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Full Length Research Paper

Effects of intercropping systems and the application of Tundulu Rock phosphate on groundnut grain yield in Central Malawi

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Low soil fertility remains a major constraint in agricultural production in Malawi. Legumes hold the promise of being a cheap alternative to improve soil fertility owing to their ability of fixing atmospheric nitrogen (N_2). Growing two leguminous crops on a piece of land at the same time and applying phosphorus (P) may increase N_2 fixation while at the same time realizing high grain yield from the legumes. A study therefore, was conducted to investigate the effect on nitrogen fixation and grain yield in a groundnut/pigeon pea intercrop, groundnut/maize intercrop treated with an indigenous rock phosphate (TRP) and groundnut treated TRP. Researcher designed but farmer managed trials involving eight farmers were mounted on farm. Treatments were laid out in a randomized complete block design. The results indicated an apparent significant ($P<0.05$) groundnut grain yield reduction in the groundnut/pigeon pea intercrop (1,163 kg ha^{-1}) and groundnut/maize intercrop (910 kg ha^{-1}) below the groundnut sole crop (1,644 kg ha^{-1}) and the groundnut that was treated with the TRP (1,518 kg ha^{-1}). However, both intercrops showed yield advantage (total LER >1.0) compared with the monoculture on equal land area. The application of the TRP appeared not to have affected the grain yield.

Key words: Groundnut, Malawi, pigeon pea, rock phosphate.

INTRODUCTION

Intercropping refers to the growing of two or more crops at the same time on a single field (Machado, 2009). The cropping system has four general subcategories, namely; mixed, row, strip and relay intercropping (Machado, 2009). Intercropping is more stable than monocropping due to the partial restoration of diversity that is lost under monocropping. Other advantages of the system include; supression of weeds, soil erosion control and reduced damage from pests and diseases (Machado, 2009).

According to Willey et al. (1979) for plants to derive benefits from intercropping, inter specific competition for growth factors should be lower than intra specific competition in single stands. In a legume-cereal combination, the legume may suffer from competition depression especially when combined with C_4 cereals like maize under high soil fertility conditions. On the other hand, the growth and yield of the cereal may be reduced under low soil fertility conditions where the legume has competitive advantage over the cereal. According to Ikisan, (2000) the groundnut plant has a universal ability to utilize soil nutrients that are relatively unavailable to other crops and is very effective in extracting nutrients from sandy soils of low nutrient supply.

Legumes play a central role in maintaining soil productivity in smallholder agriculture in Southern Africa

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in general and in Malawi in particular (Phiri, 2009). A hallmark trait of legumes like groundnut is their ability to develop root nodules and to fix atmospheric nitrogen (N_2) in symbiosis with compatible Rhizobia (Graham and Vance, 2003). Similarly some legumes have the inherent capacity to enhance the availability and efficient utilization of residual phosphorus (P) which is otherwise not available to cereals (Kumal et al., 2004). They account for 27% of the world's primary crop production, with grain legumes alone contributing 33% of the dietary protein nitrogen (N) needs of humans (Vance et al., 2000).

Phosphorus is an essential element in crop production. It plays an important role in crop maturation, root development, photosynthesis, N fixation and other vital processes (Uchida, 2000). As a nutrient it is the second in importance only to nitrogen (Davis and Westfall, 2009). In the soil, P is present in the soil solution, soil organic matter or occurs as inorganic P. Unlike nitrogen phosphorus cannot be fixed from the atmosphere. It is generally regarded as the nutrient that is most limiting in tropical soils including Malawian soils (Phiri et al., 2010). The problem of P is three fold; the quantity of P in soils is low (200 to 2000 kg P ha^{-1} furrow slice), P compounds are generally insoluble and soluble P is rapidly adsorbed and becomes insoluble (Brady, 1990). Less than 1% of total soil P may exist as soluble P (Clain and Jeff, 2005). Generally phosphorus is present in inorganic form more than organic form. However, where the parent material is very low in phosphorus levels, organic sources may be of major importance as the main source of P for plant growth (Brady, 1990). The requirement for phosphorus in nodulating legumes is higher compared with non-nodulating crops (Singh and Oswalt, 1995). Plants dependent on symbiotic N_2 fixation have ATP requirements for nodule development and function (Ribet and Drevon, 1996) and need additional P for signal transduction and membrane biosynthesis. If available soil phosphorus is less than 15 kg P ha^{-1}, there is need to apply phosphatic fertilizer (Singh and Oswalt, 1995). Single super phosphate is recommended because it contains phosphorus (17%), calcium (19.5%) and sulphur (12.5%) that are required by groundnut (Yadava, 1985).

Rock phosphate (RP) can also supply P to the soil. Large deposits of RP are available in the southern part of Malawi for example at Tundulu in Phalombe District (Hoffman, 1991). The dissolution in any particular soil is controlled largely by three soil factors, namely soil pH, concentration of P and concentration of Ca in a soil solution (Chien et al., 1987). The use of RP is limited to acidic soils because it is in such soils that the RP dissolves readily (Singh and Ruhal, 1983) and acid soils are common in Malawi. Such areas have soil pH values less than 5.5. With such soil reaction values, Tundulu RP is likely to be an effective source of P and at ameliorating soil acidity, as its dissolution is enhanced.

Among the significant chemical and nutritional constraints for crop growth on acid soils such as the ones present in Malawi are deficiencies of calcium (Ca) and magnesium (Mg) nutrients. As the apatite mineral in PR is Ca-P, there is a potential to provide Ca nutrient if there are favorable conditions for apatite dissolution (Chien and Menon, 1995). Furthermore, many sources of RP contain free carbonates, such as calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), that can also provide Ca and Mg in acid soils. However, if dissolution of free carbonates raises pH and exchangeable Ca around RP particles significantly, it can hinder apatite dissolution and thus reduce P availability from RP (Chien and Menon, 1995).

The groundnut requirement of calcium is high during the pod filling stage. Calcium is taken up directly by the developing pods from the top 5 to 7 cm of soil (Singh and Oswalt, 1995). The critical limit of calcium in soils is 1 meq 100 g^{-1} of soil in the root zone and 3 meq 100 g^{-1} soil in the pod zone (Dayal et al., 1987a). With the low available soil P in Malawian soils which is compounded with low soil pH in many soils, a study therefore, was conducted to investigate the effect on grain yield in a groundnut/pigeon pea intercrop and groundnut/maize intercrop treated with Tundulu Rock phosphate (TRP) The rock phosphate potentially could be a cheaper source of P compared with the P from mineral fertilizers and a potential source of Ca.

MATERIALS AND METHODS

Study site

The research was conducted under field conditions in Kasungu District, Mkanakhothi Extension Planning Area (EPA) (12° 35' S, 33° 31' E). Research sites were located in five villages of Kaunda (Kapopo section), Tchezo (Ofesi section), Chisazima (Ofesi section), Ndaya (Simulemba section) and Chaguma (Simulemba section). The site falls within the Kasungu plain and receives an average annual rainfall of 680 mm. The rainy season spans from November to April. During the 2007/2008 growing season, a total of 760 mm was recorded. The dominant soils are Ultisols (Ustults) (MW Lowole, University of Malawi, personal communication). These have low organic matter content, low nitrogen and low to high available phosphorus content. They have poor structure because of the sandy texture of the top soil.

Ground (<150 µm) Tundulu Rock Phosphate (TRP) was used in the study comprising 29.2% total P_2O_5 (12.8%P) of which 1.7 and 11.3% is soluble in citric acid and formic acid respectively (Mueller et al., 1993). The P content of TRP was used as a basis for calculating the rate of P applied. The TRP was sourced from OPTICHEM, a fertilizer manufacturing company. Currently, the resource at Tundulu in Phalombe, southern Malawi, is licensed to this company. Crops involved in the research include Groundnut (CG7 with a yield potential of 3 t ha^{-1}), pigeon pea (ICEAP 04000 with a yield potential of 1.6 to 2 t ha^{-1}) and maize (ZM 621, yield potential is 6 to 7 t ha^{-1}).

Experimental design

In this on-farm study, six treatments were laid in a randomized complete block design (RCBD) with eight farmers serving as replicates. The distances between farmers' fields were significant. On average the fields were 10 km apart. In general the soils across all the fields were dominantly sandy loam in texture. The treatments were as follows: 1) Sole groundnut plot as the control; 2) Sole pigeon pea as the control 3) Groundnut treated by TRP at 22.9 kg P ha^{-1} 4) Groundnut intercropped with pigeon pea; 5) Groundnut intercropped with maize and treated by TRP at 22.9 kg P ha^{-1}; 6) Sole maize. Each treatment was applied to a 10 × 10 m plot on each farmer's field.

Treatment plot description

Treatments were allocated to 10 × 10 m plots. Ridges were spaced at 75 cm apart. Pigeon pea was sown at 90 cm apart within a row while groundnut was sown at 15 cm apart representing the seed rate of 80 kg ha^{-1} both in the sole crop and in the intercrop. Maize was sown at 25 cm apart representing the rate of 25 kg ha^{-1}.

Application of phosphorus

Tundulu rock phosphate (TRP) contains in total 29.2% P_2O_5 (12.8 %P) (Mueller et al., 1993). This was used to calculate the quantity of the rock (3.3 g) that was applied per planting station to achieve the rate of 22.9 kg P ha^{-1}. This was applied through dollop method.

Data collection and analysis

Soil sample collection

Farmers' fields were visited and soil samples collected in all the eight fields. Top (0 to 15 cm) and sub (15 to 30 cm) soils were sampled at random before treatment application to plots (Okalebo et al., 2000). Four boring samples from each field were taken. The samples were air dried at Bunda College of Agriculture and then passed through a 2 mm sieve. At the time of harvest, soils were sampled from each plot (3 borings at random per treatment plot). These were thoroughly mixed and a composite sample was taken for each treatment plot.

Plant sample and agronomic data collection

Four samples of groundnut tops were randomly collected within each treatment plot in all farmers' fields at podding and at maturity stages for plant nutrient analysis. This was also done for the maize crop. For the pigeon pea, non destructive sampling was used to collect leaves and twigs from the treatments at podding and maturity stages for nutrient analysis. Agronomic data was also collected which include groundnut and maize grain yield, groundnut haulms and maize stover yield and biomass yield of pigeon pea.

Rainfall data

Monthly rainfall data for a seven year period for the study area were obtained from the Ministry of Agriculture, Kasungu Rural Development Project. Rainfall data for the year of study were also obtained. Monthly rainfall means were then computed for the period and graphs were plotted (Figure 1). It was observed that the study area receives low amounts of rainfall and that dry spells are a common phenomenon with drought also being a common occurrence in the area.

Rainfall distribution in the project area for the 2007/2008 season

The rainfall amount that was received in the area was adequate for the production of annual crops. However, the distribution over the season was poor. Firstly, rain that was adequate enough for planting came mid way the month of December 2007. Much of the rainfall recorded was received in the months of December, January and February with little amounts recorded in the month of March and April (Figure 2).

Determination of plant phosphorus and nitrogen in plant tissues

Bulked plant samples from each treatment plot for each crop and farmer were separately oven-dried at 70°C to a constant weight. The dried bulked plant materials from each treatment plot for each farmer were separately ground to pass through 1 mm sieve. One gram of each sample plant material was digested using 5 ml of concentrated sulphuric acid and 30% hydrogen peroxide (Thomas et al., 1967). Phosphorus in the digest was determined (Murphy and Riley, 1962). Plant N was determined using Kjeldahl method (Amin and Flowers, 2004).

Estimation of nitrogen fixation

To estimate the amount of N fixed by the legumes the N-difference method was used (Peoples et al., 1989). In this method a companion non-N_2-fixing control crop is grown in the same soil and under identical conditions as the legume. The N accumulated in the tissue of the legume

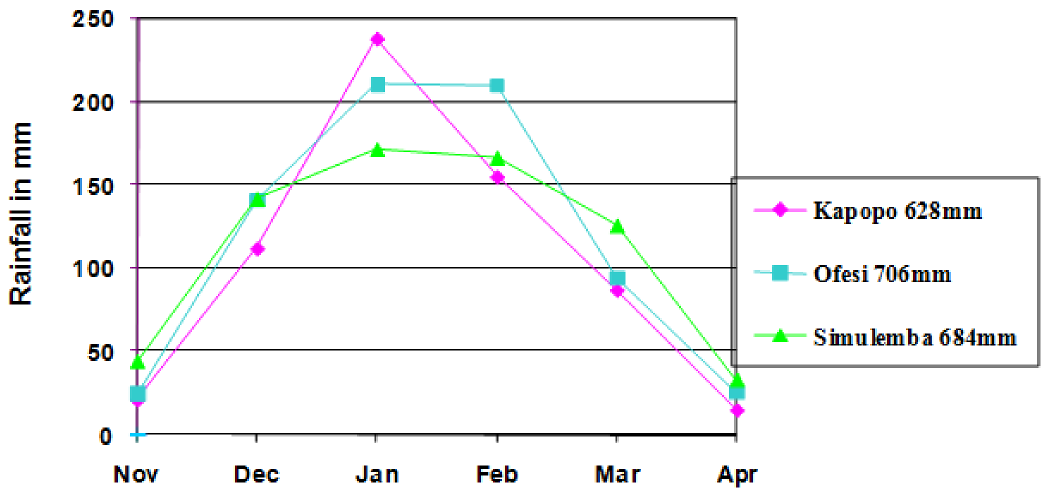

Figure 1. Rainfall distribution in Mkanakhothi extension planning area, Kasungu District, seven year means (2000/01 to 2007/2008).

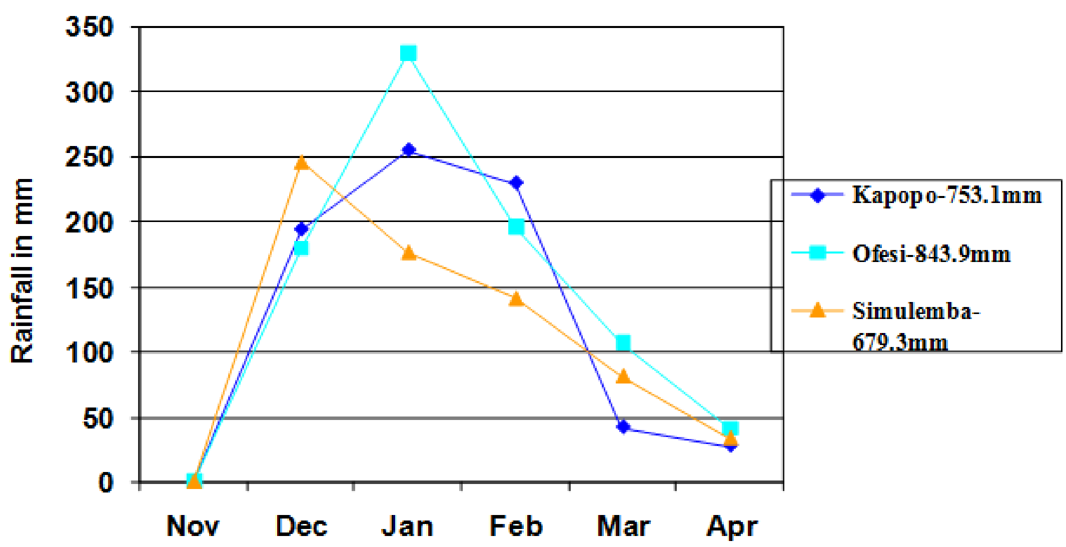

Figure 2. Rainfall distribution in Mkanakhothi extension planning area, Kasungu District for the 2007/2008 season.

and the companion crop is determined. The difference either on a per-plant or per-unit-area basis between the legume and control crop is then computed. The difference is generally regarded as the contribution of symbiotic fixation to the legume. In this trial maize was the companion non-N_2-fixing control crop.

Evaluation of the productivity of the intercropping systems

The land equivalent ratio (LER) was used to evaluate the doubled up legume intercrop as well as the cereal/legume intercrops. The LER is a measure of the yield advantage obtained by growing two or more crops or varieties as an intercrop compared to growing the same crops or varieties as a collection of separate monocultures (Andrews and Kassam, 1976). The LER is calculated using the formula LER= $\sum$ (Ypi/Ymi), where Yp is the yield of each crop or variety in the intercrop or polyculture, and Ym is the yield of each crop or variety in the sole crop or monoculture. For each crop (i) a ratio is calculated to determine the partial LER for that crop, then the partial LERs are summed to give the total LER for the

Table 1. General soil characteristics of farmers' fields under study (bulked).

Parameter	Value$_{(Depth: 0-15cm)}$	Value$_{(Depth: 15-30cm)}$
%Clay	13	13
%Silt	5	8
%Sand	82	79
Texture class	*SL	*SL
pH $_{(H2O)}$	5.4	5.3
%N	0.07	0.07
%OC	0.87	0.81
C/N	12.4	11.6
P-Mehlich 3 (mg kg^{-1})	18.0	9.6

*SL means sandy loam.

intercrop. An LER value of 1.0 indicates no difference in yield between the intercrop and the collection of monocultures (Mazaheri and Oveysi, 2004; Agrawal 1995; Kurata, 1986). Any value greater than 1.0 indicates a yield advantage for intercrop. A LER of 1.2 for example, indicates that the area planted to monocultures would need to be 20% greater than the area planted to intercrop for the two to produce the same combined yields

Data analysis

Soil analysis was done in order to characterize soil properties and assess changes due to treatments. Soil samples were analyzed for OC, total N, available P, Ca, Mg and soil pH (H_2O). Soil was sampled from the topsoil (0 to 15 cm) and subsoil (15 to 30 cm) in each farmer's field from four randomly selected points. Soils were analyzed in the laboratory for OC, total N, available P, and soil pH (H_2O). Soil analysis for P, Ca and Mg was done using Mehlich-3 extraction procedures (Mehlich, 1984) while OC was determined using the colorimetric method (Schumacher, 2002) and total N was determined using Kjeldahl method (Amin and Flowers, 2004). All the soil and agronomic data were analyzed using Genstat statistical package and were subjected to Analysis of Variance at 95% level of confidence.

RESULTS

Soil characterization of the study area

Baseline physical and chemical properties of soil used during the study

Table 1 summarize baseline physical and chemical properties of soil used during the study.

Soil chemical properties at harvest

Table 2 shows the status of soil chemical properties at harvest. Soil pH ranged from 5.3 to 5.7 for top soils while the range was 5.1 to 5.6 for sub soil. The mean value for both soil depth levels at harvest was 5.5; this mean value was similar to the baseline study values. There was high variation in Mehlich 3 soil available P across treatments. Mean values of P across treatments ranged from 3.9 to 9.4 mg P kg^{-1} in the top soil and 3.3 to 8.3 mg P kg^{-1} in subsoil. These mean values of P were below the mean values observed at the onset of the trial. Across treatments, mean total N was low, 0.04 to 0.05% for top soil and 0.03 to 0.05% for sub soil. Low to medium levels of OC across treatments both in the top soil (1.1 to 1.5%) and subsoil (0.8 to 1.2%) were observed. The mean levels for Ca across treatments ranged from 1.8 cmol kg^{-1} of soil to 2.2 cmol kg^{-1} of soil for top soil and 2.0 cmol kg^{-1} of soil to 2.6 cmol kg^{-1} of soil for sub soil. This was a decline in the mean levels of Ca from the initial status which was 2.8 cmol kg^{-1} of soil for top soil and 3.0 cmol kg^{-1} of soil for sub soil. The decline was more in sole groundnut and where the groundnut was intercropped with either pigeon pea or maize. The mean level of Mg across treatments ranged from 0.65 cmol kg^{-1} of soil to 0.95 cmol kg^{-1} of soil for both the top and sub soil. This was higher than the mean level of Mg that was observed at the beginning.

Concentration of nitrogen and phosphorus in the crops

Table 3 shows the mean tissue concentrations of N and P in the groundnut at podding and harvest. The mean concentration of N in the groundnut plant at podding ranged from 2.0 to 3.1%. This was below the sufficient range of 3.5 to 4.5% as proposed by Jones (1974) indicating a possible reduction in the grain yield. However there was no significant difference in the mean N concentration in the plant tissue at this stage across treatments.

At harvest significant differences ($P<0.05$) in mean tissue N concentration were observed. The highest mean concentration of N was in the maize + groundnut intercrop that was treated with TRP (3.1%); and the

Table 2. Status of soil chemical properties at harvest.

Treatments	%N		%OC		P (mg kg^{-1}) Mehlich 3		pH_{H2O}		Ca (cmol kg^{-1})		Mg (cmol kg^{-1})	
	0-15 cm	15-30 cm	0-15cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Gnut only	0.05	0.05	1.5	0.93	9.4[a]	8.3[a]	5.7[a]	5.3[b]	1.8	2.4	0.65[b]	0.66[b]
Gnut + TRP	0.04	0.04	1.2	0.8	5.5[b]	5.6[ab]	5.4[ab]	5.4[ab]	1.8	2.6	0.81[ab]	0.81[ab]
Gnut + ppea	0.05	0.05	1.3	1.3	8[ab]	7.8[a]	5.3[b]	5.6[a]	2	2.2	0.88[a]	0.88[a]
Ppea only	0.04	0.03	1.1	0.87	6.8[ab]	7.3[a]	5.3[b]	5.4[ab]	2	2.3	0.81[ab]	0.90[a]
Mz + Gnut + TRP	0.06	0.04	1.2	1.2	7.2[ab]	7.1[a]	5.7[a]	5.5[ab]	2.2	2.2	0.95[a]	0.95[a]
Mz only	0.05	0.05	1.2	1.2	3.9[b]	3.3[b]	5.7[a]	5.6[a]	2.2	2	0.9[a]	0.88[a]
LSD (0.05)	0.03	0.03	0.8	0.7	3.8	3.3	0.4	0.3	0.8	0.8	0.22	0.22
C.V. (%)	41	42.3	50.00	45.4	53.06	51.06	6.4	5.91	43.2	41.8	27.8	31.6

Means with different superscripts within a column are significantly different $p<0.05$; Number of replicates (N) =8; Gnut= Groundnut, Pp= Pigeon pea, Mz= Maize.

Table 3. Nutrient concentration in the plants.

Treatments	Gn at podding		Gn at harvest		Pp leaves at harvest		Pp twigs at harvest		Mz at tasseling		Mz at harvest	
	N (%)	P (%)	N (%)	P (%)	N (%)	P (%)	N (%)	P (%)	N (%)	P (%)	N (%)	P (%)
Groundnut only	2.6	0.4[b]	2.5[bc]	0.2	-	-	-	-	-	-	-	-
Sole Pigeon pea	-	-	-	-	3.3	0.5	3.2	0.5	-	-	-	-
Groundnut + Pigeon pea	2.0	0.3[c]	2.3[c]	0.2	3.4	0.5	3.2	0.5	-	-	-	-
Groundnut + TRP	2.6	0.5[a]	3.0[ab]	0.2	-	-	-	-	-	-	-	-
Maize only	-	-	-	-	-	-	-	-	1.9	0.3	0.62	0.14
Maize + Groundnut + TRP	3.1	0.5[a]	3.1[a]	0.2	-	-	-	-	1.3	0.3	0.55	0.13
LSD (0.05)	1.6	0.1	0.6	0.1	-	-	-	-	-	-	-	-
CV (%)	26.7	16.5	22.2	27.0	-	-	-	-	-	-	-	-

Means with different superscripts within the same column are significantly different $p<0.05$; Number of replicates (N) = 8; G/N= Groundnut, Pp=Pigeon pea, Mz=Maize.

lowest value was in groundnut + pigeon pea intercrop (2.3%). The concentration of N in the groundnut plant at harvest ranged from 2.3 to 3.1%. The mean N concentrations in the tissues for all the treatments at harvest were similar to mean N concentrations in the groundnut tissues at the podding stage. Hence incorporating groundnut haulms into the soil at this stage would boost soil N levels for the subsequent crop if a crop rotation system is employed.

The mean concentration of P in the groundnut plant at podding ranged from, 0.3 to 0.5% with significantly higher ($P<0.05$) mean concentration of P in plots where TRP was applied. The groundnut + pigeon pea treatment had lower concentration of mean tissue P but this was within the sufficient range while the rest were slightly above the sufficient range of 0.20 to 0.35% (Jones, 1974). The mean concentration of P in the groundnut plant at harvest was at 0.2% in all treatments. The mean P concentration in the tissues in all treatments at harvest was lower as compared to mean P concentration in the groundnut tissues during podding stage. This was due to the translocation of P during grain formation.

In maize plants from the maize + groundnut + TRP and sole maize treatment the mean tissue N concentration was 1.3 and 1.9% respectively at tasseling stage. This was neither within (2.75 to 3.5%) nor near the lower sufficiency level of 2.75% as proposed by Jones (1974). This indicated that maize grain yield at harvest will be low both in the maize + groundnut + TRP treatment and sole maize. At maturity stage, in the maize plants from the maize + groundnut + TRP treatment and sole maize tissue analysis indicated that the mean tissue P concentration was 0.3%. Similar N and P concentrations were detected in the pigeon pea leaves and twigs at harvest.

Yields of nitrogen, phosphorus, grain and haulms of groundnut at harvest

Table 4 shows the mean yields of nitrogen, phosphorus, grain and haulms of groundnut at harvest. Significant differences ($p<0.05$) in the yield of grain produced were observed. The maize + groundnut intercrop that was treated with the TRP apparently yielded the least amount of grain (910 kg ha^{-1}). This was not significantly different from the amount that was produced by the groundnut + pigeon pea intercrop (1,163 kg ha^{-1}). Both intercrops showed yield advantage (total LER >1.0) compared with the monoculture on equal land area. The highest amount was obtained from the groundnut sole crop (1,644 kg ha^{-1}) and the TRP treated plot (1,518 kg ha^{-1}); and these were not significantly different ($p<0.05$). This implies that the application of TRP did not affect the yield of groundnut. Significant differences ($p<0.05$) in the mean yield of haulms were observed. The mean yield of haulms ranged from 1,262 kg ha^{-1} to 3,713 kg ha^{-1}. The highest mean yield of haulms was obtained from the groundnut sole crop while the lowest mean yield of haulms was obtained from the maize + groundnut intercrop that was treated with TRP, suggesting possible competition for growth factors between the two crops.

Significant differences in tissue N concentration were observed ($p<0.05$). The mean concentration of N in the groundnut plant at harvest ranged from 2.3 to 3.1% (Table 3). However the maize + groundnut intercrop that was treated with TRP had a lower mean haulms yield (1,262 kg ha^{-1}) compared to the groundnut + pigeon pea intercrop (2,622 kg ha^{-1}). As such the amount of N in the groundnut per hectare was the opposite of the concentrations that were detected in the haulms. Thus, the groundnut + pigeon pea intercrop had more tissue N (60.3 kg ha^{-1}) than the maize + groundnut intercrop that was treated with TRP (39.1 kg ha^{-1}), however highest values were produced by the groundnut TRP treatment (95.8 kg ha^{-1}) and groundnut sole crop (92.8 kg ha^{-1}).

The mean concentration of P in the groundnut plant at harvest was at 0.2%. No significant differences ($p<0.05$) were observed in the amount of tissue P on a hectare basis in all treatments, this ranged from 2.5 kg ha^{-1} to 7.4 kg ha^{-1}.

Mean nitrogen yield for the maize crop from the maize + groundnut + TRP and sole maize treatment at harvest was 9.4 kg N ha^{-1} and 11.8 kg N ha^{-1} respectively while mean grain yield was 809 kg ha^{-1} (maize + groundnut + TRP) and 683 kg ha^{-1} (sole maize). The mean stover yield was 1,703 kg ha^{-1} (maize + groundnut + TRP) and 1,899 kg ha^{-1} (sole maize).

The quantity of leaves that were harvested from pigeon pea plants was 351 kg ha^{-1} (sole pigeon pea) and 429 kg ha^{-1} (groundnut + pigeon pea). The amount of mean N detected in the leaves translated to 11.6 kg N ha^{-1} to 14.6 kg N ha^{-1} while mean P concentration in the leaves was 1.8 kg P ha^{-1} (sole pigeon pea) and 2.1 kg P ha^{-1} (groundnut + pigeon pea).

The quantity of twigs that were harvested from pigeon pea plants was 463 kg ha^{-1} (sole pigeon pea) to 674 kg ha^{-1} (groundnut + pigeon pea). The mean amount of N detected in the tissue translated to 7.5 kg N ha^{-1} to 21.6 kg N ha^{-1} while mean tissue P concentration amounted to 2.3 kg P ha^{-1} (sole pigeon pea) and 3.4 kg P ha^{-1} (groundnut + pigeon pea).

Amount of nitrogen fixed in groundnut

Table 5 shows the mean amount of tissue N fixed by the groundnut on a hectare basis per year. Using the N difference method, the actual amount of N that was fixed by the groundnut and pigeon pea was determined. Quantities of N fixed by the two legume components in the groundnut + pigeon pea treatment were added to determine the total amount of N that the system fixed. The maize + groundnut intercrop that was treated with TRP fixed the least mean amount of N (29.7 kg N ha^{-1}) owing to the competition for growth factors for example nutrients and light that occurred between the maize crop and the groundnut plant. The groundnut + pigeon pea intercrop fixed a mean amount of N amounting to 84.7 kg N ha^{-1}. It is worth while noting that this amount did not take into account N fixed by the legume in the leaves that defoliated. As such the amount of N fixed by this intercropping mode was higher than the reported figure. The sole groundnut + TRP treatment fixed 84.0 kg N ha^{-1} while the groundnut sole crop fixed 81.0 kg N ha^{-1}.

DISCUSSION

The effects of groundnut and intercrop pigeon pea on their grain yield and amount of mean tissue nitrogen fixed

In the trial an apparent 29.3% significant groundnut grain yield reduction was recorded in the groundnut + pigeon

Table 4. Yields at harvest for groundnut, maize and pigeon pea.

Treatments	N kg ha^{-1} Gn	P kg ha^{-1} Gn	Grain kg ha^{-1} Gn	Haulms kg ha^{-1} Gn	N kg ha^{-1} Pp	P kg ha^{-1} Pp	kg ha^{-1} Pp	N kg ha^{-1} Mz	P kg ha^{-1} Mz	Grain kg ha^{-1} Mz	Stover kg ha^{-1} Mz
	Yields kg ha^{-1}										
Groundnut only	92.8^{a}	7.4^{a}	1,644^{a}	3,713^{a}	-	-	-	-	-	-	-
Sole pigeon pea (leaves)	-	-	-	-	11.6	1.8	351	-	-	-	-
Sole pigeon pea (twigs)	-	-	-	-	14.8	2.3	463	-	-	-	-
Groundnut + Pigeon pea (Pp leaves)	60.3^{b}	5.2^{b}	1,163^{b}	2,622^{ab}	14.6	2.1	429	-	-	-	-
Groundnut + Pigeon pea (Pp twigs)	-	-	-	-	21.6	3.4	674	-	-	-	-
Groundnut + TRP	95.8^{a}	6.4^{ab}	1,518^{a}	3,193^{a}	-	-	-	-	-	-	-
Maize only								11.8	2.7	683	1,899
Maize+ Groundnut + TRP	39.1^{b}	2.5^{c}	910^{b}	1,262^{b}	-	-	-	9.4	2.2	809	1,703
LSD (0.05)	30.3	1.6	512.1	1,398	-	-	-	-	-	-	-
CV (%)	40.27	32.66	33.36	43.97	-	-	-	-	-	-	-

Means with different superscripts within the same column are significantly different $p<0.05$; Number of replicates (N) = 8; G/N= Groundnut, Pp=Pigeon pea, Mz=Maize.

Table 5. Estimated N yields for the legumes and maize and N fixed in kg ha^{-1}.

Treatments	Yields and N fixed kg ha^{-1}				
	N kg ha^{-1} Gn	N kg ha^{-1} Pp	N kg ha^{-1} Mz	N yields kg ha^{-1}	N fixed N kg N ha$^{-1}_{\text{pigeon pea}}$ - N kg N ha$^{-1}_{\text{Maize control}}$
Groundnut only	92.8^{a}	-	-	92.8	81
Sole pigeon pea (leaves)	-	11.6	-	11.6	-
Sole pigeon pea (twigs)	-	14.8	-	14.8	-
Sole pigeon pea (total)	-	-	-	26.4	14.6
Groundnut + Pigeon pea (Pp leaves)	60.3^{b}	14.6	-	74.9	-
Groundnut + Pigeon pea (Pp twigs)	-	21.6	-	21.6	-
Groundnut + Pigeon pea (total)	-	-	-	96.5	84.7
Groundnut + TRP	95.8^{a}	-	-	95.8	84
Maize only		-	11.8	11.8	-
Maize + Groundnut + TRP	39.1^{b}	-	9.4	-	29.7
LSD (0.05)	30.3	20.01	-	-	
CV (%)	40.27	34.3	-	-	-

G/n= Groundnut, Pp=Pigeon pea, Mz=Maize.

pea intercrop below the groundnut sole crop (Table 4). However the intercrop showed yield advantage (total LER >1.05) compared to the sole crop on equal land area.

This agrees with the findings by Schilling and Gibbons (2002) where a 43% yield increase was recorded in a similar intercropping system. For the pigeon pea, both in the sole and the intercrop flower abortion was witnessed. The early disappearance of rain in the project area during the research period affected the performance of the pigeon pea (ICEAP 04000) which is a long duration cultivar (170 to 230 d). The abortion of the flowers was attributed to lack of adequate moisture that was necessary to support the pod formation and grain filling.

The sum total of N fixed by groundnut and pigeon pea in their tissues in the groundnut + pigeon pea intercrop was high (Table 5). This did not take into account the amount of N that was fixed in the leaves of pigeon pea that defoliated during the growing season. This intercropping mode shows great potential for soil fertility improvement.

In general the groundnut registered yield below the potential principally because of the inherent low soil fertility. Addition of N and P to the crop might be required to supply the initial nutrient requirement and to enhance the subsequent atmospheric N_2 fixation after nodulation.

Effect of maize/groundnut intercrop and Tundulu rock phosphate on soil nitrogen, phosphorus, maize and groundnut yield

In the trial, levels of Mehlich 3 P in soil of the maize control treatment were reduced by cropping from their initial low levels (Table 1). Tundulu RP appeared not to have an effect on levels of soil P in plots that were amended (Table 2) because the P status at harvest generally was similar across the treatments. This was the case because the soil pH might not have been low enough to solubilise TRP significantly which is known for its low reactivity. Low pH levels (<5.5) favour PR dissolution (Sanchez et al., 1997). The noted trend contrast with the findings of Weil, (2000) who found through pot experiments that amending soil with Minjingu RP of Tanzania maintained soil P levels close to the initial P level.

Apparently application of TRP does not seem to have any effect on the yield of groundnut. This is evident in tissue P concentration (Table 3) which is statistically the same both in the groundnut sole crop and the TRP treated groundnut crop. However the grain yield recorded was satisfactory. The soil Ca status was capable of supporting prolific podding and robust grain filling.

Low maize yields in the trial both for the maize/groundnut TRP treated intercrop and sole maize were recorded. Maize yield in the intercrop was in the same range as that in the control suggesting that TRP application had no effect on the yield of maize. Concentration of P in tissues that were similar, at tasselling (0.3 and 0.3%) and harvest (0.12 and 0.2%) respectively and low levels of soil P (Tables 1 and 2) further vindicates this observation. The uptake of P as indicated by the concentration in the plant tissue at tasselling for the maize crop suggested that there were no differences in terms of P uptake across treatments. However the application of TRP alone resulted in non significant maize grain yield increase of 31.6% above the maize sole crop. This agrees with the findings of Bromfield et al. (1981) who used Minjingu RP at 50 kg P ha^{-1} and found a non significant 29% increase in maize. Many researchers have reported an intriguing phenomenon in many longer-term experiments namely a delay in crop response to RP; thus the first crop grown after RP application gives little or no response, but the second and third crops respond well (Anderson 1965, 1970; Bromfield et al., 1981; Gichuru and Sanchez, 1988; Kimbi, 1991; Haque and Lupwayi, 1998).

This experiment was established on soils of low soil fertility and groundnut appeared to have had a competitive advantage over the maize crop. It is also possible that the planting pattern for maize was not suitable for the intercrop with groundnuts and hence may have contributed to the intercrop competition. The total amount of phosphorus taken up by the groundnut plant is relatively small. Up to 0.4 to 0.5 kg of available phosphorus is required to produce one quintal of pods (Ikisan, 2000). The groundnut plant is also able to grow normally with low levels of available soil phosphorus probably because of the formation of mycorrhizal association of the roots with soil fungi or due to phosphobacteria in the rhizosphere of the plant making unavailable phosphorus available to the groundnut plant (Ikisan, 2000). The mean amount of calcium recorded during baseline soil characterization (Table 1) was adequate to support nut development which were 2.8 cmol Ca kg^{-1} and 3.0 cmol Ca kg^{-1} for top soil and subsoil respectively. These were above the critical range (1.25 to 2.2 cmol Ca kg^{-1}) that is considered adequate for agronomic production (Haby et al., 1990). Apparently, the N fixation figures indicate that, relatively low amounts of N can be added to the soil upon incorporation of the residues, for the cereal-legume intercrop (29.7 kg ha^{-1}).

Conclusion

Under the conditions of this study application of TRP alone did not significantly improve soil P, groundnut and maize grain yield and also did not affect pH. The fertility status of the soil was low while on the other hand the soil pH was not acid enough to enhance the dissolution of the TRP; hence the availability of P, N and other nutrients for crop uptake and growth was low. However, the soil Ca and Mg status was adequate for the growth of groundnut. Further, groundnut was able to grow normally with low levels of available soil phosphorus probably because of the formation of mycorrhizal association of the roots with soil fungi or due to phosphobacteria in the rhizosphere of the plant making phosphorus available. As such reasonable groundnut grain yields were recorded. It is therefore recommended that long term studies need to be conducted to further investigate the effects of TRP application on groundnut yield bearing in mind that TRP has very low solubility and availability may increase with time. Further, the study has shown that groundnut + pigeon pea intercrop (doubled up legumes) accumulated substantial amounts of nitrogen in their tissues, despite of not accounting for N that was fixed in pigeon pea leaves that defoliated during the growing season. As such if their residues can be, incorporated into the soil the N can benefit subsequent crops in a rotation system. It is recommended that further studies should include litter traps. This will help to quantify properly the amount of N fixed in this intercropping mode.

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