertility and sustainability of cropping systems (Reeves, 1997; Manlay *et al.*, 2007) while N and P are the major nutrients limiting crop production in most of southern Africa (Nyamangara *et al.*, 2000; Snapp, 1998). The observed decrease in SOC, total N and available soil P in soils with decreasing farmer resource-endowment has been reported under sub-humid conditions (Mtambanengwe & Mapfumo, 2005; Zingore *et al.*, 2007) and attributed to differences in the nutrient resources available to the different classes of farmers. As the poorer farmers add little or no fertility resources to their soils, fertility is likely to decrease more rapidly within a few years of continuous cultivation on Kalahari sands (Zingore *et al.*, 2005). Resource-endowed farmers often have access to livestock manure and other resources to purchase mineral fertiliser.

Although not significant, soil fertility was higher in outfields compared to homefields, a reversal was what has widely been reported in sub-humid zones (Tittonell *et al.*, 2005; Mtambanengwe & Mapfumo, 2005, Vanlauwe *et al.*, 2006; Zingore *et al.*, 2007). In the study area, population density is relatively low (16.3 persons per km$^2$) and land for expansion is readily available (Miombo forest). As such, farmers quickly open up new fields further away from the homestead once fertility has declined (Mapedza *et al.*, 2003).

Consequently, soil fertility in the relatively new outfields will be higher than the old homefields which are continually cultivated. Masvaya (2007) reported that farmers in the area did not target particular fields for cotton production, and therefore both home- and outfields benefited from the relatively higher fertiliser rates applied to cotton compared to other crops. The lack of significant differences in fertility of the two field types was attributed to the poor physical protection of organic matter (source of nutrients) due to very low inherent clay content of Kalahari sands (Feller & Beare, 1997). It may also be attributed to the relatively short period fields in the area had been under production (< 16 years) (Masvaya, 2007). However a similar trend of increasing soil fertility from homefields to outfields has also been reported in the East African Highlands in Ethiopia (Haileslassie, *et al.*, 2007). Therefore agro-ecology and farming system are also important, in addition to farmer resource endowment and socio-economic conditions, in order to understand soil fertility spatial variability in the smallholder areas of sub-Saharan Africa.

**Table 5** Nutrient concentrations of maize plants grown on sandy clay loam soils of Gokwe South with different combinations of macro and micronutrients at 5 weeks after planting of greenhouse pot experiments

| | Treatment | N (%) | P (%) | Ca (%) | Mg (%) | Zn (mg kg$^{-1}$) | Fe (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| Homefield | Control | 0.99 | 0.43 | 0.82 | 0.31 | 36 | 481 | 42 | 15 |
| | N | 1.69 | 0.45 | 1.02 | 0.42 | 28 | 296 | 47 | 10 |
| | N+P | 1.59 | 0.45 | 0.93 | 0.40 | 21 | 340 | 68 | 15 |
| | N+P+Ca | 2.13 | 0.42 | 1.03 | 0.40 | 26 | 242 | 327 | 15 |
| | N+P+Ca+Mg | 1.80 | 0.43 | 0.94 | 0.40 | 31 | 471 | 57 | 14 |
| | N+P+Ca+Mg+Micronutrients | 2.27 | 0.42 | 0.93 | 0.38 | 24 | 614 | 66 | 14 |
| | N+P+Micronutrients+Calcitic lime | 1.78 | 0.41 | 0.93 | 0.37 | 21 | 352 | 41 | 13 |
| SE Mean | | 0.16 | 0.01 | 0.03 | 0.01 | 2 | 49 | 39 | 1 |
| Outfield | Control | 1.00 | 0.48 | 0.93 | 0.33 | 23 | 294 | 61 | 11 |
| | N | 1.74 | 0.47 | 0.88 | 0.46 | 31 | 397 | 79 | 11 |
| | N+P | 1.62 | 0.42 | 0.93 | 0.50 | 19 | 224 | 58 | 12 |
| | N+P+Ca | 2.02 | 0.45 | 1.08 | 0.57 | 30 | 464 | 68 | 15 |
| | N+P+Ca+Mg | 1.93 | 0.47 | 1.02 | 0.55 | 26 | 277 | 63 | 15 |
| | N+P+Ca+Mg+Micronutrients | 1.93 | 0.43 | 0.94 | 0.50 | 33 | 289 | 55 | 15 |
| | N+P+Micronutrients+Calcitic lime | 2.11 | 0.48 | 0.92 | 0.55 | 28 | 350 | 54 | 17 |
| SE Mean | | 0.14 | 0.01 | 0.03 | 0.03 | 2 | 31 | 3 | 1 |

Uptake of N and P by maize as indicated by cobleaf content also decreased with decreasing resource-endowment (Figure 2) indicating that farmer-induced spatial variability in soil fertility had a significant impact on nutrient uptake and ultimately crop productivity. However, cobleaf N and P contents were higher in homefields compared to outfields, yet soil fertility (N, P and OC) was higher in the latter. Cobleaf nutrient status assessed according to Mengel and Kirby (2001) indicated that N and P were deficient to low, implying that growth response was expected if these nutrients were applied to the soil. However, in Njelele and Nemangwe smallholder areas, a semi-arid zone, soil moisture is the most limiting factor.

In the SCL soil, the highest growth response occurred when N was added followed by a further but smaller increase after addition of secondary and micronutrients, but the latter only in the outfield (Figure 3), indicating that these were more limiting to plant growth. In the sandy soil, N and P were most limiting and responses being more positive in the homefield. This study also showed that sandy outfields responded to Mg addition (Figure 3). Therefore, in addition to soil type, farmer-induced soil fertility gradients will determine the effectiveness of fertiliser recommendations. Thus the agro-ecology-based fertiliser recommendations currently used in Zimbabwe (Nyamangara *et al.* 2000) can be made more effective by incorporating farmer resource endowment as the latter has a significant effect on soil fertility and hence crop response to fertilisation. Lack of incorporation of farmer resource-endowment and field type may explain the low adoption of fertiliser recommendations by smallholder farmers country-wide (Ahmed *et al.*, 1997).

**Table 6** Nutrient concentrations of maize plants grown on sandy soils of Gokwe South with different combination of macro and micronutrients at 5 weeks after planting of greenhouse pot experiments

| | Treatment | N (%) | P (%) | Ca (%) | Mg (%) | Zn (mg kg$^{-1}$) | Fe (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| (Homefield) | Control | 0.97 | 0.61 | 0.86 | 0.32 | 33 | 128 | 83 | 14 |
| | N | 1.44 | 0.37 | 0.93 | 0.42 | 26 | 152 | 83 | 16 |
| | N+P | 1.65 | 0.51 | 0.82 | 0.35 | 20 | 172 | 67 | 11 |
| | N+P+Ca | 1.48 | 0.54 | 0.92 | 0.34 | 19 | 244 | 72 | 12 |
| | N+P+Ca+Mg | 1.59 | 0.49 | 1.00 | 0.42 | 35 | 181 | 68 | 12 |
| | N+P+Ca+Mg+Micronutrients | 2.21 | 0.49 | 0.95 | 0.35 | 31 | 173 | 97 | 13 |
| | N+P+Micronutrients+Calcitic lime | 1.09 | 0.47 | 1.12 | 0.40 | 30 | 271 | 105 | 13 |
| SE Mean | | 0.15 | 0.027 | 0.037 | 0.02 | 2 | 19 | 5 | 1 |
| (Outfield) | Control | 1.06 | 0.48 | 0.91 | 0.54 | 32 | 134 | 110 | 20 |
| | N | 3.45 | 0.35 | 1.22 | 0.70 | 44 | 629 | 411 | 18 |
| | N+P | 1.96 | 0.37 | 1.05 | 0.79 | 33 | 184 | 289 | 15 |
| | N+P+Ca | 2.29 | 0.29 | 1.17 | 0.90 | 45 | 165 | 350 | 13 |
| | N+P+Ca+Mg | 2.01 | 0.34 | 0.95 | 0.70 | 32 | 332 | 373 | 13 |
| | N+P+Ca+Mg+Micronutrients | 2.42 | 0.33 | 0.95 | 0.68 | 61 | 242 | 545 | 13 |
| | N+P+Micronutrients+Calcitic lime | 1.75 | 0.24 | 1.22 | 0.92 | 51 | 179 | 94 | 15 |
| SE Mean | | 0.28 | 0.03 | 0.05 | 0.05 | 4 | 65 | 61 | 1 |

## Conclusions

The field study indicated that soil fertility varied significantly according to farmers' resource endowment as shown by higher maize cob-leaf N and P uptake in fields of wealthier farmers (RG1) compared to those belonging to poorer farmers (RG2 and RG3). In the field, although soil organic C, total N and available P tended to be higher in outfields, maize N and P uptake was higher in homefields. Greenhouse studies showed that in sandy clay soils highest maize growth response occurred in outfields when N was applied. In sandy soils highest maize growth response also occurred when N was added but only in homefields, and in outfields highest growth response was achieved when both N and P were added indicating a higher P deficiency compared to sandy clays soils. In both sandy and sandy clay soils, a further but smaller increase occurred when micronutrients were added in combination with P, Ca and Mg indicating the importance of balanced nutrient fertilisation in both soil types. It was concluded that farmer-resource endowment induced soil fertility gradients across arable fields which are large enough to affect crop response to fertilisation and therefore should be considered in the development of fertiliser recommendations for use smallholder farming areas.

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