Combined use of *Tithonia diversifolia* and Inorganic Fertilizers for Improving Maize Production in a Phosphorus Deficient soil in Western Kenya

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Abstract

The ability of *Tithonia diversifolia*, fertilizers and their combination to improve maize production in a phosphorous (P) deficient ferralsol, was compared in western Kenya. Tithonia and fertilizers were applied separately or combined in different proportions to give equal rates of 165 kg N ha^{-1}, 15.5 kg P ha^{-1} and 155 kg K ha^{-1} in two consecutive maize growing seasons, followed by two residual maize crops. Maize grain yields and P recovered in the above-ground biomass were higher in sole Tithonia than sole fertilizer treatments. Maize yields increased with increasing rate of Tithonia in the mixed treatments. When less than 36% of the total P applied in the mixture were supplied by Tithonia, there was no added yield benefit in the combined treatments compared to the sole fertilizer treatments. However, an added value ranging from 18 to 24 % increase in yields, was observed at higher Tithonia rates. Economic returns were larger from the application of Tithonia alone than from the application of sole fertilizers, with larger profit when Tithonia was collected from existing niches than when produced on site. Collecting Tithonia from current niches resulted also in larger net returns from all combined treatments than from fertilizers. The results of this study indicate that a high quality organic residue such as Tithonia can increase maize production to a greater extent than fertilizers. The combination of Tithonia and fertilizers can be an alternative to scarce resources and an added benefit can be obtained by maximizing the proportion of Tithonia in the mixture.

Key words: economic returns, leaf biomass, maize, phosphorus recovery, relative agronomic effectiveness.

Introduction

Phosphorus has been identified as one of the major limiting nutrients for crop production in many soils of East Africa. The use of fertilizers to improve soil fertility in smallholder farming systems such as those found in the East African highlands, will continue to be constrained by the high cost of fertilizers, the low purchasing power of smallholders and the restricted access to credit.

Although organic resources such as leaf biomass of agroforestry tree (shrub) species do not provide sufficient P and have no effect in increasing the total P of the system (Palm *et al.*, 1997; Buresh, 1999), they may increase the P availability of the already present P by rendering it more accessible to crops. The contribution of organics as P sources for crop production is limited by their low P content, thus requiring large amounts to meet moderate yield increases (Palm, 1995). In densely populated areas such as western Kenya, large amounts of organic residues cannot be produced on small farms averaging 0.6 ha (David and Swinkels, 1994). The limited land therefore has to be allocated to other uses than the production of organic materials for soil fertility replenishment. Where the materials can be found, the labour required for collection, transport and incorporation becomes another handicap to the use of large amounts of organic inputs (Jama *et al.*, 2000).

A supplementation of organic inputs with P fertilizers may be envisaged as it addresses both the problem of insufficient fertilizer supply and the large amount of organic material required for P supply. The success of this strategy however will depend on many factors such as the quality of the organic material used and the proportions of nutrient applied from either source (Palm *et al.*, 1997). Most trials studying the combination of organic materials and mineral fertilizers have failed to provide conclusive guidelines of the interactive effects of nutrients supplied by the various sources in combination because nutrients were not balanced. Total nutrients in the combined treatments were often the sum of the nutrients supplied by each nutrient source applied alone, explaining the higher yields from the combination compared to either source (Gachengo *et al.*, 1999).

Substitution type of experiments in which total nutrients supplied by organic and inorganic inputs added separately or combined in different proportions are equal (Mittal *et al.*,1992) provide the appropriate design for investigating the effects of combining organic and inorganic nutrient sources. Considering the current knowledge on the role of organic residues in reducing the soil P adsorption capacity (Easterwood and Sartain, 1990), increasing the pH (Kretzschmar *et al*, 1991) and increasing soil biological activity (Smith *et al*, 1993), we hypothesize the combination of organic and inorganic nutrient sources to be more beneficial than the sole application of fertilizers.

Nziguheba *et al* (1998), reported that the combination of *Tithonia diversifolia* (Hemsley A. Gray referred to as Tithonia in the text) and TSP at 15 kg P ha^{-1} had a similar or larger effect on available P pools than the sources applied alone at equal P rates. Whether crop response to the combination of Tithonia and fertilizers reflects the observed effects on soil P needs to be confirmed.

Therefore, a field experiment was conducted to:

(i) assess the ability of leaf biomass of Tithonia to substitute for equal amounts of NPK mineral fertilizers for maize production,

(ii) test possible added benefits of the combined use of fertilizer and Tithonia as opposed to sole application of either P source,

(iii) to determine the residual effects of the various sources and their combination on maize production, and

(iv) to compare the economic returns of maize produced using Tithonia and inorganic fertilizers applied alone or in combination.

Materials and Methods

Study site

The field experiment was conducted in the highlands of western Kenya (altitude 1450 m). The area has 2 growing seasons per year (a long rainy season from March to August and a short rainy season from September to January), with a mean annual rainfall of 1800 mm. The soil was classified as a ferralsol (FAO, 1990), with the following characteristics in the top 0.15 m:

pH (soil/water suspension 1.25) = 5.4,
organic C = 15 g kg^{-1}, exchangeable Ca = 4.6 cmolc kg^{-1},
exchangeable Mg = 1.9 cmolc kg^{-1},
exchangeable K = 0.08 cmolc kg^{-1},
exchangeable acidity = 0.25 cmolc kg^{-1}.
The bicarbonate extractable P = 0.9 mg kg^{-1} (Olsen and Sommers, 1982).
The soil has a clay content of 55%, silt 25%, and sand 20%.

Experiment design and management

This nutrient substitution trial was established in the short rainy season of 1997, in a randomized complete block design with four replications and 8 treatments. The treatments consist of Tithonia fresh leaf biomass and inorganic fertilizers (urea, TSP and KCl), applied separately or combined in different proportions to supply equal N, P and K rates of 165 kg N ha^{-1}, 15.5 kg P ha^{-1} and 155 kg K ha^{-1} (Table 23.1).

Table 23.1: Description of treatments used to assess the combination of Fertilizer and Tithonia for maize production in a field trial on a Ferralsol in western Kenya

Treatments	Code	Amount of nutrient added (kg ha^{-1})						% P from
		From Tithonia			From fertilizer			
		N	P	K	N	P	K	
Control		0	0	0	0	0	0	
NOK		0	0	0	165	0	155	
NPK		0	0	0	165	15.5	155	0
NPK + 0.45 Mg Tithonia	F1 + T1	15	1.4	14	150	14.1	141	9
NPK + 0.9 Mg Tithonia	F2 + T2	30	2.8	28	135	12.7	127	18
NPK + 1.8 Mg Tithonia	F3 + T3	60	5.6	56	105	9.9	99	36
NPK + 3.6 Mg Tithonia	F4 + T4	120	11.2	112	45	4.3	43	72
Tithonia		165	15.5	155	0	0	0	100

At these rates phosphorus would be the only limiting nutrient. Six rates of Tithoni*a* were applied, 0, 0.45, 0.9, 1.8, 3.6, 5 Mg ha^{-1} on a dry matter basis. A control treatment (no inputs) and a treatment with the full rates of N and K but without P addition (NOK), were included as references. Treatments were broadcasted and incorporated with hoes in the top 0.15 m for 2 consecutive cropping seasons (input phase).

This was followed by 2 consecutive maize growing seasons without treatment additions to study the residual effect of the different inputs (residual phase). Plot sizes were 5.25 m x 5 m. The average nutrient concentrations of Tithonia leaves during the input phase were 33 g N kg^{-1}, 3.1 g P kg^{-1} and 31g K kg^{-1}.

Maize (*Zea mays* L.) hybrids 511 and 512 were planted respectively in the short and long rainy seasons at a spacing of 0.75 m x 0.25 m. Two seeds were sown per hole and thinned to one after germination. Weeding was done whenever appropriate. At maturity, maize was harvested and the fresh weight taken. Subsamples of cobs and stover were taken from each plot and air-dried. At the end, maize grain yields were expressed on a 15% water content. The above-ground maize biomass and weeds were removed from the plots at each harvest.

Plant analyses

Phosphorus concentrations in grain and stover at the harvest of crop 2 were analyzed and used to calculate the amounts of nutrient held in the above-ground biomass for the different crops. It was shown from earlier studies in the same area that P concentrations do not change significantly during seasons within treatments (Gachengo *et al.,* 1999).

Samples from maize stover and grain collected at the harvest of the second crop were air-dried and ground to pass a 0.5 mm sieve. Phosphorus in the samples was extracted using the sulphuric acid *Kjeldahl* digestion method (Anderson and Ingram, 1993) and determined colorimetrically by the method of Parkinson and Allen (1975).

In order to compare the P source effect for different cropping seasons, maize yields were converted to relative increase compared to the NOK treatments. Yield increase was calculated using the following formula:

$$\text{Yield increase (\%)} \quad \frac{\text{Yield}_{\text{treatment}}\ \text{Yield}_{\text{NOK}}}{\text{Yield}_{\text{NOK}}} \times 100 \qquad (1)$$

Relative agronomic effectiveness (RAE) values of the P sources relative to yield obtained in the sole fertilizer treatment were calculated using the formula:

$$\text{RAE (\%)} \quad \frac{\text{Yield}_{\text{treatment}}\ \text{Yield}_{\text{NOK}}}{\text{Yield}_{\text{NPK}} - \text{Yield}_{\text{NOK}}} \times 100 \qquad (2)$$

The efficiency of P applied in the different treatments was estimated by calculating the P recovered in the above-ground biomass of maize (stover, core, grain) from the P applied in the treatments using the formula:

$$\text{Phosphorus recovered (\%)} \quad \frac{(\text{P uptake}_{\text{treatment}}\ \text{P uptake}_{\text{NOK}})}{\text{P added}} \text{ x } 100 \qquad (3)$$

Economic analysis

The economic returns from the application of each treatment were calculated based on the partial budgeting, which included only added costs and added benefits from the control treatment (CIMMYT, 1988). Added costs included all the expenses for buying, collecting, transporting and applying the inputs, while the added benefits referred to the gain obtained by selling the harvested maize grain at the local market (Table 23.2).

Table 23.2: Parameters used to calculate the economic returns of fertilizers and Tithonia applied alone or in combination in a maize-based system of western Kenya

Parameter	Actual values
Price of TSP	0.41 USD kg^{-1}
Price of urea	0.38 USD kg^{-1}
Price of KCl	0.44 USD kg^{-1}
Labor cost	0.16 USD h^{-1}
Labor cost for planting	17.36 USD ha^{-1}
Baseline labor for application of fertilizers	1.8 USD ha^{-1} (a)
Price of Tithonia	0.04 USD kg^{-1} DM(b)
Labor for application of Tithonia collected within the homestead	2.9 USD 100 kg^{-1} DM (c)
Price of maize	0.20 USD kg^{-1}

Key
DM= dry matter basis

Baseline labor cost for the application of fertilizers correspond to the application of 44 kg N ha^{-1} of urea, 10 kg P ha^{-1}, and 50 kg K ha^{-1}. For additional fertilizers application, an extra cost of 2% was added per kg of nutrient (Jama *et al*, 1997). The price is based on the value of maize which would be produced on the land used for Tithonia production.

Collection of *Tithonia* out of the homestead required an additional transport cost which depends on the distance of collection. In this case, the extra cost was assumed to take 20 % of the labor cost of Tithonia collected within the homestead.

Price of fertilizers and their transport cost were determined through a local market survey. Three scenarios were used in the determination of the cost of Tithonia. The first scenario was based on the current situation where Tithonia is collected from existing niches. Only the labor for collection, transport and application is counted as Tithonia cost.

If the use of Tithonia is adopted at large scale, it is unlikely that Tithonia collected from current niches will satisfy the demand of farmers. In such scenario, farmers will need to grow Tithonia. Growing Tithonia requires that farmers sacrifice part of their land normally used for crop production (e.g maize), for Tithonia production. The production cost is therefore estimated by the price of maize, which would be produced on the same plot without application of fertilizers (scenario 2). On very depleted land, a minimum of P fertilization may be required for Tithonia establishment. In this case the cost of production of Tithonia will also include the cost of fertilizers applied on Tithonia (10 kg P ha^{-1}) (Scenario 3). It was assumed that 5 Mg ha^{-1} of Tithonia on dry matter basis (2 cuttings) can be produced per year (Jama *et al.*, 2000), requiring a sacrifice of two maize crops estimated to 1 Mg ha^{-1} of grain under farmers' conditions (Shepherd and Soule, 1998).

The application of urea and TSP at 44 kg N ha^{-1} and 10 kg P ha^{-1} was estimated to take an extra 7% of the total labor cost required for planting (Jama *et al.*, 1997). The labor for collection, transport and application of Tithonia within the homestead was estimated to 2.9 USD 100 kg^{-1} on dry matter basis (Rommelse, AFRENA, pers. communication, 2000). The collection of Tithonia from existing niches (scenario 1) requires an additional transport cost, which depends on the distance of collection. For this reason, an extra 20 % of labor cost was added for Tithonia in scenario 1 compared to scenarios 2 and 3 to adjust for the added transport cost. The labor was valued at the local wage rate of 0.16 USD per hour. Harvested yields in each treatment were reduced by 10% to adjust to realistic values if the experiment was to be managed by the farmer.

Monetary values were converted to US dollars (USD) at the exchange rate of 74 Ksh=1 US$ (May, 2000).

The net benefit from each treatment was then determined as the difference between added benefits and added costs. No dominance test for checking the marginal rate of return was done because treatments with highest net benefit had the lowest added cost, thus dominating all other treatments (CIMMYT, 1988)

Data analysis

Analysis of variance was conducted using the general linear model procedure (GLM) of SAS (SAS institute, 1995), to compare treatment effects on the parameters studied. Standard errors of difference in means (SED), were used for treatment comparison. Statistical significance refers to $\alpha = 0.05$. In order to check the interaction effect from combining Tithonia and fertilizers, maize response to the integrated sources was compared to the expected response determined by the equation:

Yi = ai Yf + bi Yt,

where:
Yi = the expected maize yield from treatment i,
Yf = maize yield obtained from the application of fertilizers alone,
Yt= maize yield obtained from the application of Tithonia alone, ai = the proportion of P applied from the fertilizers in treatment i, and
bi= the proportion of P applied from Tithonia in treatment i (bi=1-ai).
Single degree freedom contrasts were also run to check the significance of the benefit or reduction of yield from the interaction.

Results

Maize grain yield

Maize yields of the control treatment were significantly increased by the addition of phosphorus sources. Despite the heavy rains (El Niño) experienced during the first season, addition of P sources more than tripled the yields obtained from the control treatments (Table 23.3).

Table 23.3: Maize grain yields over 4 consecutive seasons (2 fertilized, 2 residual) as affected by application of organic and inorganic sources of nutrients to a Ferralsol in western Kenya

Treatments	Mg ha^{-1}				
	Input phase		Residual phase		Total
	Crop 1	Crop 2	Crop 3	Crop 4	
Control	0.3	0.7	0.00	1.0	2.0
NOK	0.8	0.8	0.01	1.7	3.3
NPK	1.1	3.6	0.08	2.6	7.4
F1 + T1	1.1	3.6	0.06	2.2	7.0
F2 + T2	1.1	3.6	0.12	2.8	7.6
F3 +T3	1.3	4.0	0.12	2.8	8.2
F4 +T4	1.3	4.2	0.14	2.2	7.8
Tithonia	1.4	4.3	0.17	3.0	8.9
SED	0.3	0.3	0.04	0.4	0.7

However, there was no significant difference between treatments receiving a P source, although the highest increase was observed from the sole application of Tithonia. The same trend was observed at the second season but with much more yield increases from treatments receiving P compared to the control (414% to 514 %).

The total maize grain yields during the input phase were 1.0 Mg ha^{-1} in the control treatment, and 1.6 Mg ha^{-1} in the NOK treatment, while they ranged from 4.7 Mg ha^{-1} to 5.7 Mg ha^{-1} in treatments receiving P.

Maize grain yield tended to increase with increasing amount of Tithonia in the combined treatments with the sequence:

sole fertilizer = fertilizer + (0.45 Mg) Tithonia = fertilizers + (0.9 Mg) Tithonia < fertilizers + (1.8 Mg) Tithonia < fertilizers + (3.6 Mg) Tithonia < sole Tithonia.

All treatments having more than 36 % of the total P supplied by Tithonia more than tripled the yields of the NOK treatment. The total yield from sole fertilizers (4.7 Mg ha^{-1}), was significantly lower than that from sole Tithonia (5.7 Mg ha^{-1}).

The integration of resources with less than 36% of the total P supplied by Tithonia resulted in similar grain yields as the fertilizers applied alone, but lower than the sole application of Tithonia. However, when the P supplied by Tithonia accounted for 36% or more of the total P applied in the combination, a yield increase of at least 0.6 Mg ha^{-1} was observed compared to the addition of fertilizers alone, although this increase was not significant.

The first season of the residual phase was affected by a drought resulting in a nil grain harvest in the control treatment (Table 23.3). However, treatments followed the same trend as observed during the phase of treatment additions. For the second residual season, treatments receiving a P source still more than doubled the yield of the control. However, yields tended to be lower in the treatment receiving 9% P from Tithonia than in sole fertilizers. Two reps of the combination of fertilizers with 3.6 Mg ha^{-1} of Tithonia gave very low yields in the second residual crops. As a result, the average yield in this treatment was very low. The reason for such low yields could not be identified and was most probably not due to treatment effect. For this reason, the treatment will not be considered when discussing the residual effect of treatments.

Total maize yields obtained in the 2 seasons of residual crops were 1.0 Mg ha^{-1} in the control and 1.7 Mg ha^{-1} in NOK. Yield increases in treatments which previously received a P source relative to the NOK treatment ranged from 38 % to 90% and were less than half the increases obtained after the 2 seasons of treatment additions. Although not significant, an extra 0.5 Mg ha^{-1} grain yield was obtained from the residual maize after sole Tithonia addition compared to residual maize from sole fertilizers. The only significant difference observed between the treatments which previously received P source was from the combination of fertilizers and Tithonia with 9% of total P supplied by Tithonia, which resulted in lower maize yield than the yield obtained from the addition of sole Tithonia.

Relative agronomic effectiveness of the different P sources

Addition of sole Tithonia resulted in an added maize yield of 32 % compared to the addition of fertilizers alone at the end of the input phase (Table 23.4).

Table 23.4: Relative Agronomic Effectiveness (RAE) of Tithonia and its combination with TSP compared to TSP in a maize-based system in the highlands of western Kenya

Treatments	P added per season (kg ha^{-1})	RAE* (%)		
		Input	Residual	Total
F1 + T1	15.5	100	60	90
F2 + T2	15.5	100	116	104
F3 + T3	15.5	118	122	119
F4 + T4	15.5	124	61	108
Tithonia	15.5	132	141	135

$$* \text{RAE}(\%) \quad \frac{\text{Yield}_{\text{treatment}} \ \ \text{Yield}_{\text{NOK}}}{\text{Yield}_{\text{NPK}} - \text{Yield}_{\text{NOK}}} \times 100$$

The combination of fertilizers and Tithonia with 9 % or 18% of P supplied by Tithonia resulted in maize yields equivalent to those obtained by applying fertilizers only (RAE = 100 %). Addition of 15.5 kg P ha^{-1} from the combination of fertilizers and Tithonia with 36 % and 72 % of P supplied by Tithonia had REA values of 118 % and 124 % respectively (Table 23.4).

The benefit from the addition of Tithonia compared to fertilizers was still observed during the residual phase where an added yield of 41 % was harvested from Tithonia applied alone. The combination of fertilizers and Tithonia at 9 % P from Tithonia reduced the residual yield from fertilizers alone by 40%, while a benefit ranging from 16% to 22% was obtained from other combined treatments.

There was no significant interaction between the fertilizers and Tithonia. However, combining fertilizers and Tithonia with less than 36 % P supplied by Tithonia tended to reduce the yields predicted from the yields obtained by Tithonia and fertilizers applied separately (Figure 23.1).

When the proportion of P from Tithonia increased to 36% and above, maize yields tended to increase above the predicted values.

Phosphorus recovered in the above-ground biomass of maize

Differences in phosphorus recovered from P added in the different treatments were hardly significant. However, P recovered after the first application of treatments from Tithonia applied alone was the highest and twice the value obtained from the sole fertilizer additions (Figure 23.2).

Figure 23.1: Cumulative maize grain yields from the P added in Tithonia, fertilizers and their combination. Bars indicated the standard errors of differences in means. Number of replicates = 4.

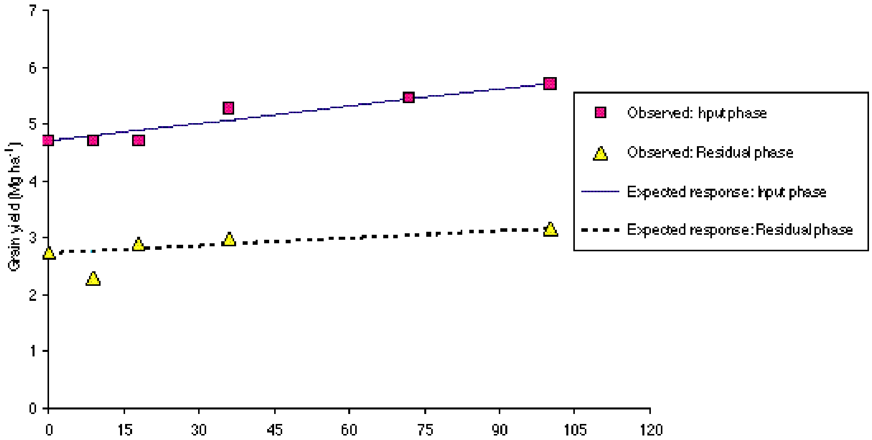
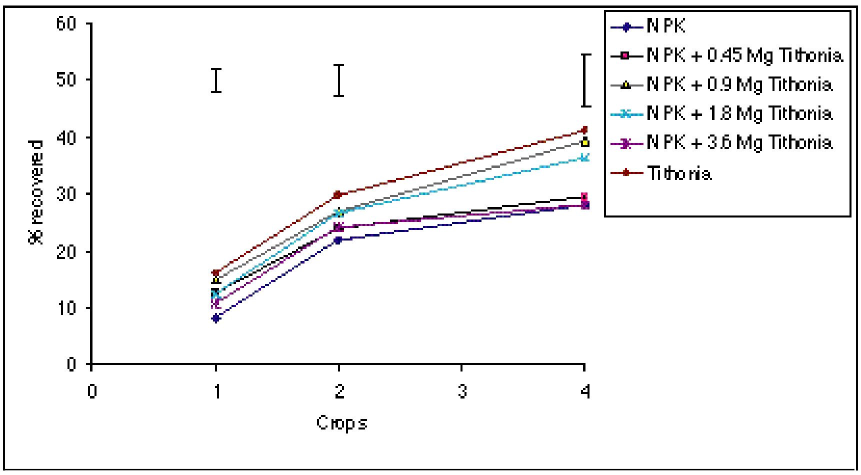


Figure 23.2: Cumulative P recoverd in the above-ground biomass of maize from the P added in Tithonia, fertilizers and their combination. Bars indicated the standard errors of differences in means. Number of replicated = 4.



The total P recovered at the end of the experiment in the 4 maize crops, was 41% of the P applied in the sole Tithonia treatments compared to 28% in the sole fertilizer treatments.

The combination of Tithonia with fertilizers resulted in larger values of P recovered compared to the pure fertilizer treatments, but were smaller compared to the sole Tithonia treatment, although the differences were not statistically significant.

Economic analysis

The net economic return from the application of N and K fertilizers without P was negative even after including the residual yields (Table 23.5).

Table 23.5: Economic returns from addition of Tithonia, fertilizers or their combination to a P deficient Ferralsol in a maize-based system

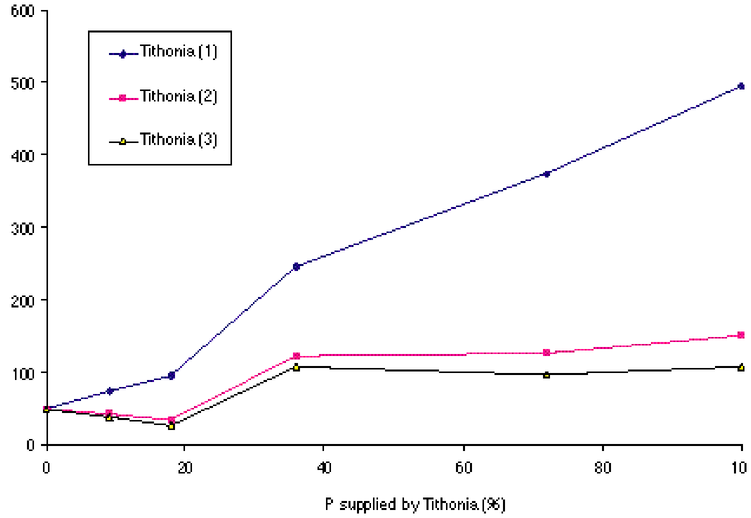
Treatments	USD ha^{-1}						
	Added Cost			Added Values		Net Benefits	
	Input 1 season	Labor 1 season	Total cost 2 seasons	2 seasons	4 seasons	2 seasons	4 seasons
NOK	273	2.6	551	102.6	219.6	-448	-331
NPK	304	2.6	614	664.2	972	50	358
Tithonia (1)		176	352	846	1233	494	881
Tithonia (2)	200	147	694	846	1233	152	539
Tithonia (3)	222	147	738	846	1233	108	495
Combine							
			Tithonia (1)				
F1 + T1	276	18	590	664	895	75	305
F2 + T2	249	34	567	662	1001	96	434
F3 + T3	194	66	519	765	1114	246	596
F4 + T4	84	128	425	799	1031	375	607
			Tithonia (2)				
F1 + T1	294	16	620	664	895	44	274
F2 + T2	285	29	628	662	1001	35	373
F3 + T3	266	55	642	765	1114	123	473
F4 + T4	228	108	671	799	1031	128	361
			Tithonia (3)				
F1 + T1	296	16	624	664	895	40	270
F2 + T2	289	29	635	662	1001	27	365
F3 + T3	274	55	657	765	1114	108	457
F4 + T4	244	108	703	799	1031	97	329

(1) no production,
(2) production of Tithonia without fertilizers,
(3) production of Tithonia with P fertilization

The application of a small dose of P fertilizers (15.5 kg P ha^{-1}) reversed the trend to a positive net benefit of 50 USD.

Net benefits from Tithonia and the combined treatments were positive, but depended on the strategy adopted for Tithonia production. For the current situation where only the labor cost for cutting, carrying and applying Tithonia are involved, higher net benefits were obtained in treatments receiving Tithonia than in the sole application of fertilizers. The benefits increased with increasing proportion of P from Tithonia, the highest being obtained from Tithonia applied alone (494 USD after 2 growing seasons) (Table 23.5, Figure 23.3).

Figure 23.3: Nets benefits from addition of Tithonia, fertilizers and their combination as affected by the proportion of P added in Tithonia and the strategy of Tithonia production. (1): Tithonia collected from existing niches, (2): Production of Tithonia without fertilizers, (3): Production of Tithonia with P fertilization



Growing Tithonia, however, reduced its benefits. Although net benefits in treatments receiving Tithonia were still positive, they were larger than those obtained from fertilizers alone only when Tithonia was applied at 1.8 Mg ha^{-1} or more.

When the residual crops were included in the economic analysis, net benefits were larger in treatments which received Tithonia than in sole fertilizer treatments for all strategies, except for the combination of fertilizers with 0.45 Mg of Tithonia (Table 23.5).

Discussion

One of the major constraints to a proper management of fertilizers in smallscale farming systems is the lack of information on limiting nutrients. The results of this study highlighted the importance of P fertilization on this site. Addition of N and K without P did not increase significantly the yield of the unfertilized plots and resulted to negative net benefit. Phosphorus either supplied by TSP, Tithonia or their combination dramatically increased the yields compared to the control treatments. However, Tithonia proved to be a more efficient P source than fertilizers by providing the largest increase in maize grain yields, the largest P recovery and an added value at least 32% higher compared to sole fertilizers. These results are consistent with the work of Nziguheba *et al.* (2000), who observed an added benefit going up to 112% from the addition of Tithonia compared to TSP on resin extractable P during one maize growing season. The results suggested that either the addition of Tithonia converted part of non-available P forms into available P forms, or the P added from fertilizers is easily transformed into non-available forms, reducing their efficiency as P sources. Nziguheba *et al.* (1998) found a decrease in P sorption from the application of Tithonia but not from TSP at equal P rates. Phan Thi Công (2000) reported a reduction of extractable aluminium and an increase of soil pH after addition of Tithonia. Aluminium plays an important role for soil phosphorus fixation (Mokwunye *et al*, 1986). In addition, an increase in microbial biomass was observed in Tithonia treatments and not in TSP treatment (Nziguheba *et al*,1998). The microbial biomass constitutes a potential source of nutrients to the crop through turnover.

The integration of fertilizers with organic inputs has been regarded as a more profitable alternative in low input systems, countering the large costs of fertilizers (Janssen, 1994). This study confirmed that the integration of fertilizers with Tithonia can be an alternative to the limited use of fertilizers. However, higher proportions of P from organic materials were required to get a small benefit from the combination. From the results here, it can be deduced that the final goal is to maximize the proportion of P supplied by Tithonia in the combination. However, this strategy has many limitations. Large amounts of Tithonia are not only difficult to produce but also require much labor for cutting, carrying and incorporating (Jama *et al.*, 2000). It is also important to consider that addition of Tithonia does not constitute an added input of P in the system but rather enhances the reutilization of P already in the system. For soil P replenishment, an addition of P fertilizers remains unavoidable.

Although the rate of P added was small, its effects were still observed in the second residual crop. However combining fertilizers and Tithonia with only 9% P supplied by Tithonia resulted in a reduction of the maize yield in the pure fertilizer treatment, during the residual phase. This therefore means that not any proportion of combination is advantageous in an integrated nutrient management. No reduction of yields was observed, (at any phase), from the combination of fertilizers and Tithonia when 36% of P were supplied by Tithonia. Maize yields from this combination tended to move above the expected values during the input phase (Figure 23.1) and net benefits were higher than in sole fertilizer treatments. Therefore this combination appears to be more advantageous than the others. This combination also is in line with the quantity of Tithonia biomass available to farmers in western Kenya, estimated between one and two Mg ha^{-1} on a dry matter basis (Buresh and Niang, 1997).

The major constraint to the use of biomass transfer for P fertilization is the labor required for collection, transport and application of organic residues. This study showed that this labor accounted for almost half of the total cost of Tithonia treatments, for each season. Despite this large cost, net benefits in treatments receiving Tithonia were positive but depended on the strategy adopted for Tithonia production. Application of Tithonia from existing niches resulted in larger net benefits than the application of fertilizers. Although this strategy appeared to be economically beneficial, it can only be envisaged at a short-term, before the full adoption of the technology. In the long-term, the production of Tithonia by farmers themselves needs to be envisaged. Growing Tithonia on land normally used for maize production reduced the net benefit obtained from collecting Tithonia from existing niches, particularly if Tithonia is assumed to be produced with a minimum of fertilization. However, the net benefits at high Tithonia rates were still larger than with the sole application of fertilizers.

Due to limited land availability, the probability of growing Tithonia on land reserved for crop production is very low. In small-scale farming systems, the most likely scenario will be to grow Tithonia on marginal areas or on field boundaries. In this case, the cost of production will be limited to establishment and maintenance costs.

Conclusion

In P deficient soils, applying P in the form of soluble fertilizers, Tithonia or their combination is very crucial for maize production. Substantial maize yields and economic returns were obtained from Tithonia applied alone. This study showed that a high quality organic resource such as Tithonia can play an important role in supplying P to a growing crop. However, considering the constraints related to the availability of Tithonia biomass and the need for soil P replenishment, a combination of Tithonia and fertilizers will be a more sustainable strategy, the goal being to maximize the proportion of P derived from Tithonia in the combination.

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