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Response of *Tephrosia vogelii* to Minjingu Phosphate Rock Application on a Ferralsol of Varying Soil pH

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Abstract

Low available P and low soil pH are among soil conditions, which could lead to poor growth of some N_2 fixing plants. The effect of these two soil conditions to *Tephrosia vogelii* (agroforestry leguminous shrub) growth parameters needs to be determined. A Glasshouse study using *T. vogelii* was conducted on a Ferralsol with soil pH 5.0 and 5.9 and low available P (2.5-2.9 mgP kg^{-1}). The objectives of this study were to assess the effects of soil pH and Minjingu Phosphate Rock (MPR) on *T. vogelii* plant height, dry matter production and shoot N and P contents. The two soils were treated with P as MPR and planted with *T. vogelii* for twelve weeks. The pots were replicated six times and arranged in a completely randomized design. The parameters assessed include plant height and dry matter yields at three and twelve weeks and shoot N and P contents at twelve weeks.

Soil pH 5.9 had significant ($P \leq 0.05$) effect on plant height, dry matter yields, shoot N and P concentration and shoot N and P uptakes. Application of P as MPR significantly ($P \leq 0.05$) increased these parameters on both soil pH values. The results suggest that in strongly acid soils with low available P, *T. vogelii* biomass will be improved by addition of MPR.

Key words: T. vogelii, soil pH, Ferralsol, Minjingu phosphate rock, plant height, dry matter yields, shoot N and P concentrations and shoot N and P uptakes

Introduction

Low soil pH and inadequate levels of N and P are common features in highly weathered tropical soils (Fox *et al*., 1985; National Soil Service, 1989), and are among major factors limiting crop production in sub-Saharan Africa (Eswaran *et al.*, 1997). Soil pH *per se* is not the growth limiting factor but rather one or more secondary factors, which are pH dependent (Mengel and Kirkby, 1982). Some of the pH dependent secondary factors, which limit plant growth at low soil pH include Al and Mn toxicity, fixation and hence unavailability of P and deficiency of Ca and Mo. Others are depression of the activity of microorganisms involved in nitrification and N fixation and inhibition of the activity of symbiotic microorganisms, which lead to poor nodulation of some legumes (Brady, 1984). The situation is even worse when such soils are continuously cultivated without addition of any fertilizers. The overall consequences are low crop yields, persistent food insecurity, malnutrition and wide spread rural poverty.

In order to remain productive, such soils need to be carefully managed. Use of fallows (particularly improved fallows) - a common feature of small scale farming throughout the tropics can achieve this goal. Improved fallows consists of deliberately planted species-usually legumes with the primary purpose of fixing N_2 as part of a crop-fallow rotation (Sanchez, 1999). Improved fallows have the advantage of *in-situ* accumulation of biomass, optimisation of nutrient cycling, enhancing soil biological activities and maximising the use efficiency of minimal external inputs (Sanchez, 1994). *T. vogelii* Hook. F. is one of the indigenous leguminous shrubs with high potential of improving soil fertility when used in improved fallow situations (Balasubramanian and Sekayange, 1992). This species is a valuable leguminous cover crop in grass areas, relatively resistant to periodic fires, unpalatable to animals and hence a suitable fallow species in places where livestock are traditionally allowed to graze crop residues in the fields after harvest

(ICRAF, 1993). As a fallow species, *T. vogelii* has been reported to increase significantly yields of maize in Tanzania (Mgangamundo, 2000), maize in Malawi and Zambia (Kwesiga *et al*., 1999) and maize, sorghum and beans in Rwanda (Balasubramanian and Sekayange, 1992; Hagedorn *et al*., 1997).

The soil fertility improvement potential of *T. vogelii* fallow has been noted in Nyabisindu, Rwanda (Prinz, 1986) and in Gairo, Tanzania (Mgangamundo, 2000). The chemical constituents of *T. vogelii* foliar biomass as analysed in different laboratories are 2.85-4.0 % N, 0.38 % P, 1.03 % K, 1.89 % Ca, 0.16 % Mg, 8.0-8.3 % lignin, 2.37 % polyphenols, 21.1 % cellulose and 0.97 % retonones (Hagedorn *et al*., 1997; Mutuo *et al*., 1998; TSBF, 1999). However, poor growth of *T. vogelii* at Morogoro in Tanzania has been reported (Mugasha, 1999 Personal Communication). Also, Ngazi and Kapinga (1998) reported low cotton and cassava yields following a one year of *T. vogelii* fallow at Ukiriguru, Tanzania. Low cotton and cassava yields were attributed to low biomass produced by yield *T. vogelii*. Inadequate levels of available P at low soil pH could be the causal factors. Donald and Williams (1955) noted that generally legume growth and *Rhizobium* symbiosis are sensitive to available P. Phosphorus deficiency reduces nodulation, N_2 fixation and plant growth. Research elsewhere reported that low available P limits N_2 fixation and growth of *Leucaena lucocephala* and *Sesbania goetzei* (Luyindula and Haque, 1992). Hence in order to optimise the benefits from *T. vogelii* fallows, it is important to identify soil factors that may limit its performance. Based on this background, a glasshouse experiment was conducted using two soils with Bray-I low available P (2.5-2.9-mgP kg^{-1}) and low soil pH (pH 5.0 and 5.9), applied with and without P as MPR and *T. vogelii* as a test agroforestry species. The objectives of the experiment were as follows:

- To assess the effect of low soil pH on *T. vogelii* growth and shoot N and P contents.
- To evaluate the effect of MPR applications on such soils on *T. vogelii* growth and shoot N and P contents.

Materials and Methods

General description of the study area

The soils for the glasshouse trial were obtained from experimental site located in the Sokoine University of Agriculture (SUA) Farm, in Tanzania at longitude 37°39'12.4"E and latitude 06°50'24.5"S, and an elevation of 540 m above sea level. The experimental site has a slope of about 1.5 - 2%. Prior to field experimentation, the soils of the site were classified by using both World Reference Base for Soil Resources (1998) as Hyperdystri-

Umbric Ferralsol and by Soil Taxonomy system (Soil Survey Staff, 1998) as Typic Haplustox (Table 18.1). The soil pH of the site is variable and thus two soil samples, one with pH 5.0 and another with pH 5.9 were collected from different areas of the field and used for the glasshouse study. The two soils were analysed for selected chemical and physical properties using standard analytical methods as described by Okalebo *et al.* (1993) and the results are presented on Table 18.2. The glasshouse study was conducted between December and March 2001.

Table 18.1: Initial soil physical and chemical properties of trial site

Parameter	Magnitude
Sand (%)	36
Silt (%)	10
Clay (%)	54
Textural class	Clay
Soil pH (water)	5.06
Soil pH ($CaCl_2$)	4.60
Organic Carbon (%)	1.3
Total N (%)	0.07
C:N ratio	18.6
P (Bray-1 method) (mg kg^{-1})	2.1
Exchangeable Bases (me $100g^{-1}$)	
Ca	4.4
Mg	2.3
K	0.68
Na	0.18
Cu (mg kg^{-1})	1.13
Zn (mg kg^{-1})	0.63
B (mg kg^{-1})	Nd
Exch. Al^{3+} ($me100g^{-1}$)	0.005
Exch. H^{+} ($me100g^{-1}$)	0.11
Total Acidity ($me100g^{-1}$)	0.115

Glasshouse study

Five-litre plastic pots were filled with 5kg soil (air-dry weight) that was sieved through 8mm sieve. Two levels of P *viz.* 0 and 400mg P kg^{-1} soil were tested as MPR in a completely randomized design replicated six times. Basal applications of potassium (K), magnesium (Mg), and zinc (Zn) were made at the rate of 50 mg kg^{-1} soil K as K_2SO_4, 25 mg Mg kg^{-1} soil as $MgSO_4$ and 5 mg Zn kg^{-1} soil as $ZnSO_4$ kg^{-1} soil. Also, a starter N dose as NH_4SO_4 at 20 mg N kg^{-1} soil was applied because the N and O.C levels were < 0.12 and < 1.5 %, respectively. The fertilizers were thoroughly mixed with soil by hand and five *T. vogelii* seeds planted in each pot and then watered with deionized water to 80 % of the field capacity by weight as described by Klute (1986). The seedlings were thinned to two plants per pot one week after germination (WAG). *T. vogelii* plant height and dry matter yield data were collected at 3 and 12 WAG and N and P contents analysed in the plant samples collected at 12 WAG. Dry matter yield was obtained by cutting the plants at 2.0 cm above the soil, then washed to remove the adhering soil particles, weighed and then dried in an oven at 70°C to constant weight. The dried plant materials were weighed, cut into small pieces of about 1.0 x 0.5 cm and ground by Sample Mill to pass through 0.5mm sieve.

Table 18.2: Initial properties of two soils used in the Glasshouse study

Soil property	Soil 1	Soil 2
Sand (%)	36	34
Silt (%)	10	10
Clay (%)	54	56
Textural class	clay	clay
Soil pH (water)	3.0	3.9
Soil pH ($CaCl_2$)	1.63	1.60
Organic carbon (%)	1.3	1.2
Total N (%)	0.07	0.07
C:N ratio	18.6	17.1
P ($mgkg^{-1}$)	2.5	2.9
Exchangeable bases ($me100g^{-1}$)		
Ca ($me100g^{-1}$)	3.0	3.9
Mg ($me100g^{-1}$)	1.63	1.60
Na ($me100g^{-1}$)	0.23	0.19
K ($me100g^{-1}$)	0.9	0.68
Cu ($mgkg^{-1}$)	1.3	1.2
Zn ($mgkg^{-1}$)	0.64	0.63

Laboratory Analyses

Laboratory methods as described by Okalebo *et al.* (1993) were used for both soil and plant analysis. Soil pH was measured using 1:2.5 soil-water and 1*M*-potassium chloride mixture using a pH meter. Available P was extracted using the Bray-1 reagent and was determined colourimetrically after developing colour with ascorbic acid. Organic carbon was determined by the wet digestion method of Walkley-Black method. Total N was determined by the macro-Kjeldahl digestion-distillation method. Cation exchange capacity (CEC) was determined by the ammonium saturated method. Available Cu and Zn were extracted by the DTPA and their concentrations determined by AAS. Particle size analysis was done by the hydrometer method.

Phosphorus in plant samples was analysed using dry ashing method and determined colourimetrically while calcium was determined by AAS.

Statistical analyses

The data were analysed by MSTAT-C using completely randomized design. Significant means were separated using Duncan's New Multiple Range Test.

Results and Discussion

Plant height

Plant height of *T. vogelii* at three and twelve weeks as affected by soil pH and P application is given on Table 18.3. At three weeks, plant height on the soils without P applications was lower (11.62 cm plant^{-1}), on soil with pH 5.0 compared to soil with pH 5.9 (17.97 cm plant^{-1}), and at twelve weeks plant heights were 81.33 and 99.76 cm plant^{-1}for soil pH 5.0 and 5.9, respectively. The plant height for the soil with pH 5.9 without P application at 3WAG was higher (17.97 cm plant^{-1}) than that obtained on soil with pH 5.0 (15.6 cm plant^{-1}) with P application. The plant heights observed on soil that had pH 5.0 without P application were significantly ($P \leq 0.05$) different both at 3WAG and at 12WAG. Also, the plant heights for the soil pH 5.9 without P application and pH 5.0 with P application at 3WAG were statistically ($P \leq 0.05$) different. Low plant heights at soil pH 5.0 with P application at 3WAG is probably due to inadequate levels of some nutrients especially Ca (3.0 me100g-1) as compared to soil with pH 5.9 (3.9 me100g^{-1}) (Table 18.2). Application of P on soil with slightly higher levels of Ca and a lower level of Al^{3+} at 3WAG led to higher plant height (23.2 cm plant^{-1}) which was significantly ($P \leq 0.05$) different from the other treatments.

Table 18.3: Effect of soil pH and MPR applications on plant height (cm plant^{-1}) of *T. vogelii*

Treatment	3WAG	12WAG
Soil pH 5.0 -MPR	11.62 c	81.33 b
Soil pH 5.0 +MPR	15.60 c	93.00 a
Soil pH 5.9 -MPR	17.97 b	99.77 a
Soil pH 5.9 +MPR	23.20 a	104.37a
LSD (0.05)	1.53	11.56
Std error	0.44	3.341
C.V. (%)	5.81	6.12

The *T. vogelii* plant heights at three weeks on soil with pH 5.0 were 15.6 and 11.62 cm plant^{-1} for with and without P application, respectively. The plant heights for twelve weeks on soil with pH 5.0 were 93.03 cm plant^{-1} with P and 81.3 cm plant^{-1} without P application. P applications did not significantly increase plant heights at three weeks but significantly ($P \leq 0.05$) increased it at twelve weeks possibly due to increased Ca uptake and P dissolution from MPR (Rajan *et al.*, 1996) at 12 weeks.

At twelve weeks, application of P on soil with pH 5.9 increased plant height from 99.7 to 104.3 cm plant^{-1}. The increase in plant height for soil with pH 5.0 due to P application was statistically comparable to plant height obtained on soil with pH 5.9 without P application. The small increase in plant height on soil pH 5.0 that received P was caused by strong soil acidity, which depressed the activity of microorganisms involved in various activities (including nitrification) in the rhizosphere (Brady, 1984; Mengel and Kirkby, 1982).

Dry matter yield

The dry matter yield (DYM) of *T. vogelii* accumulated at three and twelve weeks as affected by soil pH and P application is shown on Table 18.4. At three weeks, P application on soils with pH 5.0 increased DYM from 0.75 to 1.2 gpot^{-1} and for the soil with pH 5.9 DYM increased from 1.2 and 1.8 gpot^{-1}. Soil at pH 5.0 without P application had significantly ($P \leq 0.05$) lower dry matter production than the other treatments. The dry matter production from the soil with pH 5.9 applied with P was significantly ($P \leq 0.05$) higher than the other treatments.

Table 18.4: Effect of soil pH and MPR applications on dry matter production (gpot^{-1}) of *T. vogelii*

Treatment	3WAG	12WAG
Soil pH 5.0 -MPR	0.75[c]	17.90[c]
Soil pH 5.0 +MPR	1.20[b]	34.80[b]
Soil pH 5.9 -MPR	1.20[b]	37.63[b]
Soil pH 5.9 +MPR	1.80[a]	51.33[a]
LSD (0.05)	0.21	7.98
Std error	0.061	2.306
C.V. (%)	8.40	11.28

At twelve weeks, the DMY was doubled by the application of P on the soil with pH 5.0. The dry matter production were 17.9 and 34.8g pot^{1} with and without P application, respectively. The DMY at soil pH 5.9 was also increased from 37.63 without P treatment to 51.3 gpot^{-1} in pots that were applied with P. The difference was significant ($P \leq 0.05$).

The observations made by Fox *et al*. (1985), Aggarwal, (1994) and Giller *et al.* (1998) using different N_2 fixing species are similar to the results obtained in this study with *T. vogelii.* Fox *et al.* (1985) in Hawaii assessed the growth response of *L. lucocephala* to varying soil pH that ranged from < 5 to > 7 and found that relative yield increased with increasing soil pH until above pH 7. The increased relative yield was attributed to improved Ca nutrition that was associated with increasing soil pH in the range of 6 to 7. Aggarwal (1994), assessed 15 bean varieties on limed soils with soil pH 4.6-5.0 and low available P 0.35-1.40 in Malawi and reported a linear increase in the nodule number and grain yield with increased lime application up-to 75 % level of Al neutralisation. Giller *et al.* (1998) observed that addition of P fertilizer (26 kgPha^{-1}) on soils with pH ranging from 5.8-7.0 and available P 0.2-6.6 mg Pkg^{-1} dramatically increased the number of root nodules, N and seed yields of *Phaseolus vulgaris* in farmers fields in the West Usambara Mountains in northern Tanzania.

Balasubramanian and Sekayange (1992) in Rwanda obtained contradicting results with other N_2 fixing species. These workers compared the responses of *Crotalaria ochroleuca, Mucuna pruriens, Cajanus cajan* and *Sesbania sesban* to P applications (9-40 kgPha^{-1}) on a soil with pH 5.1 and 7 mg kg^{-1} of Bray II P and reported that P applications had no effect on the biomass production.

Shoot N and P concentration and uptake at twelve weeks

Table 18.5 gives the shoot N and P contents (%) and their uptakes (g pot^{-1}) as influenced by soil pH and P application of twelve weeks old *T. vogelii.* MPR application increased shoots N content both at pH 5.0 and pH 5.9. At pH 5.0, N concentration increased from 2.3% in the pots that were not applied with P to 3.5 % in the pots that were applied with P while at pH 5.9 the corresponding increase was from 2.5 to 3.2 %. The N concentration for the soil of pH 5.9 treated with MPR was lower than the comparable treatment of pH 5.0. However, the N uptakes (g pot^{-1}) for the soil of pH 5.9 treated with MPR was higher than the comparable treatment of pH 5.0 confirming that there was more available P after MPR application. The N uptakes (g pot^{-1}) for the soil of pH 5.9 treated with MPR was higher because at this soil pH level the activities of micro-organisms involved in various processes like nitrification are increased (Brady, 1984; Mengel and Kirkby, 1982).

On both soil pH levels, the shoot N concentrations were significantly ($P \leq 0.05$) increased due to P application. Similar observation was made on *P. vulgaris*. Addition of P fertilizer (26kgPha^{-1}) on soils with pH ranging from 5.8-7.0 and available P (0.2-6.6 mg Pkg^{-1}) dramatically increased N content of *P. vulgaris* (Giller *et al.*, 1998). The shoot N content for both soils when P was not applied was statistically the same, which suggests that N_2 fixation was depressed due to possibly one or more secondary factors which are pH dependent (Mengel and Kirkby, 1982). Contrary to the observation made in this study Balasubramanian and Sekayange (1992), reported that P applications to *C. ochroleuca*, *M. pruriens*, *C. cajan* and *S. sesban* (9-40 kgPha^{-1}) on a soil with pH 5.1 and 7 mg kg^{-1} of Bray II P had no effect on N content of these fallow species.

Table 18.5: Effect of soil pH and MPR applications on shoot N and P concentration (%) and uptake (g pot^{-1}) of *T. vogelii* after twelve weeks

Treatment	Shoot concentrations (%)		N and P uptake (g pot^{-1})	
	N	P	N	P
Soil pH 5.0 -MPR	2.32^{c}	0.22^{d}	0.43^{c}	0.04^{c}
Soil pH 5.0 +MPR	3.53^{a}	0.32^{b}	1.26^{a}	0.12^{ab}
Soil pH 5.9 -MPR	2.53^{c}	0.25^{c}	0.95^{b}	0.09^{bc}
Soil pH 5.9 +MPR	3.21^{b}	0.35^{a}	1.28^{a}	0.18^{a}
LSD (0.05)	0.32	0.02	0.039	0.006
Std error	0.091	0.006	0.018	0.018
C.V. (%)	5.47	7.30	2.01	2.62

The shoot P concentrations and P uptakes as influenced by soil pH and P application at twelfth week are presented on Table 18.5. MPR application increased shoot P concentration at soil pH 5.0 from 0.22 % to 0.32 % for pots that were not treated with P and for pots that were treated with P, respectively. At soil pH 5.9, MPR application increased shoot P concentration from 0.25 % for pots that were not treated with P to 0.35 % for pots that were treated with P. These shoot P concentrations were significantly ($P \leq 0.05$) different, with the highest shoot P concentration on soil with 5.9. *T. vogelii* P uptake at twelfth week was also increased with MPR application on both soil pH levels tested. However, the P uptakes at both soil pH levels when MPR was applied were not significantly ($P \leq 0.05$) different suggesting that P is necessary for *T. vogelii* in soils with low pH. The P uptakes for the soil of pH 5.0 in pots that were treated with P were statistically similar to pots that were not treated with P at soil pH 5.9. Similar observations were made on *Tritcum aestivum* and *Lupinus albus*. Kamh *et al.* (1999) reported significant ($P \leq 0.05$) N and P uptakes and shoot dry weight of *T. aestivum* and *L. albus* after P application as $Ca(H_2PHO_4)_2$.

Conclusion

From this pot experiment, the following conclusions can be made:

- On soils low in pH (strongly acid soil) and low available P, *T. vogelii* performance is appreciably reduced.
- On soils with low soil pH and low levels of available P, improved *T. vogelii* performance is observed when P levels are increased.
- Applications of P as MPR significantly increase *T. vogelii* plant height, dry matter yield, shoot N and P concentrations and shoot N and P uptakes. However, the increase of these parameters on a more strongly acid soil (pH 5.0) applied with MPR was lower than that obtained on soil pH 5.9, suggesting that P was not the only nutrient element limiting *T. vogelii* performance on soil with pH 5.0.

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