Effect of organic and inorganic phosphate fertilizers and their combination on maize yield and phosphorus availability in a Yellow Earth in Myanmar

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Abstract

Phosphorus (P) deficiency is a major constraint for crop production in many parts of the world including Myanmar and field research into management of P fertilisers and P responsiveness of crops on infertile soils has been limited. The purpose of this study is to determine maize yield response to different forms of P fertilisers on an acidic (pH 4.9) P deficient Yellow Earth (Acrisol) in Southern Shan State, Myanmar and to establish relationship between soil Olsen-P test values (0.5 M sodium bicarbonate extracted P) and maize yield. Field experiments were conducted during two cropping seasons. There were 15 treatments in total: P was applied at 7 rates of a soluble P fertiliser as Triple superphosphate (TSP) (0 to 120 kg P ha^{-1}) to establish a P response curve; one rate of a partially soluble P fertiliser (Chinese partially acidulated phosphate rock, CPAPR) and two organic P fertilisers (farmyard manure (FYM) and *Tithonia diversifolia*) at 20 kg P ha^{-1}; combination of TSP and CPAPR at 20 kg P ha^{-1} with FYM and *T. diversifolia* at 20 kg P ha^{-1}; an additional treatment (TSP 20 kg P ha^{-1} plus 2.5 t ha^{-1} dolomite) for assessing the liming effect of a local dolomite.

In Year 1, applications of TSP at 40–60 kg P ha^{-1} produced near maximum grain yields, whereas in Year 2 this could be achieved with a reapplication of 20–30 kg P ha^{-1} on top of the residual value of the Year 1 application. In both years, CPAPR, TSP and *T. diversifolia* significantly increased maize grain yield, but FYM failed to increase grain yield. In Year 1, CPAPR and TSP effects on grain yield were higher than that of *T. diversifolia* but in Year 2 the effects were same for all these three treatments. The combination of FYM (20 kg P ha^{-1}) or *T. diversifolia* (20 kg P ha^{-1}) with TSP (20 kg P ha^{-1}) or CPAPR (20 kg P ha^{-1}) was as effective as TSP (40 kg P ha^{-1}) applied at an equivalent P rate for optimum grain yields of maize in both years. The combined data from the two years experiment suggests that 90% of maximum maize grain yields can be obtained by raising the Olsen-P to 30-35 mg P kg^{-1} soil at the silking stage of growth. Olsen-P for the treatments at silking in Year 1 was: Control $<$ FYM, *T. diversifolia* $<$ TSP, CPAPR and in Year 2 was: Control $<$ FYM $<$ *T. diversifolia* $<$ TSP, CPAPR. The results showed that for a long-term approach, repeated annual applications of *T. diversifolia* can be considered as a potential P source for improving soil P status in the Yellow Earth.

Keywords: Phosphate fertiliser; partially acidulated phosphate rock; *Tithonia diversifolia*; Olsen-P, Yellow Earth; Acrisol, Maize

Introduction

The fertility of many tropical soils in the world including the Red Earths and Yellow Earths (Acrisols in FAO/UNESCO classification) in the highlands of Myanmar are gradually degrading due to shifting cultivation with shortening fallow periods, and insufficient use of fertilizers, manures and restorative crops in current soil fertility management practices by farmers. Acrisols have very low available phosphorus (P) status for optimum production of crops (Aye 2001; Ikerra et al. 2006). These soils also have low pH, low soil organic matter (SOM) content that results in limited nitrogen (N), P and sulphur (S) reserves and low effective cation exchange capacity (ECEC) resulting in poor retention of exchangeable basic cations. Application of P fertilizers, especially watersoluble P, and liming have been shown to improve P availability and reduce acidity in the Red Earths and Yellow Earths, and increase crop yield (Sanchez and Uehara 1980; Naidu 1985; von Uexku¨ll and Bosshart 1989; Budianta 1999; Cong 2000). Imported water-soluble P fertilizer (Triple super phosphate, TSP) is expensive, but it is the major P fertilizer used to correct P deficiency in many tropical counties including Myanmar. Water-soluble P fertilizers will supply P immediately after application but a greater proportion of the dissolved P might get fixed in the soil and thus become unavailable to the crops. Recently there has been renewed research interest in using partially acidulated phosphate rocks, PAPRs (Hammond et al. 1986); organic manures (Budianta 1999; Cong 2000; Nziguheba et al. 2002; Cong and Merckx 2005; Ikerra et al. 2006) as alternatives to expensive water-soluble fertilizers to improve soil P fertility and yield sustainability in the tropical regions. The sulphuric acid acidulated PAPRs are often the most economic P fertilizers because they have immediately available soluble P, greater residual P value and an agronomically useful S supply (Gregg et al. 1988). The addition of organic manures (plant residues and animal manures) increases organic matter (OM) content and nutrient reserves in soils (Khaleel et al. 1981; Darmody et al. 1983; Hue 1992; Falih and Wainwright 1996). Application of green manures such as Tithonia diversifolia (Tithonia) to low P soils increase maize yields by improving P availability and providing extra supply of P during their decomposition (Nziguheba et al. 2002; Cong and Merckx 2005; Ikerra et al. 2006). Tithonia is widespread in the uplands of Southeast Asian countries including Myanmar. The plant has relatively high concentrations of N, P, K as well as other nutrients such as Ca and Mg (Jama et al. 2000; Cong and Merckx 2005). Field research into evaluation of the agronomic effectiveness of phosphate rocks (PR) and green manure (Tithonia) on infertile upland soils has been conducted in tropical Africa regions (Nziguheba et al. 2002; Ikerra et al. 2006). Integrated application of Tithonia with modest rates of soluble P fertilizer as TSP has also been documented (Nziguheba et al. 2002). However, research on the agronomic effectiveness of various forms of inorganic and organic fertilizers and their combinations on crops on infertile upland soils are still lacking in tropical Southeast Asia regions. In recent years, Myanmar farmers have realized that maximum returns per investment in fertilizer are required, rather than maximum production per hectare and this has been forcing farmers to purchase cheaper P fertilizers such as PR, PAPR and organic manures (FYM and Tithonia). Combination of organic manures with modest rates of inorganic P fertilizers (TSP and CPAPR) could be a cost-effective and more appropriate option for smallholder farmers. Such combinations might provide both immediately available and slowly available P to crops and also improve many soil chemical, physical and biological properties. Organic manures, especially Tithonia has also been shown to ameliorate soil acidity (Haynes and Mokolobate 2001; Cong and Merckx 2005). Olsen-

P test is a common soil test method used to assess the soil P fertility levels for many crops throughout the world. However, before using this test it is essential that this test should be calibrated against crop yield response to different rates of P application in the region of interest. Availability of such calibrations is limited for maize production in Myanmar and many other tropical countries. This study was designed to evaluate methods of overcoming P limitations on maize growth by using low-cost locally available organic and inorganic P fertilizers that may be economically attractive alternatives to poor smallholder farmers than the use of more expensive imported P fertilizers in tropical soils. The paper presents the results of a 2-year field trial on determining the effects of organic and inorganic P fertilizers and their combinations on maize yield and establishing the optimum Olsen-P test value for obtaining economical yield in Myanmar Acrisols.

Materials and methods

Experimental site

A 2-year maize field experiment was conducted during two growing seasons at Aungban Research Farm (96839.430 East Longitude and 20840.750 North Latitude) in Kalaw Township, Southern Shan State, Myanmar. The experimental area is described as sub-tropical highlands with undulating landscapes. The elevation of the site is 1,280 m above mean sea level. The average annual rainfall of between 780 and 1,320 mm was concentrated within a growing period of only 5 months (June–October). In the experimental area maximum temperature was between 31 and 33ºC in March–April and minimum temperature was 2ºC in January. The soil was a Yellow Earth and is described as an Orthic Acrisol in the FAO/UNESCO system. Some of the relevant chemical characteristics of 30 soil samples from the experimental site are presented in Table 1.

Experimental design and treatments

The experimental design was a randomized complete block design with four replications. A soluble (Triple superphosphate, TSP), a partially soluble (Chinese partially acidulated (50% sulphuric acidulated) phosphate rock, CPAPR) and two organic phosphorus (FYM and Tithonia) fertilizers were used. The physical form, and the total P contents of the fertilizers and the percentage of total P soluble in water, citric, and formic acids of the manufactured fertilizers are presented in Table 2. The solubility of CPAPR contained 56% less P by weight than TSP and its P content was only 47% soluble in water. The low (58%) solubility of CPAPR in 2% citric acid (less concentrated, chelating acid) compared to the high solubility (94%) in 2% formic acid (a more concentrated non-chelating acid) indicates that the unacidulated P is unlikely to be associated with iron and aluminium phosphates and more likely to be associated with a relatively reactive apatite residue (Bolan et al. 1990). There were nine treatments for organic and inorganic sources at two P rates (20 kg P ha-1 and 40 kg P ha-1) and seven treatments for P response curve with two common treatments (9 ? 7 - 2 = 14). The range of different rates of TSP was 0–120 kg P ha-1 for the P response curve. The experiment included an additional treatment, which was soluble P (20 kg P ha-1 as TSP) plus a dolomite (\250 *l*m particle size) rate of 2.5 t ha-1. Dolomite was included in the experiment for assessing the liming effect of the local dolomite. The total number of treatments were therefore 15 (Table 3). The plot size for each treatment was 5 m 9 6 m, with 20 seed hills in eight rows and maize plant spacing was 25 cm 9 75 cm. All plots were supplied with urea (50 kg N ha-1) and KCl (50 kg K ha-1) as a basal application.

Subsequent dressings of N fertilizer at a rate of 25 kg N ha-1 as urea were applied to maize at 3 weeks after emergence and again at the silking stage. Triple superphosphate, CPAPR, FYM and the basal fertilizers were applied in a band in the centre between rows of plants (width 25–30 cm) approximately 5 cm deep and incorporated, prior to seeding in June 1998 Tithonia and dolomite were broadcast over each plot and incorporated into the soil. Immediately after the P fertilisation of the plots, Maize (Zea mays; local hybrid var. Yezin 3) as a test crop in this experiment was shown in June–September 1998 and subsequent year in June–September 1999.

Soil and herbage sampling

Soil samples (composite of ten cores (diameter 20 mm), 0–15 cm soil depth) were taken from each plot before fertilizer application (initial), at 21 days after crop emergence (21 DAE), and at silking in both 1998 and 1999. Soil samples were air-dried, sieved to pass a 2 mm mesh and stored for chemical analysis. Herbage samples (fully expanded young leaves and the whole plants) were collected from four representative maize plants in each plot at 3 weeks after emergence and again at silking. At harvest, herbage samples were collected from six representative plants and dry matter (DM) yields were measured using 40 plants from each plot. The soil samples were air freighted to New Zealand from Myanmar under the NZMAF Biosecurity Authority Control for chemical analysis. After the completion of this study all these samples were incinerated.

Relative agronomic effectiveness and substitution ratio of P fertiliser

The relative agronomic effectiveness (RAE) of P fertilisers at different P rates relative to reference P fertiliser was calculated using the following equation (Mnkeni *et al.*, 2000).

$$RAE\ (\%) = (Y_F - Y_C) / (Y_T - Y_C) \times 100$$

where Y_F = yield from P fertiliser, Y_T = yield from reference fertiliser (in this case TSP), and T_C = yield from the control treatment. In this equation the RAE is used as vertical comparison of fertilisers

The substitution ratio (SR) of P fertiliser was compared by calculating the amount of reference fertiliser required to produce same yield response (Chien *et al.*, 1990). The substitution ratio of P fertiliser is known as horizontal comparison of fertilisers and this is calculated using the following equation.

$$SR = X_{RF}/X_{TF}$$

where X_{RF} = reference fertiliser rate (in this case TSP) and X_{TF} = test P fertiliser rate, required to produce the same yield response. It is to be remembered that all the test fertilisers were evaluated at one P level (20 kg P ha^{-1} for CPAPR, FYM and *T. diversifolia*). Therefore to calculate the SR values, the P level required as TSP to achieve the maize yields obtained at 20 kg P ha^{-1} for the test fertiliser was estimated from the TSP response curve.

Soil and herbage analysis

Soil samples were analysed for plant available P using standard soil test "Olsen P" by extraction with 0.5 M $NaHCO_3$ (Olsen et al., 1954). Olsen P test was selected because this is the common soil test used in Mayanmar and many other Southeast Asian countries (Aye 2001). Herbage samples were dried at 105º C for 2 h and weighed for determining dry matter yield.

Statistical analysis

Results were tested for significant differences between treatment means. An analysis of variance was performed on measured and calculated variables using the general linear models (GLM) procedure of SAS statistical analysis package (SAS, 1989). The data points were analysed by regression method using cfit program for curve fit.

Results and Discussion

Effect of P fertilisers on Olsen-P test-Year 1

Before application of P fertilisers in Year 1, the initial Olsen-P values for all treatments were not significantly different (average 6.7 ± 0.09 mg Olsen-P kg^{-1}) (Table 2). However, at 21 DAE and silking (approximately 58 DAE), increased rate of addition of TSP significantly ($P<0.05$) increased Olsen-P showing that the P availability in the soil significantly responded to P fertiliser application within a month.

At 21 DAE, the Olsen-P values were significantly higher in P treatments than in control treatment, except for FYM 20, *T. diversifolia* 20, TSP 10 and FYM 20 + CPAPR 20 kg P ha^{-1} ($P<0.05$) (Table 2). There was considerable variation between

Olsen-P values for the TSP treatment replicates (Figure 1) which was presumably caused by uneven mixing and sampling of the TSP banded fertiliser within the soil. The TSP and CPAPR raised the Olsen-P values significantly higher, compared to the organic materials at 20 kg P ha^{-1} rate (Table 2).

The major difference between samples taken at 21 DAE and silking was that Olsen-P values at silking in all plots treated with P fertilisers were significantly higher than the control ($P<0.05$) (Table 2); whereas at 21 DAE, all the P treatments except the organic materials (FYM and *T. diversifoli*) and combinations of FYM and CPAPR at 20 kg P ha^{-1}increased Olsen-P values ($P<0.05$). At silking, combinations of TSP and CPAPR at 20 kg P kg^{-1} with organic materials at 20 kg P ha^{-1} caused similar increases in Olsen-P values ($P<0.05$) and these values were not significantly different from values for TSP treatment at 40 kg P kg^{-1}. This shows that Olsen-P can be maintained by 50% substitution of the P input from TSP and CPAPR with organic fertilisers. Dolomite + TSP treatment significantly ($P<0.05$) increased soil pH to 5.51 compared with soil pH of 5.01 for TSP alone treatment but this increased pH had no effect on Olsen-P. In acidic soils, increase of pH is expected to increase availability of P by reducing the surface adsorption of P by soil colloids only if there was an adequate reserve of native P. Possible reasons for dolomite not increasing Olsen P in spite of it increasing soil pH could be that the soils at the trial site may be poor in reserve P and/or the pH increase (0.50 unit) was not sufficient to cause an increase in Olsen-P. The pH for dolomite treatment (pH 5.51) was lower than that for *T. diversifolia* treatment (5.92). The reason for the lower pH effectiveness of dolomite may be that dolomite may not have appreciably dissolved during the period of the trial.

Effect of P fertilisers on maize DM yield-Year 1

At the earlier stage of 21 DAE, the lower rates of water-soluble P applied as TSP (10 and 20 kg P ha^{-1}) as well as the FYM and *T. diversifolia* applied at 20 kg P ha^{-1} did not significantly increase DM yield of maize above that of the control. However, at harvest, the DM yield showed a significant (P<0.05) response to all rates of TSP application, but not to FYM and *T. diversifolia* applied at 20 kg P ha^{-1} (Table 3). Though *T. diversifolia* did not increase DM, it increased grain yield. But both the DM and grain yield from FYM and *T. diversifolia* applied at 20 kg P ha^{-1} were significantly lower than those for TSP. The combinations of TSP and CPAPR at 20 kg P ha^{-1} with organic materials at 20 kg P ha^{-1} produced similar grain yields as TSP applied at 40 kg P ha^{-1} because the Olsen-P values were similar (Table 2). Therefore, as reported under Olsen-P discussion, the grain yield data also shows that 50% of the inorganic P fertilisers can be substituted by organic P fertilisers to obtain the same yield as from the use of 100% inorganic P fertiliser.

CPAPR applied at 20 kg P ha^{-1} was as effective as TSP applied at the same rate for DM yield at silking (Table 3) and this similar (or slightly greater) agronomic effectiveness was also mirrored in grain yields.. Addition of dolomite to TSP produced slightly more DM and grain yield than TSP alone at 20 kg P ha^{-1}, however, this was not significant at P<0.05. As discussed in the previous section, dolomite significantly reduced soil acidity (pH increased) but had no effect on Olsen-P. The absence of DM and grain yield response to dolomite therefore indicates that P deficiency is more critical than soil acidity at the trial site.

Maize DM yields at silking as influenced by increasing rates of TSP application have been plotted as data points in Figure 2 and a soluble P fertiliser response curve has been obtained by least squares fitting of a Mitscherlich equation. The response curve explains 89% of the variation in DM yield caused by increasing rates of soluble P, and indicates that near maximum (>90%) yields were obtained from applications of P varying from 80 to 120 kg P ha^{-1}. The mean DM yields produced by other fertilisers are represented as vertical bars. Figure 2 clearly shows that *T. diversifolia* and FYM alone are ineffective in providing P for maize plants, being less than 30% as effective as TSP applied at the same rate (using a vertical comparison of Mnkeni *et al.* (2000) at 20 kg P ha^{-1}). Substitution ratio or Horizontal comparison (using the equation of Chien *et al.*, (1990) suggests that by the time maize had reached silking stage, FYM and *T. diversifolia* were only 15 and 30% as effective as TSP.

There was a significant curvilinear relationship between P added as TSP and maize grain yield at harvest (Trend line in Figure 3). Greater than 90% of maximum grain yields were obtained with TSP applications of 40 to 60 kg P ha^{-1}. Substitution ratios calculated using the TSP response curve for grain yield indicated that both the organic sources were <20% as effective as P sources compared to TSP. Farm yard manure was particularly poor with a Substitution ratio of <5%.

Relationship between soil Olsen-P status and DM yield of maize-Year 1

A growth response curve using P fertiliser applied as the predictor (Figure 3) is not a portable model to use for determining the P fertiliser requirements in other locations (farmers fields) because soil contributions to plant P uptake may vary from site to site. The combined tools of soil testing, knowledge of how much P is required to raise the soil P test values and the P test values that are associated with optimum yields provide more portable diagnosis of P fertiliser requirements. For this reason the DM yields at silking and grain yields have been replotted against the Olsen-P soil test values from the soil sampling at 21 DAE.

The plots showed that there was a significant asymptotic relationship between soil Olsen-P values at 21 DAE and DM yield of maize at silking stage or grain yield at harvest (Figures 4 and 5). The trend line for DM yield at silking (Figure 4) suggests that 90% of maximum yield occurs at an Olsen-P value of 50 mg P kg^{-1} at 21 DAE. The trend line for grain yield (Figure 5), however, indicates that 90% of maximum grain yield can occur with an Olsen value of 34 mg P kg^{-1}soil. As grain yield provides the economic return to the farmer this is perhaps the better relationship to adopt for preliminary advice.

Effect of P fertilisers on soil P test values and DM yields in Year 2

Prior to fertiliser application in Year 2 the initial Olsen-P tests for all treatments were slightly higher (Table 4) than the initial Olsen-P test values in Year 1 (Table 2). This is due to the residual effect of P fertilisers applied in Year 1. After reapplication of fertilisers, the increasing rates of TSP not only significantly increased soil Olsen-P values (Table 4) but also the maize DM yield (Table 5).

At the fertilisation rate of 20 kg P ha^{-1}, CPAPR gave similar Olsen-P test values compared to TSP alone (Table 4), thus they also produced similar amounts of maize DM yield at the silking stage (Table 5) as observed in Year 1. The significant increase in Olsen-P obtained through addition of CPAPR implied that PAPRs have immediately available soluble P (Hammond *et al.*, 1986; Gregg *et al.*, 1988) and also it underwent considerable dissolution in this low pH soil. However CPAPR dissolution is a slow process and hence greater Olsen-P could be expected in the subsequent years from CPAPR. FYM failed to significantly raise Olsen-P values at 20 kg P ha^{-1} rate and also did not increase the maize DM yield. This finding confirms the Year 1 result that the local FYM at the rate of 20 kg P ha^{-1} cannot supply enough immediately available P required for optimising maize growth in the short-term. *T. diversifolia* was slightly better than FYM, in that by 21 DAE in Year 2 the Olsen-P value had been increased significantly above the control. Also, unlike FYM, *T. diversifolia* significantly increased grain yield (Table 5) as in Year 1 (Table 3). Although Olsen-P value for *T. diversifolia* was significantly lower than that for TSP, the grain yields for these two treatments were similar probably because *T. diversifolia* known to reduce soil acidity and aluminium concentration in soils (Cong and Merckx 2005; Ikerra et al. 2006) which may have contributed to better maize growth in this trial. The soil pH at the end of Year 1 trial was 5.01 for TSP treatment and 5.92 for *T. diversifolia* treatment.

Relationship between Olsen-P values and maize yield in Year 2

As in Year 1, there were significant asymptotic relationships between soil Olsen-P value at 21 DAE and DM yield of maize at silking stage (Figure 8) and grain yield (Figure 9). The trend line suggests that 90% of maximum DM yield at silking occurs at an Olsen-P of 44 mg P kg^{-1} at 21 DAE (Figure 8). The curvilinear relationship for Year 2 grain yield suggests that 90% of maximum yields can be obtained at Olsen-P values of 28 mg P kg^{-1} soil (Figure 9). This value is close to the value of 34 mg P kg^{-1} soil obtained in Year 1 (Figure 5).

Conclusion

The two-year maize experiment on a Yellow Earth showed that application of P at the rate of 20 kg P ha^{-1} in the form of TSP, CPAPR, and *T. diversifolia* significantly increased maize grain yield in both years. FYM application had no effect on the yield. In Year 1, application of TSP at the rate of 40–60 kg P ha^{-1} produced near maximum yields, whereas in Year 2 this could be achieved with a reapplication of 20–30 kg P ha^{-1} on top of the residual value of the Year 1 application. In both years CPAPR produced similar yields as TSP at 20 kg P ha^{-1}. *T. diversifolia,* however, produced similar yield as CPAPR and TSP only in Year 2; in Year 1 it produced a lower yield because there was not enough time for this organic material to decompose and release P to soil. Therefore, for a long-term approach, repeated annual applications of *T. diversifolia* can be considered as a potential P source for improving the soil P status in the Yellow Earth.

The combination of FYM (20 kg P ha^{-1}) or *T. diversifolia* (20 kg P ha^{-1}) with TSP (20 kg P ha^{-1}) or CPAPR (20 kg P ha^{-1}) was as effective as TSP (40 kg P ha^{-1}) applied at an equivalent P rate for optimum grain yields of maize in both years. Therefore, another approach to P fertilisation is to substitute 50% of the inorganic P fertilisers by organic P fertilisers to achieve the same yield as from the use of 100% inorganic P fertiliser.

Olsen-P test is found to be a useful predictor of yield and effectiveness of fertilisers in the Yellow Earth. The combined data from the two years suggests that 90% of maximum grain yields can be obtained by raising the Olsen-P to 30-35 mg P kg^{-1} soil.

Acknowledgements

Ministry of Foreign Affairs and Trade of New Zealand Government for providing a Doctoral scholarship to Dr Tin Maung Aye through New Zealand Official Development

Assistance. The Acid soils network of the former International Board for Soil Research and Management (IBSRAM), and Fertilizer and Lime Research Centre of Massey University, for financial and technical support for this study.

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Table 1. Selected chemical characteristics of the Yellow Earth (0-15cm) at the field experiment site at Aungban, Southern Shan State (the average of 30 soil samples).

Chemical characteristic	**Value**
pH	4.9 (soil:water ratio of 1:2.5)
Available P	8 mg Olsen-P kg^{-1} (Olsen et al., 1954)
ECEC	5 meq % (IBSRAM, 1994)
Total P	327 mg kg^{-1} (Parkinson and Allen, 1975)
P retention	71% (Saunders, 1965)
Carbon	1.1% (Walkley and Black, 1934)

Table 2 Properties of the P fertilizers used in the trial

Fertilizer	**Form**	**Water-soluble Pa**	**Citric acid soluble Pa**	**Formic acid soluble Pa**	**Total P (%)**

TSP	Granular	93.5	94.1	97.6	20.6
CPAPR	Powder	47.2	58.3	94.0	11.6
FYM	Solid	-	-	-	1.1
Tithonia	Wilted hay	-	-	-	0.1

a Percentage of total P; methods of analyses as described by Hedley et al. (1988)

Table 3. Soil Olsen-P values at initial, 21 DAE and silking of maize grown on the Yellow Earth fertilised with different P fertilisers and rates in Year 1.

Treatment	**Soil Olsen-P (mg P kg^{-1} soil)**		
	Initial	**21 DAE**	**Silking**
Control 0 kg P ha^{-1}	6.8	6.2g	4.7f
TSP 20 kg P ha^{-1}	6.7	20.2de	22.4d
CPAPR 20 kg P ha^{-1}	6.8	16.5ef	23.5d
FYM 20 kg P ha^{-1}	6.9	6.6g	10.1e
FYM 20 kg P ha^{-1} + TSP 20 kg P ha^{-1}	6.2	15.9ef	23.4d
FYM 20 kg P ha^{-1}+ CPAPR 20 kg P ha^{-1}	6.9	14.0efg	19.8d
T. diversifolia 20 kg P ha^{-1}	6.7	7.5g	13.2e
T. diversifolia 20 kg P ha^{-1} + TSP 20 kg P ha^{-1}	6.3	21.3de	24.1d
T. diversifolia 20 kg P ha^{-1} + CPAPR 20 kg P ha^{-1}	6.6	17.6def	23.6d
TSP 10 kg P ha^{-1}	6.4	10.6fg	11.1e
TSP 40 kg P ha^{-1}	7.2	24.9d	24.6d
TSP 60 kg P ha^{-1}	6.7	35.4c	32.9c
TSP 80 kg P ha^{-1}	6.5	55.9b	53.6b
TSP 120 kg P ha^{-1}	7.5	103.9a	111.1a
TSP 20 kg P ha^{-1}+ Dolomite 2.5 t ha^{-1}	6.9	19.14de	24.9d
LSD ($P<0.05$)	NS	7.9	5.3

Mean treatments followed by the same letter in a column are not significantly different at P<0.05.

Table 4 Dry matter yield at 21 DAE and silking stage, and stover and grain yields at harvest of maize grown on Yellow Earth in Year 1.

Treatment	**Dry mater yield**			
	21 DAE (g plant^{-1})	Silking (g plant^{-1})	Stover (kg ha^{-1})	Grain (kg ha^{-1})
Control 0 kg P ha^{-1}	1.2e	7f	3459h	424f
TSP 20 kg P ha^{-1}	1.9cde	103d	6627ef	2583cd
CPAPR 20 kg P ha^{-1}	2.4cd	112cd	5769g	2484d
FYM 20 kg P ha^{-1}	0.8e	24ef	3481h	601f
FYM 20 kg P ha^{-1} + TSP 20 kg P ha^{-1}	2.4cd	105d	8113c	3111b
FYM 20 kg P ha^{-1}+ CPAPR 20 kg P ha^{-1}	2.9c	119cd	7934cd	3103b
T. diversifolia 20 kg P ha^{-1}	1.0e	35e	3974h	1127e
T. diversifolia 20 kg P ha^{-1} + TSP 20 kg P ha^{-1}	2.5cd	114cd	6332fg	2610cd
T. diversifolia 20 kg P ha^{-1} + CPAPR 20 kg P ha^{-1}	2.4cd	132c	7646dc	3144b
TSP 10 kg P ha^{-1}	1.9cde	44e	5607g	2317d
TSP 40 kg P ha^{-1}	3.0c	130c	7293de	2735bcd
TSP 60 kg P ha^{-1}	5.9b	167b	9939ab	4040a
TSP 80 kg P ha^{-1}	7.6a	219a	10238a	4121a
TSP 120 kg P ha^{-1}	6.5ab	204a	9427b	3877a
TSP 20 kg P ha^{-1}+ Dolomite 2.5 t ha^{-1}	2.8c	116cd	7275de	3041bc
LSD (P<0.05)	1.3	23	748	465

Mean treatments followed by the same latter in a column are not significantly different at $P<0.05$.

Table 5. Soil Olsen-P values at initial, 21DAE and silking stage of maize grown on the Yellow Earth in Year 2.

Treatment	**Soil Olsen-P (mg P kg^{-1})**		
	Initial	**21 DAE**	**Silking**
Control 0 kg P ha^{-1}	10.5h	9.8j	8.8i
TSP 20 kg P ha^{-1}	20.3ef	25.4e	23.5def
CPAPR 20 kg P ha^{-1}	19.0efg	24.7ef	26.0de
FYM 20 kg P ha^{-1}	9.8h	12.0ij	12.0h
FYM 20 kg P ha^{-1} + TSP 20 kg P ha^{-1}	16.5fg	22.3efg	22.8ef
FYM 20 kg P ha^{-1}+ CPAPR 20 kg P ha^{-1}	16.3g	21.1fg	20.2fg
T. diversifolia 20 kg P ha^{-1}	10.1h	16.3ih	17.5g
T. diversifolia 20 kg P ha^{-1} + TSP 20 kg P ha^{-1}	19.7efg	25.0ef	23.2ef
T. diversifolia 20 kg P ha^{-1} + CPAPR 20 kg P ha^{-1}	22.3de	24.7ef	24.0def
TSP 10 kg P ha^{-1}	20.0efg	19.8gh	16.5gh
TSP 40 kg P ha^{-1}	25.8d	31.3d	28.7d
TSP 60 kg P ha^{-1}	33.0c	37.4c	34.4
TSP 80 kg P ha^{-1}	41.8b	46.8b	44.6b
TSP 120 kg P ha^{-1}	47.5a	57.5a	75.3a
TSP 20 kg P ha^{-1}+ Dolomite 2.5 t ha^{-1}	18.9efg	24.5ef	25.8de
LSD ($P<0.05$)	3.8	4.3	5.1

Mean treatments followed by the same letter in a column are not significantly different at $P<0.05$.

Table 6 Maize dry matter yield at 21 DAE and silking, and maize stover and grain yields at harvest when grown on a Yellow Earth and fertilised with different P fertiliser sources and rates in Year 2.

Treatment	**Dry mater yield**			
	21 DAE (g plant^{-1})	Silking (g plant^{-1})	Stover (kg ha^{-1})	Grain (kg ha^{-1})
Control 0 kg P ha^{-1}	0.8e	24g	2435de	1935f
TSP 20 kg P ha^{-1}	3.0cb	100cd	5418a	3965cde
CPAPR 20 kg P ha^{-1}	2.7bcd	92cd	3743abcd	4178bcde
FYM 20 kg P ha^{-1}	1.1e	37fg	1675e	1400f
FYM 20 kg P ha^{-1} + TSP 20 kg P ha^{-1}	3.4b	101cd	4798ab	5155ab
FYM 20 kg P ha^{-1}+ CPAPR 20 kg P ha^{-1}	2.0cde	74def	3650de	3373bcde
T. diversifolia 20 kg P ha^{-1}	1.2e	54efg	2523cde	3120e
T. diversifolia 20 kg P + TSP 20 kg P ha^{-1}	3.5b	116bc	4498ab	4650abcd
T. diversifolia 20 kg P + CPAPR 20 kg P ha^{-1}	1.7de	95cd	4240abc	4148bcde
TSP 10 kg P ha^{-1}	2.6bcd	77de	3180bcde	3878cde
TSP 40 kg P ha^{-1}	5.4a	147ab	4025abcd	4560abcd
TSP 60 kg P ha^{-1}	6.0a	155a	4538ab	4963abcd
TSP 80 kg P ha^{-1}	6.1a	153a	3740abcd	5355a
TSP 120 kg P ha^{-1}	6.0a	146ab	4685ab	4775abc
TSP 20 kg P ha^{-1}+ Dolomite 2.5 t ha^{-1}	2.6bcd	104cd	3285bcde	4620abcd
LSD ($P<0.05$)	1.2	37	1770	1180

Mean treatments followed by the same letter in a column are not significantly different at $P<0.05$.

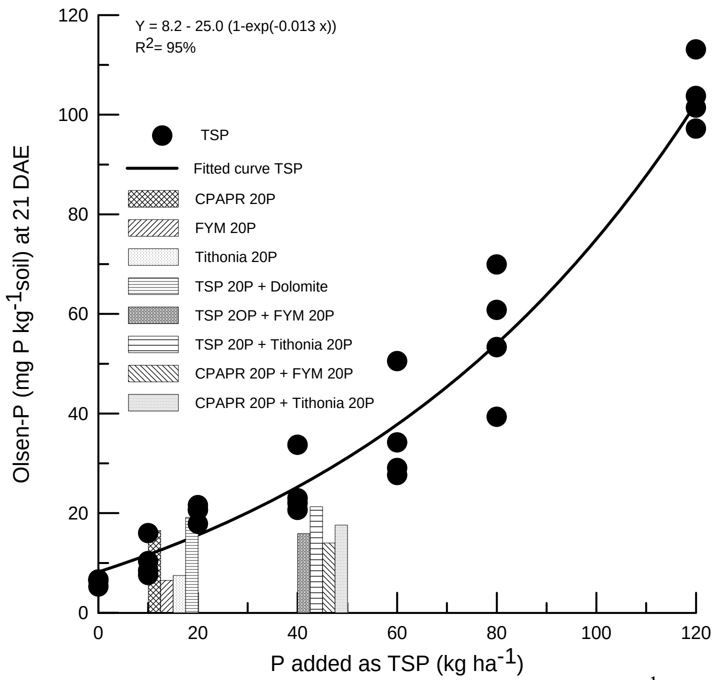

Figure 1 The effects of different P fertilisers of 20 and 40 kg P ha^{-1} rate on Olsen-P test values at 21 DAE of maize (1998).

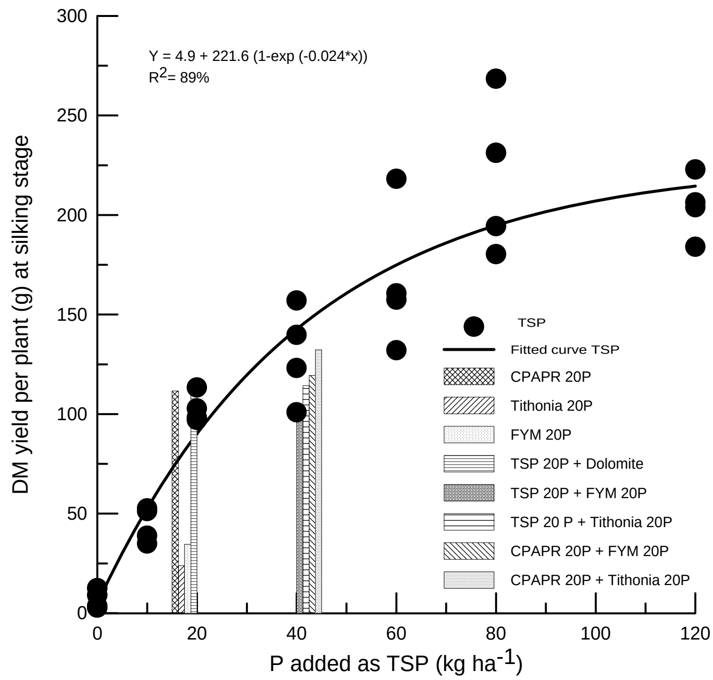

Figure 2. The effects of P rates on dry matter yield of maize at silking in June planting 1998.

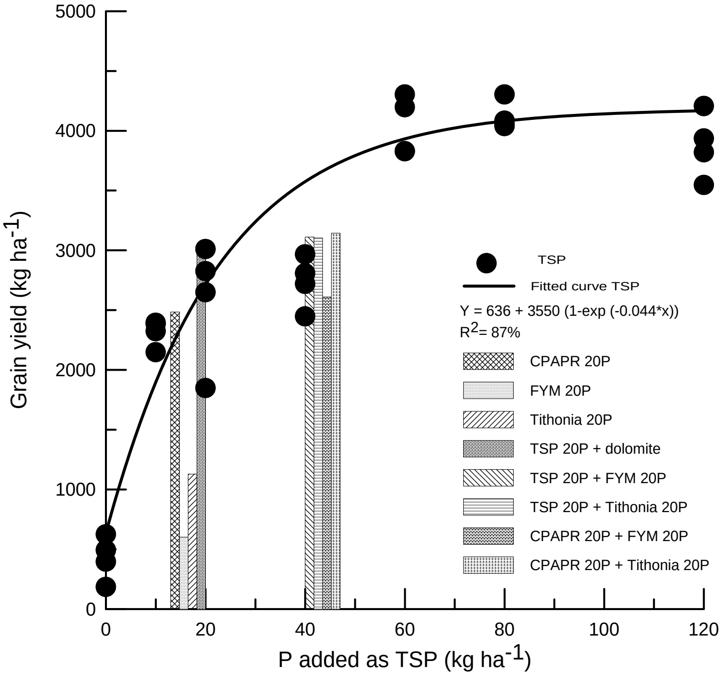

Figure 3. The effects of P rates on maize grain yield at harvest in June planting 1998.

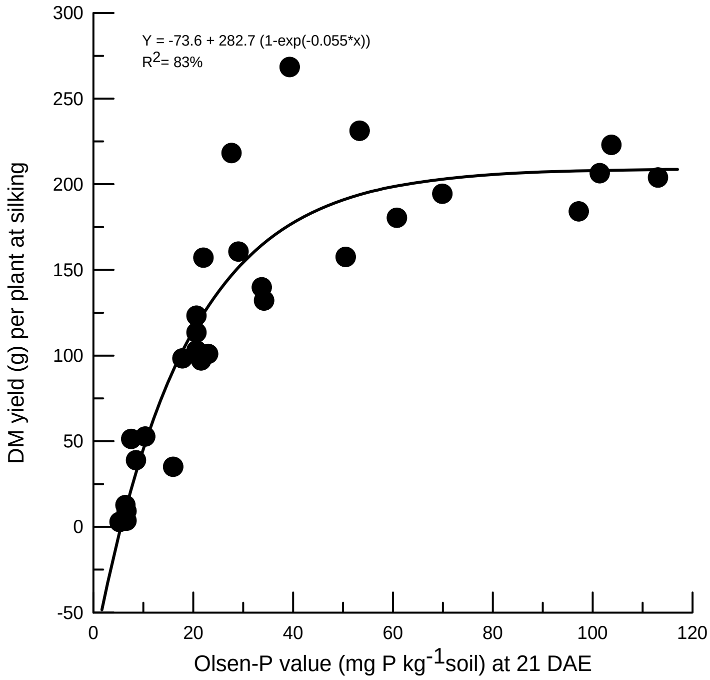

Figure 4. The relationship between soil Olsen-P value at 21 DAE and maize DM yield at silking in June planting 1998 (• = TSP response curve).

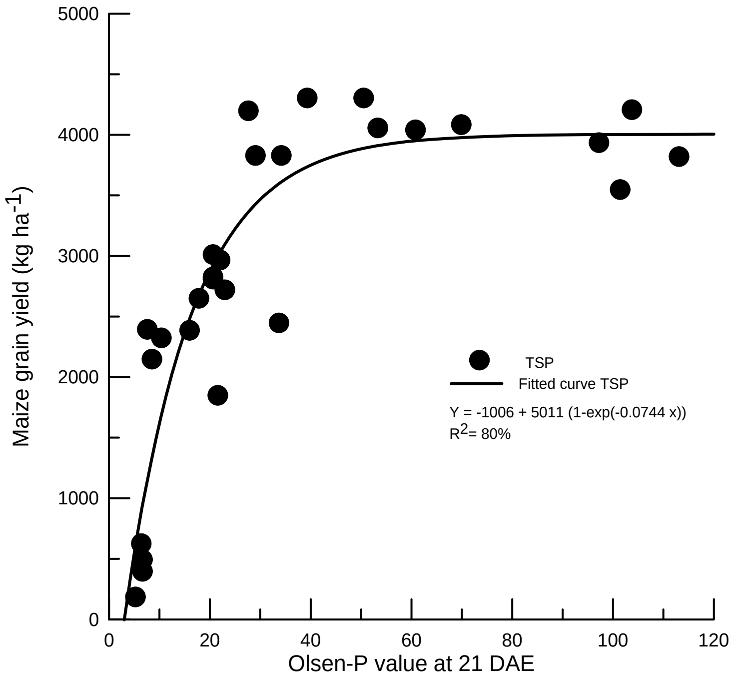

Figure 5. The relationship between soil Olsen-P value at 21 DAE and maize grain yield at harvest in June planting 1998 (● = TSP response curve).

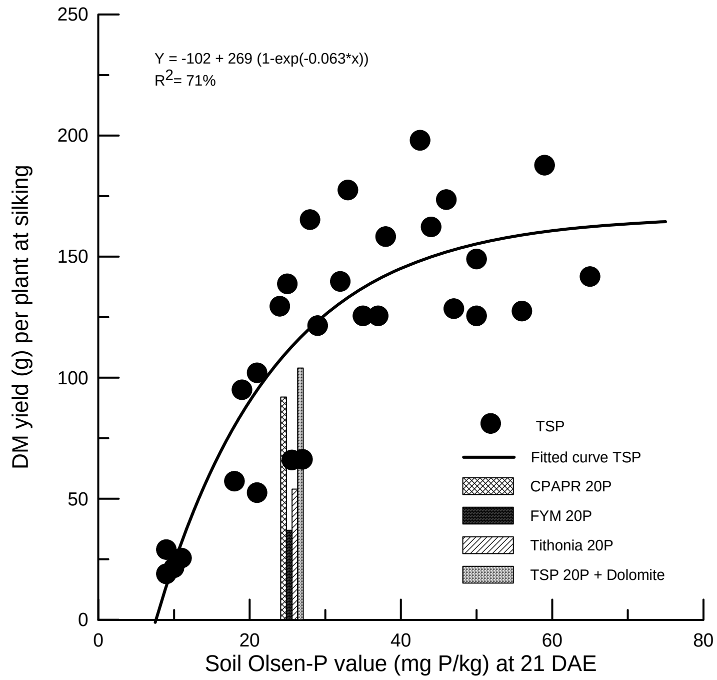

Figure 8. The relationship between soil Olsen-P value at 21 DAE and maize DM yield at silking in 1999 (●= TSP response curve).

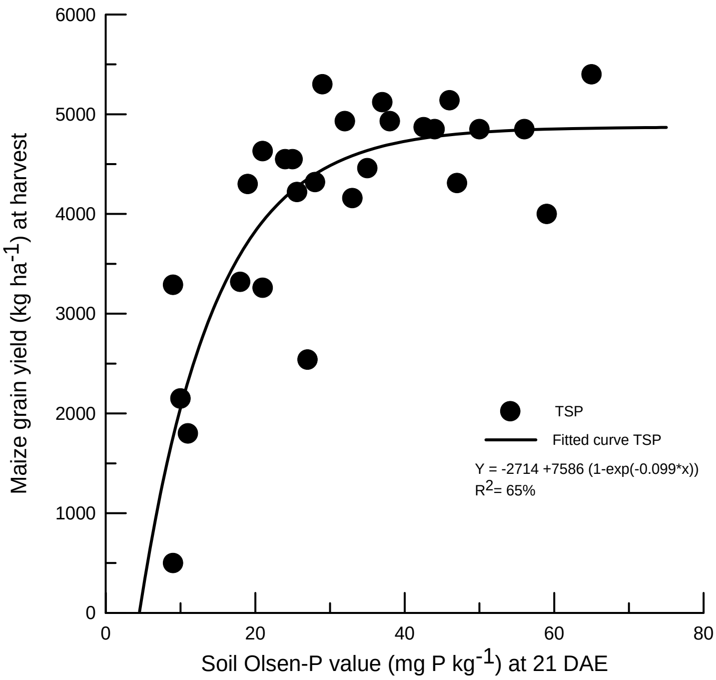

Figure 9. The relationship between soil Olsen-P value at 21 DAE and maize grain yield at harvest from June 1999 planting (● = TSP response curve).

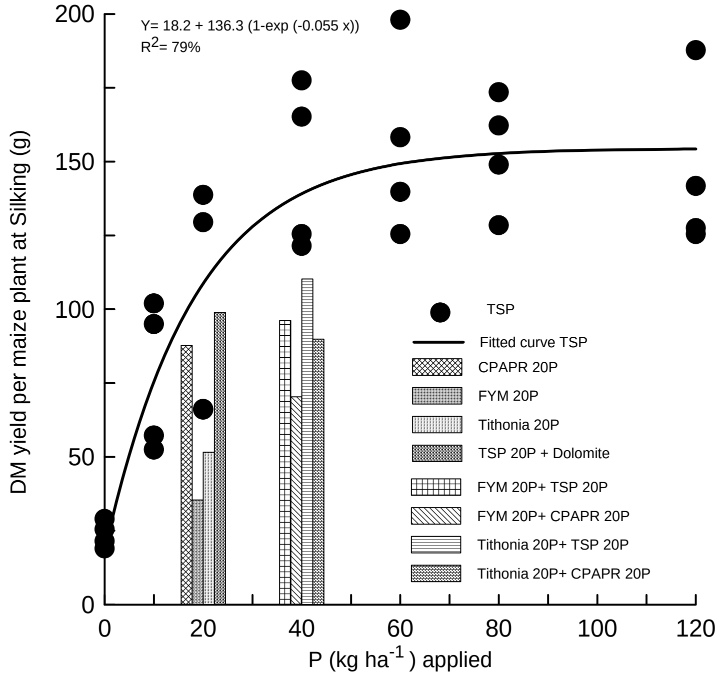

Figure 6. The effects of P rates on maize dry matter yield at silking from the June 1999 planting (● = TSP response curve).

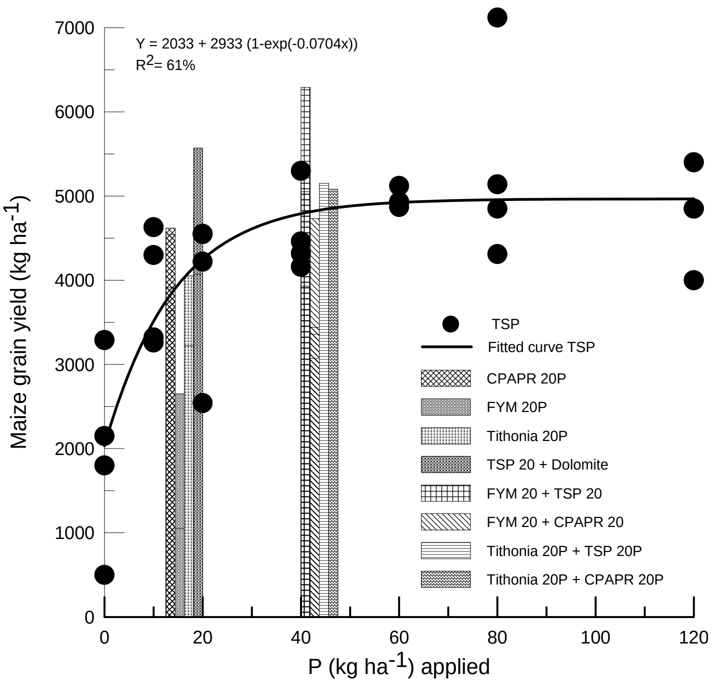

Figure 7. The effects of P rates on grain yield at harvest from June 1999 planting (● = TSP response curve).