Base Nutrient Dynamics and Productivity of Sandy Soils Under Maize-Pigeonpea Rotational Systems in Zimbabwe

Mapfumo, P.* and Mtambanengwe, F.

Department of Soil Science and Agricultural Engineering,
University of Zimbabwe, P.O. Box MP 167, Mount Pleasant,
Harare

*Corresponding Author: pmapfumo@agric.uz.ac.zw

Abstract

A two-year study was conducted in a smallholder farming area in northeast Zimbabwe to determine the rotational effects of pigeonpea (*Cajanus cajan* L. Millsp.) of different maturity genotypes on maize (*Zea mays* L.) yields. Researcher and farmer-managed on-farm rotation experiments were established on ten sites in farmers' fields, with a long history of maize monocropping. A maize crop receiving different rates of mineral N fertilizer followed long, medium and short duration pigeonpea genotypes plus control maize. Relationships between N management factors and nutrient uptake by maize under the three pigeonpea genotypes were examined in light of the current soil fertility management practices by the farmers. Significant ($p<0.05$)

maize yield responses were obtained after pigeonpea despite low productivity of these legumes at all sites. Relative to the control, medium and long duration pigeonpea treatments resulted in maize yield increases of 46% to 37% for biomass and 20% to 28% for grain, respectively, while there was a 6-19% decrease in yield after short-duration pigeonpea. The low N contributions from pigeonpea, which ranged from 6-18 kg N ha^{-1} could not account for the observed yield responses. Yields across all treatments increased with increasing mineral N application. Maize tissue analyses at 6 and 15 weeks after emergence (WAE), showed significant increases in P, K, Ca and Mg uptake. Regression analysis showed highly significant ($P<0.001$) linear relationships between N uptake and Mg ($R^2 = 0.74$; DF = 78), Ca ($R^2 = 0.62$; DF = 78) and K ($R^2 = 0.53$; DF = 78) uptake. Based on multiple regression models, N and Mg uptake accounted for most of the maize grain yield increases observed. Because of the low N contributions from pigeonpea, increases in maize yields were largely attributed to improved availability of base nutrients, particularly Mg. Pronounced maize yield responses to mineral N observed under pigeonpea systems, were likely due to increased N use efficiency.

We concluded that the residual benefits of pigeonpea in these cropping systems are largely due to their capacity to remobilize and recycle base nutrients, and that the productivity potential of granitic sandy soils is undermined by continued depletion of these cations under current management practices.

Introduction

Positive residual effects of N_2-fixing legumes on subsequent cereals in rotations have been widely reported in both olden and modern agriculture (Giller and Wilson, 1991; Kumwenda *et al.*, 1995; Peoples *et al.*, 1995). The yield increases have been primarily attributed to an improvement in N economy of the soils. However, beneficial effects may also arise from breaks in disease and pest cycles, changes in soil microbial and faunal activity, and chemical and physical attributes (Peoples and Craswell, 1992), although these factors have seldom been quantified. In order to optimize the ecological contribution of legumes in low-input agricultural systems, it is imperative that the differential effects of these factors are clearly understood and the benefits due to their interaction quantified. This is particularly important in tropical savanna agro ecosystems in which soil nutrient stocks are inherently low.

Studies on the predominantly sandy soils of Southern Africa have shown the complexity of soil fertility problems on smallholder farms and the challenges in developing sustainable management options (Scoones *et al.*, 1996; Scoones, 1998; Snapp *et al.*, 1998; Giller, 2001). There are slim chances of building soil organic matter and hence nutrient stocks (Giller *et al.*, 1997), rendering farmers to rely heavily on external nutrient inputs on a seasonal basis. However, most of the smallholder farmers use sub-optimal amounts of fertilizers due to cash limitations and poor access to fertilizer markets (Kumwenda *et al.*, 1995; Ahmed *et al.*, 1996). This, therefore, calls for increased efficiency in use and recycling of both exogenous and endogenous nutrient pools in the cropping systems. Although problems of multiple nutrient deficiency are often apparent under most continuously cropped soils (Grant, 1981; Mukurumbira and Nemasasi, 1998), little has been done to determine the influence of the various soil fertility technologies on availability of nutrients such as K, Mg and Ca. In this study, we examined the residual effect of pigeonpea (*Cajanus cajan* (L.) Millsp.) cropping has on maize (*Zea mays* L.) yields on a sandy soil in Zimbabwe, with particular attention on N, P, K, Mg and Ca uptake.

Pigeon pea, a relatively new crop in Zimbabwe, was chosen for its ability to grow on relatively infertile soils, and tolerance to drought and other environmental stress (Whiteman *et al.*, 1985; van der Maesen, 1990).

Study site

The study was conducted in Murewa Communal Area, 130 km north east of Harare (17°45'S and 31°31'E). The area has a unimodal rainfall pattern, receiving an average of 750-1000 mm annually, between November and March and is about 1300 m above sea level. The mean annual temperature is 22°C. Soils are predominantly Lixisols (FAO Classification), derived from granitic parent material. Because of intensive agricultural activity and population pressure, most of the natural *Julbernardia globiflora* and *Brachystegia spiciformis* (miombo) tree vegetation has disappeared.

Materials and Methods

The experiment was conducted for two seasons on 10 farm sites, with each farm site considered as a replicate. All sites had been under maize monocropping with no manure application for at least five years. Soil samples were taken from 0-20 cm depths for physical and chemical analysis, at the beginning of each growing season. Three pigeonpea maturity types, namely short (cv. ICPL 87109 – 90 days to maturity), medium (cv. ICP 9145 – 150 5ays), long duration (cv. Ex-Marondera – 180 days), were grown during season one. Maize (cv. SC 501) was included as a fourth treatment to serve as a control in season two. Each plot measured 18 m x 4.5 m in gross area. Pigeonpea was spaced at 0.9 m between rows and 0.2 m within rows while maize was spaced at 0.9 m x 0.3 m. Land preparation was done by farmers using an ox-drawn plough. The pigeonpea received 12.5 kg P ha^{-1} and 18 kg S ha^{-1} in form of single superphosphate (SSP) incorporated just before planting. The maize received a basal dressing of Compound D at 200 kg ha^{-1} (16.0 kg N ha^{-1}; 12.4 kg P ha^{-1}; 11.6 kg K ha^{-1} and 13 kg S ha^{-1}), and was top-dressed with ammonium nitrate at 63.8 kg N ha^{-1}. The short duration pigeonpea was harvested for grain at 101 days after planting (DAP) and residues retained in the field for incorporation. The medium and long duration pigeonpea were incorporated as green manure at flowering at the request of farmers who feared interference from livestock. An ox-drawn plough was used for incorporation. For each pigeonpea cultivar, a net plot of 17 m x 2.7 m was harvested to determine fresh shoot biomass before incorporation. Sub-samples of three whole plants each were taken in replicates for moisture correction and quality analysis. Maize harvesting was done at physiological maturity. The samples were oven-dried at 60°C to constant mass, for dry matter measurements. Dried samples were ground and passed through a 1 mm sieve in a Wiley Mill. Total C, N, lignin and polyphenol contents were determined using methods described by Anderson and Ingram (1993).

In the second season, all plots were planted with maize. The crop was given a basal P, K and S fertilizer dressing in form of Compound D as described above for year one. However, each of the season one plot was divided into two, with one half receiving no mineral N application and the other getting 60 kg N ha^{-1} in form of ammonium nitrate. This gave rise to a split plot design, with the different rotation treatments (pigeonpea maturity types + maize control), providing for main plots and the two N fertilizer rates as subplots. The N was split applied, with 30 percent being applied at 2 WAE, 50% at 6 WAE and other 20% at 9 WAE. Three randomly selected plants were taken for biomass estimates at 2, 6 and 15 WAE. At each sampling time, the biomass was analyzed for N, P, K, Mg and Ca uptake. Individual farmers did the weeding whenever it was necessary. Grain yield was determined from a net plot of 4 m x 2.7 m and measured at 12.5% moisture content.

Pigeonpea productivity was also determined in the second season by planting the three maturity types on areas adjacent to the season one plots. All the areas had been put under maize by farmers in the previous season and the plots measured 4.5 m x 5 m. Shoot biomass were determined at flowering and physiological maturity by destructive sampling from a 1.8 m^2 area. At maturity, cumulative litter was handpicked from the sampled area and quantified for dry matter. The plant shoot samples were analyzed for total C, N, lignin and polyphenol content as described above. An area measuring 4 m^2 was harvested for grain yield determination.

All soils were analysed using methods given by Anderson and Ingram (1993). Organic C was determined using a modified Wakley-Black method while the resin method was used to measure available P. Ammonium and nitrate N were determined using the indophenol and cadmium-reduction methods respectively, with the N measured colourimetrically. Soil exchangeable K was determined by flame photometry and Mg and Ca by atomic absorption spectrophotometry following leaching of soil with ammonium acetate.

Treatment differences were tested using ANOVA and treatment means compared by LSD at $P<0.05$. Linear and multiple regression analyses were used to determine the relationships between maize yields and nutrient uptake.

Soil properties

All the farm sites used in the study were low in major plant nutrients, especially N and P (Table 16.1).

Table 16.1: Soil characteristics for the ten farm sites used for a pigeonpea study in Murewa Communal Area, Zimbabwe

Site	Clay (%)	Sand (%)	pH ($CaCl_2$)	Avail. N (ppm)	Resin P(ppm)	Organic C (%	Total N (%)	K (cmolc-kg^{-1})	Ca (cmolc-kg^{-1})	Mg (cmolc-kg^{-1})
Mukarakate	4	89	4.2	17	8	0.26	0.02	0.07	0.39	0.15
Shangwa	4	90	4.3	30	2	0.35	0.02	0.09	0.68	0.35
Gutu	4	92	4.1	17	6	0.28	0.01	0.06	0.52	0.21
Chikurunhe	3	92	4.6	34	10	0.23	0.02	0.06	0.96	0.30
Chawanda	4	86	4.4	26	3	0.40	0.02	0.07	1.19	0.40
Marume	5	88	4.2	27	2	0.24	0.02	0.06	0.60	0.20
Chiroodza T	9	82	4.5	31	2	0.44	0.01	0.14	1.39	0.59
Chiroodza M	6	90	4.6	18	11	0.32	0.02	0.08	2.06	0.75
Chamboko	9	86	4.4	27	4	0.47	0.02	0.13	0.94	0.26
Chituwu	6	92	4.2	16	8	0.32	0.02	0.10	0.85	0.30

Clay content ranged from 3 to 9%. Available P ranged from 2 to 11 mg kg^{-1}, while N ranged from 17 to 34 mg kg^{-1} soil. The soils were strongly acidic and had a mean organic C of 0.33% (Table 16.1).

Pigeonpea productivity and quality attributes

Pigeonpea biomass yields recorded during the season one were highly variable across the different farm sites. The yields ranged from 264 kg ha^{-1} for the short duration type to 1104 kg ha^{-1} for the long duration type. High variability was partly due to excessive rainfall, as severe waterlogging was experienced in some of the farms. The yields for Short-duration pigeonpea yields are likely to have been undermined by the relatively low plant population used. Maize biomass and grain yields in control maize plots averaged 2856 and 450 kg ha^{-1} respectively. The long duration pigeonpea yielded 1.5 times more biomass than the medium duration variety (Table 16.2).

Table 16.2: Biomass yields and resource quality characteristics for pigeonpea of different maturity types (at flowering) grown on poor sandy soils in Murewa Communal Area, Zimbabwe

Parameter	Cultivar /duration		
	ICPL 87109 (short)	ICP 9145 (medium) (medium)	Ex-Marondera (long)
Season 1			
*biomass (kg ha^{-1})	264 (95)	733 (251)	1104 (302)
Shoot N (kg ha^{-1})	6 (2)	13 (5)	18 (5)
N (%)	2.35 (0.05)	1.78 (0.08)	1.65 (0.07)
C (%)	43 (0.5)	44 (0.2)	44 (0.5)
C:N	18 (0.4)	25 (1.2)	27 (1.3)
Polyphenols	2.8 (0.04)	2.8 (0.05)	3.3 (0.05)
Lignin	10.7 (0.3)	13.2 (0.6)	12.7 (0.4)
Season 2			
*biomass (kg ha^{-1})	1884 (259)	6071 (721)	7619 (900)
Shoot N (kg ha^{-1})	46 (7)	130 (16)	157 (19)
N (%)	2.48 (0.05)	2.20 (0.10)	2.16 (0.08)
C (%)	43 (0.4)	43 (0.6)	44 (0.5)
C:N	17 (0.3)	20 (0.9)	20 (0.8)
Polyphenols	2.2 (0.04)	2.4 (0.04)	3.3 (0.03)
Lignin	11.2 (0.2)	10.8 (0.4)	13.0 (0.6)

*biomass = shoot biomass determined at flowering; Numbers in parentheses indicate standard errors

Because of poor biomass yields and low shoot N concentration, the total N produced by all the pigeonpea types were low. In season two, pigeonpea yields were about 6-8 times more than those obtained in season one, partly due to a favourable rainfall pattern. The long duration genotype, Ex-Marondera, gave four times more biomass than the short duration variety at flowering stage (Table 16.2). Potential N contribution to soil, as measured at flowering stage, ranged from 46 kg ha^{-1} for the short duration to 150 kg ha^{-1} for the long duration type. There was only a small increase in biomass between flowering and maturity stages due to terminal drought (Table 16.3). There was also a rapid increase in litterfall between the two growth stages.

Table 16.3: Biomass (at physiological maturity) and grain yields for pigeonpea of different maturity types grown on a sandy soil in Murewa Communal Area, Zimbabwe

Pigeonpea Maturity Type	Biomass (kg ha^{-1})	Litterfall (kg ha^{-1})	Grain Yield (kg ha^{-1})
Short (ICPL 87109)	1939 (263)	112 (±13)	725 (±68)
Medium (ICP 9145)	6436 (701)	745 (±108)	284 (±28)
Long (Ex-Marondera)	8106 (879)	994 (±131)	391 (±67)

*Numbers in parentheses indicate standard errors.

Although most of the litterfall was observed to occur soon after maturity, this could not be quantified due to disturbances of plots by livestock. The terminal drought also contributed to poor grain yields by the medium and late pigeonpea (Table 16.3). Grain filling was apparently more affected by moisture stress than pod set.

Residual effects of pigeonpea on yields of subsequent maize

An analysis of variance on grain yield and biomass yields at 2, 6 and 15 WAE, showed significant ($P<0.05$) rotation and mineral N fertilizer effects. There was no significant interaction between rotation and mineral N fertilizer. The medium and long duration pigeonpea gave rise to significantly higher maize yields compared with the maize-maize control and short duration pigeonpea (Table 16.4).

Table 16.4: Maize biomass at 2, 6 and 15 weeks after emergence, and grain yields obtained following pigeonpea of different maturity types grown under two mineral N fertilizer rates on sandy soils in Murewa Communal Area, Zimbabwe

Pigeonpea rotation/ mineral N fertilizer	Biomass (kg ha^{-1})			Grain (kg ha^{-1})
Maturity Type	2 WAE	6 WAE	15 WAE	
Short (ICPL 87109)	49^{ab}	717^{a}	3015^{a}	733^{a}
Medium (ICP 9145)	70^{c}	1064^{bc}	4690^{b}	1156^{b}
Long (Ex-Marondera)	$59b^{c}$	1069^{b}	4442^{b}	1229^{b}
Maize control (SC 501)	45^{a}	803^{ac}	3203^{a}	962^{ab}
SED	6	129	526	173
Fertilizer Level				
0 (kg N ha^{-1})	nd	709^{a}	2499^{a}	615^{a}
60 (kg N ha^{-1})	nd	1118^{b}	5176^{b}	1425^{b}
SED	nd	57	290	125

Numbers in the same column followed by the same letter are not significantly different; WAE = weeks after maize emergence; nd = not determined

At all harvesting stages, there were no significant differences in yield between short duration pigeonpea and maize-maize control plots, although the latter gave numerically higher yields at 6 and 15 WAE.

The maize grown after medium and long duration pigeonpea treatments yielded 46% and 37% more biomass, respectively, relative to the control. Similarly, there was 20% and 28% more grain under the two treatments, respectively. Mineral N fertilizer had a highly significant effect on maize yields, with yield increase ranging from 58% for biomass at 6 WAE to 132% for grain relative to the unfertilized treatments (Table 16.4). Without mineral N fertilizer application, the maize grain yields ranged from 427 kg ha^{-1} after short duration pigeonpea to 779 kg ha^{-1} after the long duration genotype. Grain yield for the control maize was 530 kg ha^{-1}.

Effect of pigeonpea cropping on soil N availability and maize nutrient uptake

Rotation treatments had no significant ($P<0.05$) effect on N and P uptake at 2 WAE, while only P and K uptake were influenced by the rotation systems at 6 WAE. While P, Ca and Mg uptake were significantly increased by mineral N fertilizer application at this stage, N and K uptake were not affected (Table 16.5).

Table 16.5: Rotational effects of pigeonpea of different maturity types on maize nutrient uptake under a sandy soil in Murewa Communal Area, Zimbabwe

Rotation system / N level	Nutrient (kg ha^{-1}) /sampling stage (WAE)									
	N		P		K		Ca		Mg	
	6	15	6	15	6	15	6	15	6	15
Maturity Type										
Short	18	22^{a}	0.2^{a}	0.7	16^{ab}	14^{a}	3	5^{a}	1	2^{a}
Medium	17	38^{b}	0.3^{b}	0.9	15^{ab}	30^{b}	4	8^{b}	2	4^{b}
Long	16	37^{b}	0.3^{b}	0.9	23^{a}	24^{ab}	4	8^{b}	2	4^{b}
Maize control	13	24^{a}	0.2^{a}	0.6	9^{a}	15^{a}	4	5^{a}	1	2^{a}
SED	ns	4	0.02	ns	6	5	ns	0.5	ns	1.4
Fertilizer Level										
0 (kg N ha^{-1})	19	18^{a}	0.2^{a}	0.5^{a}	13	12^{a}	2	4^{a}	1	2^{a}
60 (kg N ha^{-1})	18	43^{b}	0.3^{b}	1.1^{b}	19	29^{b}	4	9^{b}	2	4^{b}
SED	ns	3	0.01	0.07	ns	4	0.5	1	0.2	0.3

Short duration = variety ICPL 87109; medium duration = ICP 9145; Long duration = Ex-Marondera; Maize = cv. SC 501. WAE = weeks after maize emergence. Numbers in the same column followed by the same letter are not significantly different at $P<0.05$.

There was a 50% increase in P uptake after medium and long duration pigeonpea, relative to the control maize. Although maize yield after short duration pigeonpea was generally lower than that of the control, this treatment resulted in a 90% increase in K uptake (Table 16.5). Unlike early in the maize growth stages, both rotation systems and mineral N had a highly significant effect on uptake of all the measured nutrients at 15 WAE.

In general, there were no significant ($P<0.05$) differences in nutrient uptake between the medium and long duration pigeonpea rotation systems and between the control and the short duration. Regression analyses showed highly significant ($P<0.001$) linear relationships between N uptake and Mg ($R^2 = 0.74$; DF = 78), Ca ($R^2 = 0.62$; DF = 78), and K ($R^2 = 0.53$; DF = 78) uptake. Uptake of these nutrients increased with increased N application rates and uptake. There were significant ($P<0.05$) relationships between maize grain yield and nutrient uptake, particularly N and Mg (Table 16.6).

Table 16.6: Linear relationships between maize grain yield and nutrient uptake rotated with pigeonpea of different maturity types on sandy soils in Zimbabwe

Regression equation	DF	R^2	P-level
Y (Grain yield) = 34 X (total N uptake)	78	0.76	0.001
Grain yield = 1429 (total P uptake)	78	0.57	0.001
Grain yield = 131 + 34 (total K uptake)	78	0.55	0.001
Grain yield = 256 + 117 (total Ca uptake)	78	0.44	0.001
Grain yield = 313 (total Mg uptake)	78	0.75	0.001

Discussion

Pigeonpea productivity under poor soil fertility

Low pigeonpea biomass yields during the first season was mainly attributed to waterlogging and poor soil fertility of the soils at the study sites. Waterlogging occurred during the early vegetative phase. This could have interfered with N_2-fixation resulting in poor N nutrition and hence growth of the plants (Mapfumo *et al.*, 1999). Because of their relatively long growth duration, the medium and long maturity pigeonpea were able to recover from the adverse effects of excessive soil moisture resulting in relatively high yields. Wide plant spacing could also have contributed to low biomass for short duration pigeonpea. While the high biomass yields obtained in the second season strongly indicated pigeonpea tolerance to poor soil fertility, the results also suggest that there could be significant interactions between soil moisture and crop nutrition under sandy soils. According to Grant (1981), soil acidity may contribute to soil infertility in high rainfall areas. About 50% of the farm sites used in this study had a pH of 4.3 ($CaCl_2$), a value considered critically low for most crops, particularly legumes (Grant, 1981). Liming is a possible solution in a number of communal areas including Murewa (Dhliwayo et al., 1998). However, the dynamics of soil acidity under different soil moisture regimes in sandy soils in Zimbabwe is not well understood.

Low grain yields found for the medium and long duration pigeonpea were indicative of problems likely to be encountered by farmers in regenerating seed. Although pigeonpea was able to sustain growth on residual moisture, the soil moisture reserves were apparently not sufficient to promote grain filling. Because of the poor water-holding capacity of sandy soils, there is usually a rapid soil moisture decline soon after the end of the rainy season (Mapfumo, 1995). Terminal drought has been reported as a major constraint to grain production in long duration pigeonpea (Whiteman *et al*., 1985; ICRISAT, 1993). This may be a disincentive for farmers whose primary interest is grain production. The short duration type may be attractive to farmers in that respect. There is need to identify germplasm of appropriate maturity types to minimize terminal drought effects while ensuring optimum biomass accumulation.

Rotational effects on subsequent maize

Because of the low levels of pigeonpea biomass produced during season one, the potential N contribution to the cropping system was low despite the high quality of the incorporated biomass. Only 6-18 kg N ha^{-1} could be added to the system from pigeonpea shoots. Given that only 20% of this N was likely to be taken up in maize (Palm, 1995; Palm *et al*., 1997), it was therefore highly likely that the observed treatment differences were due to rotational effects other than N. While there were significant treatment effects on maize biomass yield at 6 WAE, both rotation systems and mineral N did not significantly affect N uptake during the same period. This further suggests that N *per se* had no significant effect on early maize development.

During the same period (6 WAE), P, K and Ca uptake were significantly higher under medium and long duration pigeonpea rotations than under the other two treatments. The yield increases may, therefore, be partly attributable to the increased availability of these nutrients after pigeonpea.

Rotation and mineral N effects on maize N uptake only became significant at crop maturity. This could have been due to increased nutrient use efficiency (NUE) under the pigeonpea treatments between

6 and 9 WAE. In sandy soils of the Sahel region, there was a 20% NUE, under pearl millet monocropping compared with 28% after a cowpea rotation (Bationo *et al.*, 1991; Bationo and Vlek, 1997). The results in this study also showed a highly significant linear relationship between maize grain yield and Mg uptake, suggesting that Mg may be a major limiting nutrient for maize production in these sandy soils. Magnesium uptake was also linearly related to N uptake, suggesting that increased use of mineral N fertilizers in maize monocropping may accelerate Mg depletion in sandy soils. Magnesium deficiency on continuously cropped sandy soils has been historically reported from smallholder farms in Southern Africa (Grant, 1981). Application of pigeonpea residues did not only improve Mg nutrition, but also increased P, K and Ca uptake. Although it may be difficult to account for the observed yield depression under short duration pigeonpea based on our limited results, it is likely that low potential of the short duration pigeonpea to remobilize and recycle these nutrients was a factor. The genotype may therefore not be suitable for soil fertility enhancement on sandy soils.

Practical significance of rotational benefits and pigeonpea productivity on-farm

Maize grain yields of about 1000 kg ha^{-1} obtained after pigeonpea, may fall short of farmers' expectations despite their statistical significance. Currently, most successful farmers achieve high yields (about 3000 kg ha^{-1}), by applying more than the recommended rates of mineral N (Mapfumo and Mtambanengwe, 1999). Athough there is little documentation on the economics of such production systems, low N use efficiency may be eroding profits. Pigeonpea rotations, may help to improve NUE and increase the yield potential of the cropping system through remobilization and cycling of other nutrients such as Mg, Ca and K. Our limited results indicate that there is merit in directing our focus on non-N benefits of organic resources, particularly the influence on availability of base nutrients, which may be undermining the productivity of sandy soils even in cases where N becomes available. The productivity potential of the granitic sandy soils in Southern Africa might be declining due to base nutrient depletion.

Acknowledgements

Funding for this study was provided by the European Union through the Institute of Enviromental Studies of the University of Zimbambwe.

References

Ahmed, M. M., Rohrbach D. D., Gono L. T., Mazhangara E. P., Mugwira L., Masendeke D. D. and Alibaba S. (1996) Soil Fertility Management in the Communal Areas of Zimbabwe: Current Practices, Constraints and Opportunities for Changes. Results of a diagnostic survey. Southern and Eastern Africa Regional Paper number 6. ICRISAT-Southern and Eastern Africa Region. 27 pp.

Anderson, J.M. and Ingram, J.S.I. (1993) Tropical Soil Biology and Fertility: A handbook of Methods. Second Edition. C. A. B. International. Wallington, UK. 221pp.

Bationo, A., Ndunguru, B.J., Ntare, B.R., Christianson, C.B. and Mokwunye, A.U. (1991) Fertilizer management strategies for legume-based cropping systems in the West African Semi-Arid Tropics. In: Johansen, C., Lee, K.K., Sahwat K.L (eds.), *Phosphorus Nutrition of Grain Legumes in the Semi-arid Tropics*. ICRISAT, 1991. Patancheru, A.P. 502 324, India:ICRISAT.

Bationo, A. and Vlek, P.L.G. (1991) The role of mitrogen fertilizers applied to food crops in the Sudano-Sahelian zone of West Africa. In: Renard, G., Neef, A., Becker, K., and von Oppen, M. (eds.). *Soil fertility management in West African land use systems*. Wekersheim, Germany: Margraf Verlag. pp. 437–444.

Dhliwayo, D.K.C., Sithole, T. and Nemasase, H. (1998) Soil acidity - Is it a problem in Zimbabwe? In: Waddington, S.R., Murwira, H.K. Kumwenda J.D.T., Hikwa D., Tagwira F. (eds.), *Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe*. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe. pp. 217-221

Giller, K.E. (2001) Targeting management of organic resources and mineral fertilizers: Can we match scientists' fantasies with farmers' realities? In: Vanlauwe, B., Sanginga, N., Diels, J., Merckx, R. (eds.), *Balanced Nutrient Management Systems for the Moist Savanna and Humid Forest Zones of Africa*. CAB International, Wallingford. pp. 155 -168.

Giller, K.E. and Wilson, K.J. (1991)*Nitrogen Fixation in Tropical Cropping Systems*. CAB International, Wallingford, UK. 313 pp.

Giller, K.E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W.D. and Mafongoya, P.L. (1997) Building soil nitrogen capital in Africa. In: Buresh, R.J., Sanchez, P.A. (eds.), *Replenishing Soil Retility in Africa*. SSSA Special Publication 51. SSSA, Madison, WI, USA. pp. 151-192.

Grant, P. M., (1981) The fertilization of sandy soils in peasant agriculture. *Zim. Agric. J.* 78(5):169-175.

ICRISAT, (1993) *Improvement of Pigeonpea in Eastern and Southern Africa*. Biannual Progress Report submitted to African Development Bank. 20 pp.

Kumwenda, J.D.T., Waddington, S.R., Snapp, S.S., Jones, R.B. and Blackie, M.J. (1995) Soil Fertility Management for Smallholder Maize-Based Cropping

Systems of Southern Africa: A Review. Network Working Paper No. 1. *Soil Fertility Network for Maize-Based Cropping Systems in Countries of Southern Africa*. CIMMYT, Harare, Zimbabwe. 34 pp.

Mapfumo, P. (1995) Agronomic and ecological adaptation of Lupinus spp for Communal Area farming systems in Zimbabwe. M. Phil Thesis. Department of Crop Science, University of Zimbabwe.Harare, Zimbabwe. 218 pp.

Mapfumo, P. and Mtambanengwe, F., (1999) Nutrient mining in maize-based systems of rural Zimbabwe. In: CIMMYT and EARO, 1999. *Maize Production Technology for the Future: Challenges and Opportunities*. Proceedings of the Sixth Eastern and Southern Africa Regional Maize Conference, 21-25 September, 1998, Addis Ababa, Ethiopia. pp. 274-277.

Mapfumo, P. Giller, K.E. Mpepereki S. and Mafongoya, P.L. (1999) Dinitrogen fixation by pigeonpea of different maturity types on granitic sandy soils in Zimbabwe. *Symbiosis* 27:305-318.

Mtambanengwe, F. and Kirchmann, H. (1995) Litter from a tropical savanna woodland (Miombo): chemical composition and C and N mineralization. *Soil Biol. Biochem*. 27:1639-1651.

Mukurumbira, L. and Nemasasi, H. (1998) Micronutrients in the maize-based system of the communal areas of Zimbabwe. In: Waddington, S.R. Murwira, H.K. Kumwenda, J.D.T. Hikwa, D. Tagwira F. (eds.), *Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe*. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe. pp. 229-232.

Palm, C.A. (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. *Agrofor. Syst.* 30:105-24.

Palm, C.A., Myers, R.J.K. and Nandwa, S.M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh, R.J. Sanchez, P.A. (eds.), *Replenishing Soil Fertility in Africa*. SSSA Special Publication 51. SSSA, Madison, WI, USA. pp. 193-217.

Peoples, M. B. and Craswell, E.T. (1992) Biological nitrogen fixation: Investments, expectations and actual contributions to agriculture. *Plant and Soil* 141:13-39.

Peoples, M.B., Herridge, D.F. and Ladha, J.K. (1995) Biological nitrogen fixation: An efficient source of nitrogen for sustainable agricultural production. *Plant and Soil* 174:3-28.

Scoones, I. (1998) Investigating soil fertility in Africa: Some reflections from research in Ethiopia and Zimbabwe. In: Bergstrom, L. Kirchmann, H. (eds.), *Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems*. CAB International, Wallingford, UK. pp. 245-259.

Scoones, I., Chibudu, C., Chikura, S., Jeranyama, P., Machaka, D., Machanja, W., Mavedzenge, B., Mombeshora, B., Mudhara, M., Mudziwo, C., Murimbarimba, F., and Zirereza, B. (1996) ha*zards and opportunities. Farming livelihoods in dry land Africa: Lessons from Zimbabwe*. London, UK and New Jersey, USA: Zed Books Ltd, in association with International Institute for Environment and Development (IIED). 267 pp.

Snapp, S.S., Mafongoya, P.L. and Waddington, S. (1998) Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. *Agric. Ecosyst. Environ.* 71:185-200.

van der Maesen, L.J.G. (1990) Pigeonpea: Origin, History, Evolution and Taxonomy. In: Nene, Y.L. hall S.D., Sheila U.K. (eds.), *The Pigeonpea*. C.A.B. International, UK. ICRISAT. pp. 15-46.

Whiteman, P.C., Byth, D.E. and Wallis, F.S. (1985) Pigeonpea (Cajanus cajan L.). In: Summerfield, R.J. and Roberts, E.H. (Eds.), *Grain legume crops*. Collins, London. pp. 658-698.