International Scholars Journals

Advances in Agriculture and Agricultural Sciences ISSN 2381-3911 Vol. 4 (3), pp. 001-008, March, 2018. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Nitrogen budgets in crop sequences with or without phosphorus-fertilised cowpea in the maize-based cropping systems of semi-arid eastern Africa

J. M. Vesterager, N. E. Nielsen and H. Høgh-Jensen*

Department of Agricultural Sciences, Faculty of Life Sciences, University of Copenhagen, Højbakkegaard Alle 9, DK-2630 Taastrup, Denmark.

Accepted 16 January, 2018

Advantages of cowpea were tested in terms of net N-input by cowpea mono- or intercropped with maize in a crop sequence where sparingly soluble P sources were added to the first year crop. The grain yield of maize grown after cowpea monocrop was doubled and the N uptake increased by 60% compared to maize following maize. The N-value of growing cowpea monocropped prior to maize monocrop was equivalent to the application of 50 kg N ha^{-1} as mineral fertiliser. When maize followed a maize-cowpea intercrop, grain yield was increased by 67%. Around 34% of the N contained in cowpea residues was recovered in the following maize as estimated by ^{15}N. There was however no benefit on the second season maize of applying sparingly soluble P sources to the first season legume.

Key words: Cowpea, crop sequences, maize, nitrogen budgets, sparingly soluble phosphorus.

INTRODUCTION

Nitrogen (N) and phosphorus (P) deficiencies are among the major biophysical constraints affecting crop produc-tion in large parts of the sub-Saharan Africa (Buresh et al., 1997; Bationo and Mokwunye, 1991). However, the input of these nutrients via mineral fertilisers remain very low because of various socio-economic, cultural and infrastructure reasons (Nandwa and Bekunda, 1998). In semi-arid environments with limited and erratic rainfall, the investment in fertilisers can be risky because of variable and general low utilization efficiency (Pilbeam et al., 1995; Tobita et al., 1994; Vesterager et al., 2007). Besides, according to farmers' perceptions, the use of fertiliser is associated with a risk of damaging the roots of the young plants in years with low rainfall and dry spells when the fertilisers are applied in the planting hole. Hence, resource-poor farmers are reluctant to take risks associated with the use of fertilisers for crops like maize that are mainly grown to cover the household demand. Under such conditions the role of N_{2-} fixation by legumes like cowpea to improve N-availa-bility and soil fertility maintenance has great potential. Crop sequences where cereals follow legumes often benefit the cereals (Dakora et al., 1987; Peoples and Craswell, 1992; Steiner, 1991). Recent research has shown that legume roots, rhizodeposits (Khan et al., 2002; Rochester et al., 1998; Russell and Fillery, 1996) and residues (Rao and Mathuva, 2000; Vesterager et al., 2007) are important N pools. The positive added effect of legumes on following crops may, apart from N provision, include i) improved control of pest and disease cycles, ii) improved soil physical properties, iii) increased availabi-lity of other nutrients than N, iv) reduction of phytotoxic and allopathic effects of decomposing cereal residues (Karlen et al., 1994). Knowledge is lacking on the effects of crop sequences with legumes interchanging with cer-eals under farmers' conditions. Therefore, there is a need for investigating possible ways for utilizing sparingly solu-ble P sources strategically in the cropping sequences in the common maize/cowpea intercrop systems among smallholder farmers in semi- arid Africa. The aim of this study was to examine the N budgets of crop sequences consisting of maize-maize, cowpea-maize, and maize / cowpea intercrops-maize with different P sources applied

*Corresponding author. E-mail: hhj@life.ku.dk. Tel.: +45 3533 3391.

Table 1. Treatments in the first (1996-97) and the second (1997-98) cropping season. All treatments had four replicates.

Treatments first cropping season		Treatments second cropping season
Maize mono	nil P	Maize
Maize mono	nil P	Maize + 50 kg N as CAN
Cowpea mono	nil P	Maize
Maize/cowpea	nil P	Maize
Maize mono	TSP	Maize
Maize mono	TSP	Maize + 50 kg N as CAN
Cowpea mono	TSP	Maize
Maize/cowpea	nil P	Maize
Maize mono	MRP	Maize
Maize mono	MRP	Maize + 50 kg N as CAN (^{15}N microplot - fertiliser)
Cowpea mono	MRP	Maize (^{15}N microplot - residues)
Maize/cowpea	MRP	Maize

to the first-year crop under farmers' conditions in semi-arid Tanzania. The hypotheses were:

- That a legume-based system would produce maize equivalent to a pure maize cropping system, and
- That sparingly soluble P sources applied to the first-year legume crop would have a residual effect on the second-year maize crop.

MATERIALS AND METHODS

Experimental conditions

The experiment was conducted under rainfed conditions on a farmer's field (Kandic Paleustalf; 1.1% C; 5.7 ppm Olsen P; pH 6.3 in $CaCl_2$; slope ~3%) in the Iringa region (Ikuwala, 36° 01 E 7° 38 S, 1370 m asl.) in semi-arid Tanzania with common maize yields below 1 Mg ha$^{1.}$. The climate is semi-arid with unimodal rainfall and the growth season is approximately 140 days. Total precipitation was 500 mm with a dry spell from about 40 to 70 days after planting (data not shown) during the first season (1996-97; termed year-1) while it was 950 mm during the second cropping season (1997-98; termed year-2).

The experiment was a completely randomised block design with four replicates. Each plot measured 6.4 x 12 m and included eight ridges. The treatments were sole maize, sole cowpea and maize-cowpea intercrop combined with three P treatments: nil P (0P), triple super phosphate (TSP; 20 kg P ha^{-1}), and Minjingu rock phosphate [MRP; 52 kg P ha^{-1}, containing 10 kg ammonium-citrate soluble P according to Mnkeni et al. (1992)] plus 5 kg TSP-P ha^{-1} as starter dose. The treatments are summarized in Table 1. The plots monocropped with maize in year-1 were divided year-2 so that one half was fertilised with 50 kg N ha^{-1} in the form of calcium ammonium nitrate (CAN) while the other half received no N. Before the first rain the field was ploughed. The very heavy rainfall in December 1997 ("El Nino" year) seriously impeded fieldwork (data not shown). The rain ceased in late December 1997, which allowed for ridge construction. The ridges were 0.2 m high and the furrows were tied for every 2- 3 m. The heights of the ties were kept lower than the ridges so that in case of breakage, the water would flow side-ways into the next basin and not down the slope. The field was plan-ted on the 5th of January. A local variety of maize *Ukiliguru* was planted in monoculture on top of the ridges at a density of 37,500 plants ha^{-1} (0.33 m between plants and 0.8 m between ridges). Four seeds were planted per position and were thinned to one after establishment.

Utilization of crop residues

The N fertiliser was applied two weeks after planting in a rill made on the side of the ridges and covered with soil. A ^{15}N microplot (4.0 m^{2}) was installed in treatment 10 (Table 1). ^{15}N enriched NH_4NO_3 (5.51 atom % ^{15}N excess) was applied at a rate equivalent to 50 kg N ha^{-1}. The ^{15}N labelled NH_4NO_3 was mixed with sand and distribu-ted uniformly on the soil surface. At maturity the 3 maize plants in the centre (0.8 m^{2}) were harvested for $^{15}N/^{14}N$ determination.

By using ^{15}N labelled cowpea residues produced in year-1 a ^{15}N-mineralization study of cowpea residues was done. In the plots with treatment 11 (Table 1) cowpea residues equivalent to 1.7 Mg DM ha^{-1} and 28 kg N ha^{-1} was incorporated in a 2 x 2 m microplot (679 g DM, of cowpea residues; 1.6% N; 0.138 atom %^{15}N excess). The central maize plants in the centre were harvested to determine N concentration and $^{15}N/^{14}N$ ratio at maturity. The estimated total N uptake and recovery of residue N (% of applied) was based on the N accumulation of the central maize plants in the microplot (2.7 m^{2}). The rationale for using the ^{15}N residue microplot for estimating total N uptake in maize was i) that the microplot was located where cowpea in year-1 was harvested just prior to litter fall, and ii) that the cowpea residues were incorporated shortly after the final pod harvest in the main plot and around five months later in the microplot.

Plant sampling

Final grain and residue production was determined at maturity. Weeds were controlled by hand hoe and a minimum insects control was applied with appropriate insecticides. Eight maize plants were sub-sampled per plot for dry matter determination and N analysis.

Calculations and statistics

N inputs were calculated based on fertiliser N and the N acquired to the system via symbiotic N_2-fixation by cowpea at peak biomass (102 DAP). The first year, all plots contained a ^{15}N microplot for estimation of N_2 fixation and fertiliser use efficiency. Thus, the applied ^{15}N equal-led 15 kg N ha^{-1} which is included as a standard input in the calculations. The peak biomass includes the accumulated litter shed by cowpea as based on biweekly collection of fallen litter until 102 DAP. Below- ground N was assumed to represents 30% of the standing shoot N at 102 DAP (peak biomass).

The N outputs are based only on the N removed from the field in vested products (cowpea pods, maize cobs and residues). The N budgets presented do not include the N inputs via atmospheric deposition in rain and dust nor N-losses via leaching, gaseous losses and losses via runoff and erosion considered. In year-1, P applied as either TSP or MRP enhanced the N_2-fixation in cowpea. Therefore the estimated N-input via N_2-fixation is calculated differently for the controls (−P) and those plots receiving TSP or MRP (+P). As P did not affect the output of N via pods, cobs and residues, only the average output of N across P treatments from the mono- and intercrops presented. In the first cropping season cowpea shed practically all of its leaves of which virtually nothing was left on the soil surface at final harvest. Hence, cowpea residues at final harvest consist of haulm.

Management coupled N- budgets are calculated showing the consequence of removing or conserving maize and cowpea residues. However, in the actual experiment only pods, cobs and maize residues were removed from the field whereas the cowpea residues were returned to the soil.

Total N in the cowpea (above- plus below-ground N) at peak biomass (102 DAP) was calculated by:

$$\text{Total CowpeaN} = \frac{\text{Standing shootN}}{0.70}$$

Fore the second year, the N derived from residues (Ndfr) in the microplots based on the ^{15}N technique was calculated by:

$$\text{Ndfr} = \frac{\text{atom\% }^{15}\text{N excess in maize}}{\text{Atom\% }^{15}\text{N excess in residues}} \text{ X totalN in maize}$$

The N derived from fertiliser (Ndff) based on the ^{15}N method was based on the same principle as Equation 2. Apart from the ^{15}N estimate on Ndfr based on the microplots, the Ndfr was also calculated by N-difference based on the main plots as: (Maize $_{\text{(after cowpea)}}$ N - Maize $_{\text{(after maize)}}$ N). Similarly the Ndff based on the main plot was calculated by N-difference as: (Maize $_{\text{(after maize 50N)}}$ N - Maize $_{\text{(after maize 0N)}}$ N). The recovery of cowpea residue N was calculated by: 100 x (uptake of residue-N / residue-N applied). The recovery of fertiliser N was calculated by: 100 x (uptake of fertiliser-N / fertiliser-N applied).

Statististical analysis of variance was performed using GLM of the Statistical Analysis System (SAS Institute Inc., 1993).

RESULTS

N budgets for the year-1 intercrop experiment

The N budgets are presented in Table 2. The increased N_2-fixation as a result of P application (+P) improved the N budgets for both the mono- and the intercrops. For monocropped cowpeas 39 and 61 kg N ha^{-1} would have remained in litter, residues and below-ground-N for the −P and +P treatment, respectively. For the maize mono-crop the output of N via cobs and residues exceeded the input via fertiliser by -37 kg N ha^{-1}. In the intercrop the removal of pods, cobs and maize residues resulted in a net N-balance of -17 kg N ha^{-1} for the −P treatment and +1 kg N ha^{-1} for the +P treatment. Even if all the cowpea residues available at final harvest (haulm) in the mono-crop had been removed, the N budget would remain positive (Table 2) . In contrast the intercrop without P application resulted in a negative N budget except if all residues were recycled. With P application in the inter-crop, N inputs balanced N outputs if either the cowpea or the maize residues were removed in addition to pods and cobs, but not if all the residues were removed.

Residual effect on the following maize crop (year-2)

Difference in N budgets for the preceding maize and cowpea monocrops was significantly reflected in the grain yield and N uptake in the following maize crop (Figure 1). The average grain yield of maize following maize mono-crop (control) was 1.2 Mg ha^{-1} and the yield was doubled when maize followed monocropped cowpea (Figure 2). Application of 50 kg N ha^{-1} to the 2nd year maize following monocropped maize increased the yield similar to the increase due to cowpea monocrop grown prior to maize. The grain yield of maize following the maize-cowpea intercrop was 67% higher than the control (Figure 2).

The preceding crops likewise affected the N accumulation of the 2nd year maize (Figure 3). Maize following monocropped maize accumulated 37 kg N ha^{-1} whereas maize following monocropped cowpea accumulated 59 kg N ha^{-1} which was similar to the value of applying 50 kg N ha^{-1} as fertiliser. The N uptake following the maize-cowpea intercrop was also higher than the control. The higher N- uptake in the maize following the maize-cowpea intercrop, the cowpea monocrop, or when N -fertiliser were applied caused more N accumulated in the cobs whereas the amount N in the residues were almost constant across treatments (Figure 3).

The application of 50 kg N ha^{-1} as fertiliser N increased the average N uptake by 22.5 kg in the maize following maize (Figure 3). Thus the overall N-fertiliser recovery based on the N-difference method was 45%. The ^{15}N fertiliser microplots in treatment 10 allowed for a comparison of the recovery of fertilizer N based on the ^{15}N technique and the N- difference method. Hence in the plots with treatment 10 the recovery of fertiliser N was 32 $\pm$ 8% ($\pm$S.E.) based on the ^{15}N technique and 40 $\pm$ 5% ($\pm$S.E.) based on the N-difference method.

The N-recovery of cowpea residues in the following maize (treatment 11) was 34$\pm$10% ($\pm$S.E.) as based on ^{15}N and the N accumulation in the ^{15}N microplots. The amount of N accumulated in the microplots in treatment 11 was 48 $\pm$1 8 kg N ha^{-1} ($\pm$S.E.) and in the main plots 44 $\pm$ 6 kg N ha^{-1} ($\pm$S.E.). Hence, the variation in the total N accumulated in the microplots was higher than in the main plots but the amount of N accumulated was almost the same. Calculating the overall recovery of cowpea N in the following maize using the N-difference method gives a very similar result as the ^{15}N estimate. Maize following cowpea monocrop accumulated 22.0 kg N ha^{-1} more than maize following maize (Figure 3). The total aboveground N returned to the soil after cowpea monocrop (shoot- and litter N at 102 DAP minus pod N removed at harvest) was on average 64 kg N ha^{-1}. Thus the recovery of the above ground cowpea N was 34%. However, some of the additional 22 kg N accumulated in maize following cowpea

Table 2. Nitrogen accumulation, N_2 fixation, nitrogen removal and nitrogen balance following removal of pods, cobs and residues in maize-cowpea mono- and intercrops in the first cropping season. -P indicates no P was applied, and +P indicate P applied either as TSP or Minjingu Rock Phosphorus in the first cropping season.

Cropping system and treatments [a]	N-yield in cowpea [b]			N-fixed	N-input		N-output				N-balance in year-1 following the removal of			
	Standing Shoot-N	Litter-N	Total crop-N [c] (estimate)		N-fixed	Fertiliser N	Cowpea		Maize		(A)	(B)	(C)	(D)
							Pods	Residue	Cobs	Residue	Pod/cob	Pod/cob cowpea residue	Pod/cob maize residue	Pod/cob all residues
	---------- (kg ha^{-1}) ----------			(%)	----- (kg ha^{-1}) ----		---- (kg ha^{-1}) ---		--(kg ha^{-1})--		------------ (kg ha^{-1}) ----------------			
Cowpea monocrop - P	100	13	156	52	82	15					+39	+16	-	-
+ P	108	18	172	60	104	15	58	23	-	-	+61	+38	-	-
M/C intercrop - P	54	3	81	53	43	15					0	-13	-17	-30
+ P	60	3	88	68	60	15	25	13	33	16	+17	+4	+1	-12
Maize monocrop	-	-	-	-	-	15	-	-	36	16	-21	-	-37	-

[a]The cropping systems were cowpea monocrop, maize/cowpea intercrop, maize monocrop. Control indicates no P was applied, and +P indicate P applied either as TSP or Minjingu Rock Phosphorus in the first cropping season. [b]The N yield in cowpea at peak biomass (102 DAP). [c]Crop-N adjusted to include an estimate of the contribution of below-ground cowpea N; Total crop-N = (Standing shoot-N / 0.7) + Litter-N.

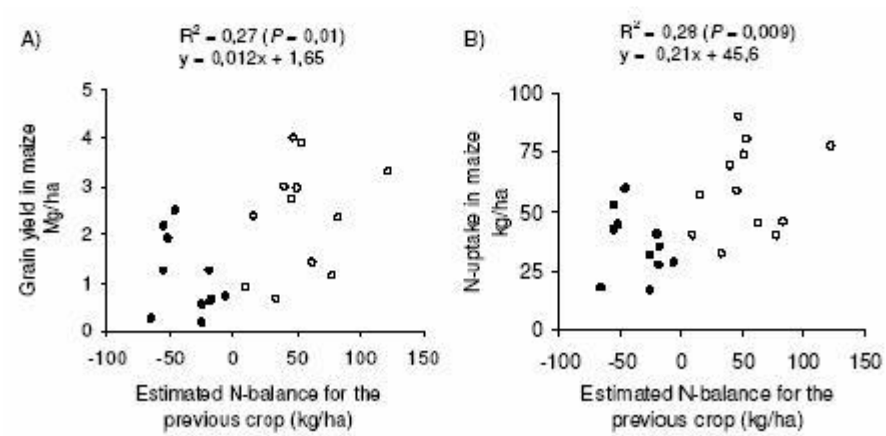

Figure 1. Grain yield (A) and N uptake (B) by monocropped maize as a function of the estimated N balance for the previous crops: denote monocropped maize, denote monocropped cowpea (based on individual plots).

Table 3. Residual effect of phosphorus applied in the first cropping season on grain yield and nitrogen uptake in the monocropped maize in the second cropping season. Nil is no P applied, MRP is Minjingu Rock P and TSP is Triple Super Phosphate.

Residual P- effect	**Grain yield Mg ha^{-1}**	**Nitrogen uptake (kg ha^{-1})**		
		Residues	**Cobs**	**Total N**
Residual phosphorus				
Nil	2.0ab	19a	35ab	54a
MRP	1.6a	16b	26a	41b
TSP	2.3b	20a	38b	58a
Pr > F [a]	0.02	0.0002	0.02	0.002

[a]Significance level of treatment effects. [b]Means within a column followed by different letters are significantly different at P = 0.05 level based on the Tukey-Kramer test.

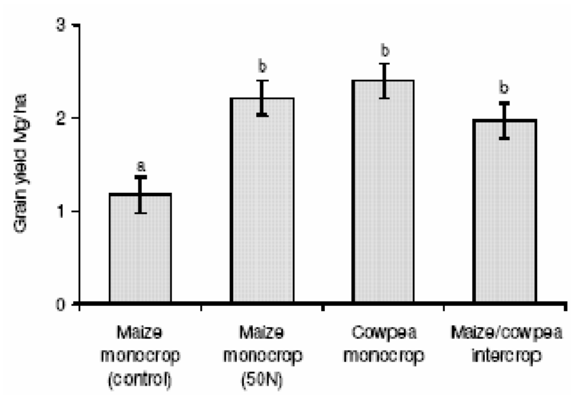

Figure 2. Grain yield in the maize monocrop in year- as affected by the preceding crop in the first cropping season and application of 50 kg N ha^{-1} as mineral fertiliser to the maize following monocropped maize. Bars indicate ± S.E. Bars with different letters are significantly different at P = 0.05 level based on the Tukey-Kramer test

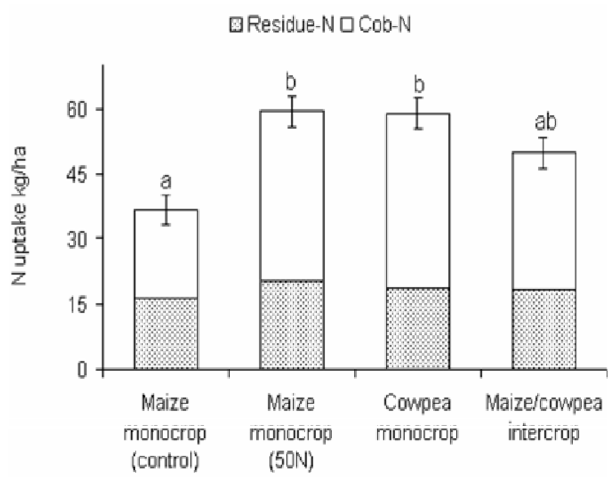

Figure 3. Nitrogen accumulations in cobs and stovers in the Monocropped maize in the second cropping season as affected by the preceding crop in the first cropping season, and application of 50 kg N ha^{-1} as mineral fertiliser to maize following monocropped maize. Bars indicate ± S.E. Bars with different letters are significantly different at P = 0.05 level based on the Tukey-Kramer test.

has been derived from below-ground cowpea-N which would cause overestimation of the recovery of residues when using the above N-difference method.

Residual effect of P applied in year-1

In the first year, the P applied as either triple super phosphate (TSP) or Minjingu rock phosphate (MRP) did not affect the performance of the maize and low N availabi-lity was considered the main limiting factor (Vesterager et al., 2007). Likewise, there was no residual effect of TSP on the yield and N accumulation in the following maize crop. In contrast, the maize grown in the plots amended with MRP in the first year produced less grain and accumulated less N than the control (Table 3) –for unknown reasons. However, in the first year experiment the uptake of soil N estimated at 102 DAP tended to be lower in the MRP treatment compared to the control (data not shown). From an agronomic point of view it is unlikely that MRP had a negative residual effect following maize -especially as maize in year-1 was unaffected by MRP and as there was no effect of TSP in either years.

N-balance over the two seasons

The overall N-balances over the two-year experimental period including the actual practice only (removal of pods, cobs and maize residues) are presented in Table 4. Only the rotation of monocropped cowpea and maize resulted in a positive N-balance. The most negative bala-nce was when all the residues were removed form the continuously grown maize without N fertiliser application and the maize cowpea intercrops.

DISCUSSION

Nandwa and Bekunda (1998) underline the need for the

Table 4. Overall N-balance for the second cropping season based on the actual practice of removing cowpea pods, maize cobs and maize residues, and net N-balance after removing only pods and cobs. –P indicates no P was applied, and +P indicate P applied either as TSP or Minjingu Rock Phosphorus in the first cropping season.

First cropping season	Second cropping season			Net N balance over two cropping seasons following the removal of [a)]		
Cropping system and treatments	**Cropping system N-fertiliser input**	**N-output via maize cobs**	**N-output via maize residues**	**Pod/cob (A)**	**Pod/cob maize residues (B)**	**Pod/cob all residues (C)**
	------------------------ (kg ha^{-1}) -------------			------------------------ (kg ha^{-1}) -------------------		
Cowpea mono - P	Maize monocrop 0			-2	-20	-43
+ P	0	40	19	+21	+2	-21
M/C intercrop - P	Maize monocrop 0	32	18	-32	-67	-80
+ P	0			-15	-49	-62
Maize monocrop	Maize monocrop 0	21	16	-41	-74	-
	50	39	20	-10	-46	-

development of local, zone-and crop- specific nutrient management recommendations. Thus, the hypothesis tested was that a legume-based system would produce maize equivalent to a pure maize cropping system. The grain yield of maize grown after cowpea monocrop was doubled and the N uptake increased by 60% compared to maize following maize (Figure 2). This agrees with studies in northern Ghana (Dakora et al., 1987) and semi-arid Kenya (Rao and Mathuva, 2000). Increased yield of millet and maize following cowpea compared with cereals has been reported from the semi-arid West Africa (Bagayoko et al., 2000; Muleba, 1999; Reddy et al., 1992; Reddy et al., 1994). In Nigeria, Nnadi et al. (1981) reported a substantial yield increase in maize following cowpea compared to sorghum even though all the cowpea residues were removed from the field.

The N-value of growing cowpea monocropped prior to maize monocrop was equivalent to the application of 50 kg N ha^{-1} as mineral fertiliser (Table 2; Figure 3). When maize followed a maize-cowpea intercrop, grain yield was increased by 67%. Higher yield of cereals following cowpea have commonly been associated with higher amounts of inorganic soil- N following cowpea compared with cereals (Bagayoko et al., 2000; Dakora et al., 1987; Nnadi et al., 1981; Rao and Mathuva, 2000). However, Jones (1974) reported significant yield increase of maize following groundnut compared to cotton or sorghum whereas cowpea had little or no residual effect on the grain yield in Nigeria. The higher yield following groundnut was related to higher inorganic-N content in the topsoil whereas cowpea showed little effect of similar advantage. More over, higher root densities (Horst and Härdter, 1994) and higher mycorrhiza infection rates (Bagayoko et al., 2000) have been reported for cereals following cowpeas compared to when following cereals. Other probable benefits from crop rotation include;

- Improved control of pest and disease cycles.
- Improved soil physical properties.
- Increased availability of nutrients other than N.
- Reduction of phytotoxic and allopathic effects of decomposing cereal residues (Karlen et al., 1994).

Utilization of cowpea residues

The C:N ratio is critical for the turnover of tropical plant residues and a critical C:N ratio of 20 - 25 has been identified (Seneviratne, 2000). In the present study, the cowpea residues had an N content of 1.6%, which is equivalent to a C:N ratio of 26. Consequently a fairly rapid N release can be anticipated from these residues. Approximately 34% of this residue N was recovered in the subsequent maize as estimated by ^{15}N (Table 2). This value is similar to the findings of Dakora et al. (1987) that the recovery of cowpea residues in the following maize was 27% whereas the comparable recovery of groundnut residue N was as high as 60%. Sisworo et al. (1990) found, using ^{15}N labelled cowpea residues, that between 11 and 28% of the N applied in the cowpea residues was recovered by a following upland rice crop. Likewise, Franzleubbers et al. (1994) reported a recovery of cowpea residues of 34% by difference in millet grown with or without cowpea residues. However, comparing the recovery of residue N to other studies are difficult because the quality of residues may differ significantly (Dakora et al., 1987), and because environmental conditions influences the utilization efficiency (Sisworo et al., 1990).

The recovery of cowpea residue N, based on the ^{15}N estimate and the N-difference method, agreed well in the present study although they may not estimate the same. In the present study the higher N uptake in maize following cowpea compared to maize after maize may apart from the N in the cowpea residues arise from below-ground N after cowpea and greater rooting depth. This may overestimate the recovery of the cowpea residues by the N-difference method. In contrast, the ^{15}N estimate is a direct measure of the N supplied in the residues and taken up in the maize and is relatively independent of the amount of N supplied from other sources.

N-recoveries vary with climate conditions, soil fertility conditions, crops species, type and amount of N -fertilisers applied and method for application. However, in the semi- arid zones the recovery of fertiliser N is often around or less than 30% (Eaglesham et al., 1982; Pilbeam et al., 1995; Tobita et al., 1994; Vesterager et al., 2007). Hence, a development of strategies for improved N fertiliser use efficiencies deserves further attention.

Net N gain or N drain from legumes

If the inclusion of cowpea is to contribute to the sustainability of maize based cropping system, the net N budget of a cowpea monocrop grown in sequence with maize, or a maize/cowpea intercropped should be less negative than the continuous monocropped cropped maize. Strictly speaking a cropping system is only N-sustainable if the N-inputs balances or exceeds N-outputs. Two important parameters is the proportion of N_2-fixation and the N harvest index (NHI). These parameters vary widely between genotypes and are influenced by environmental factors. Hence, legumes that accumulate a large amount of N, fix a large proportion of its N and divide a relative small proportion of the N to the harvestable products will add N to the system if residues are returned to the soil (Giller et al., 1994). However, farmers who focus on optimising the grain harvest in the short term may prefer legumes with a high NHI.

The cowpea in the present study fixed around 60% of its N (Vesterager et al., 2007). By using the most common way of calculating the NHI, which is based on the amount of N in the shoot of the standing crop, and the N in the harvested products (pods or grain) at maturity, the NHI of the monocropped cowpea averaged 72%. However, when calculating the NHI based on the total amount of N in above-ground materials at peak biomass (standing shoot-N plus litter-N) the NHI averaged 48%. If in addition the total N in the legume was adjusted to account for belowground N (according to equation 1) the NHI was as low as 35%. The first estimate leads to the conclusion that cowpea cultivation will result in a net N-drain to the system, whereas the later two estimates lead to the conclusion that cowpea will result in a considerable net N contribution to the system. Hence, since N in fallen litter and below-ground N often have been excluded in previous N-balance studies the N-contribution of legumes has been seriously underestimated (Table 4).

Management of residues

Open grazing by livestock during the dry season is quite common in semi-arid areas, which reduces the quantities of cowpea residues available for soil fertility improvement. In the present study the maize residues were removed from the field to reduce pest problems and to reduce N immobilization. However, if applying smaller quantities of maize residues the resulting N immobilization may be appropriate for reducing N-losses associated with the N-flush occurring at the onset of the rainy season. Such practice may help conserving N in the systems without yield losses if combined with timely additions of fertiliser N to match the crop demands. If the soil-N is reduced after a maize crop and residue addition, a legume crop could follow. This may force the legume to depend more on biological N_2-fixation (Evans et al., 1995).

Management of sparingly P sources

The hypothesis tested was that sparingly soluble P sources applied to the first-year legume crop would have a residual effect on the second-year maize crop. This hypothesis is based on the condition that many soils in semi-arid Africa are relatively neutral like the current experimental area (pH –$CaCl_2$ 6.3). As legumes that fix a high proportion of their N needs will acidify the rhizosphere (Raven, 1986) it has to verified whether sparingly soluble P sources applied to a legume crop may be made more available to the subsequent crops.

However, this hypothesis could not be verified as there was no effect ($P>0.05$) of the P source on the production of the subsequent maize (Table 3). The rock phosphate used in the current study is considered among the most promising and more soluble. Birch (1948) underlined early that a distinction must be made between acid, neutral and alkaline soils. However, even on quite acid soils (pH-KCl 4.2) in western Africa, Buerkert et al. (2001) found in an extensive multi-factorial field trial only a response from sparingly soluble P supplied to a precrop of ground-nut (Ae and Otani, 1997; Hallock, 1962) but not from cowpea. Thus, the potential for such technologies is not very promising and the effect of sparingly soluble P sour- ces should only be considered for the first season of application to cowpea on neutral soils.

ACKNOWLEDGEMENT

The study was supported by the Faculty of Life Sciences, University of Copenhagen, and the Centre for Research on Sustainable Agriculture in Semi-arid Africa (SASA) in Denmark. We gratefully acknowledge the excellent and skilled field assistance provided by Mr. and Mrs. Mwanyika and the good collaboration by the farmers in Ikuwala village.

REFERENCES

Ae N, Otani T (1997). The role of cell wall components from groundnut roots in solubilizing sparingly soluble phosphorus in low fertility soils. Plant Soil 196: 265-279.

Bationo A, Mokwunye AU (1991). Alleviating soil fertility constraints to increased crop production in West Africa: The experience in the Sahel. Fert. Res. 29:95-115.
Birch HF (1948) Soil phosphates – a review of the literature. East Afr. Agric. For. J. 14:29-32.
Buerkert A, Bationo A, Piepho H-P (2001). Efficient phosphorus application strategies for increased crop production in sub-Saharan West Africa. Field Crop Res. 72:1-15.
Bagayoko M, Bauerkert A, Lung G, Bationo A, Römheld V (2000). Cereal/legume rotation effects on cereal growth in Sudano-Sahelian West Africa: soil mineral nitrogen, mycorrhiza and nematodes. Plant Soil 218:103-116.
Buresh RJ, Sanchez PA, Calhoun FG (1997). Replenishing soil fertility in Africa. Soil Science Society of America. SSSA special publication number 51, Madison , WI, USA.
Dakora FD, Aboyinga RA, Mahama Y, Apaseku J (1987). Assesment of N_2 fixation in groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* L. Walp) and their relative N contribution to a succeeding maize crop in northern Ghana. MIRCEN J. App. Microbiol. Biotech. 3:389-399.
Eaglesham ARJ, Ayanaba A, Ranga Rao V, Eskew DL (1982), Mineral N effects on cowpea and soybean crops in a Nigerian soil. I. Development, nodulation, acetylene reduction and grain yield. Plant Soil 68:171-181.
Franzleubbers K, Juo ASR, Manu A (1994). Decomposition of cowpea and millet amendments to a sandy Alfisol in Niger. Plant Soil 167:255-265.
Giller KE, McDonagh JF, Cadisch G (1994) Can biological nitrogen fixation sustain agriculture in the tropics? In: Syers JK, Rimmer DL (eds) Soil Science and Sustainable Land Management in the Tropics. CAB International, Wallingford. pp. 173-191.
Hallock DL (1962). Effect of lime and rate of fertilizer application on yield and seed size of jumbo runner peanuts. Agron. J. 54:428-430.
Horst WJ, Härdter R (1994). Rotation of maize with cowpea improves yield and nutrient use of maize compared to maize monocropping in an alfisol in the northern Guinea Savanna of Ghana. Plant Soil 160:171-183.
Jones MJ (1974). Effects of previous crop on yield and nitrogen response of maize at Samaru, Nigeria. Expl. Agric. 10:273-279.
Karlen DL, Varvel GE, Bullock DG, Cruse RM (1994). Crop rotation for the 21st century. Adv. Agron. 53:1-45.
Khan DF, Peoples MB, Chalk PM, Herridge DF (2002). Quantifying below-ground nitrogen of legumes. A comparison of ^{15}N and non isotopic methods. Plant Soil 239:277-289.
Mnkeni PNS, Semoka JMR, Mwanga SN (1992) Dissolution of some Tanzanian phosphate rocks of igneous and sedimentary origin. Zimbabwe J. Agric. Res. 30:67-75
Muleba N (1999). Effects of cowpea, crotalaria and sorghum crops and phosphorus fertilizers on maize productivity in semi-arid West Africa. J. Agric. Sci. Camb. 132:61-70.
Nandwa SM, Bekunda MA (1998). Research on nutrient flows and balances in East and Southern Africa: state-of-the-art. Agri. Ecosyst. Environ. 71:5-18.
Nnadi LA, Singh L, Balasubramanian V (1981). Effect of grain legumes and sorghum on soil nitrogen status and the yield of subsequent maize crop. Samaru J. Agric. Res. 1:183-190.
Peoples MB, Craswell ET (1992). Biological nitrogen fixation: Investments, expectations and actual contribution to agriculture. Plant Soil 141:13-39.
Pilbeam CJ, Wood M, Mugane PG (1995). Nitrogen use in maize-grain legume cropping systems in semi-arid Kenya. Biol. Fert. Soils 20:57-62.
Rao MR, Mathuva MN (2000). Legumes for improving maize yields and income in semi-arid Kenya. Agric. Ecosyst. Environ. 78:123-137.
Raven JA (1986). Biochemical disposal of excess H^+ in growing plants? New Phytol. 104:175-206.
Reddy KC, Visser P, Buckner P (1992). Pearl millet and cowpea yields in sole and intercrop systems, and their after-effects on soil and crop productivity. Field Crops Res. 28:315-326.
Reddy KC, Visser PL, Klaij MC, Renard C (1994). The effect of sole and traditional intercropping of millet and cowpea on soil and crop productivity. Expl. Agric. 30:83-88.
Rochester IJ, Peoples MB, Constable GA, Gault RR (1998). Faba beans and other legumes add nitrogen to irrigated cotton cropping systems. Aust. J. Exp. Agric. 38:253-260.
Russell CA, Fillery IRP (1996). Estimates of lupin below-ground biomass nitrogen, dry matter and nitrogen turnover to wheat. Aust. J. Agric. Res. 47:1047-1059.
SAS Institute Inc. (1993). SAS/STAT® Software: Syntax, Version 6, first Edition. Cary, NC: SAS Institute Inc.
Seneviratne G (2000). Litter quality and nitrogen release in tropical agriculture: a synthesis. Biol. Fert. Soils 31:60-64.
Sisworo WH, Mitrosuhardjo MM, Rasjid H, Myers RJK (1990). The relative roles of N fixation, fertilizer, crop residues and soil in supplying N in multiple cropping systems in a humid, tropical upland cropping system. Plant Soil 121:73-82.
Tobita S, Ito O, Matsunaga R, Rao TP, Rego TJ, Johansen C, Yoneyama T (1994). Field evaluation of nitrogen fixation and use of nitrogen fertilizer by sorghum/pigeonpea intercropping on an Alfisol in the semi-arid tropics. Biol. Fert. Soils 17:241-248.
Steiner KG (1991). Overcoming soil fertility constraints to crop production in West Africa: Impact of traditional and improved cropping systems on soil fertility. In: Mokwunye AU (ed) Alleviating Soil Fertility Constraints to Increased Crop Production in West Africa, 69-91. Kluwer Academic Publisher, Dordrecht. pp. 69-91.
Vesterager JM, Nielsen NE, Høgh-Jensen H (2007). Effects of precrop and phosphorus source on land and nitrogen uptake efficiency in sole or intercropped cowpea maize crops. Nutr. Cycl. Agroecosyst., accepted