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INTEGRATED NUTRIENT MANAGEMENT STRATEGIES FOR SOIL FERTILITY IMPROVEMENT AND *STRIGA* CONTROL IN NORTHERN ETHIOPIA

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INTRODUCTION

Soil productivity is dependent upon soil physical, chemical and biological characteristics. Continuous cultivation of arable land without nutrient inputs results in degraded soils, accelerated soil erosion, depletion of soil nutrient reserves, reduced soil organic matter content, loss of soil physical structure, and reduced crop productivity. The continuous removal of biomass (i.e., grain and crop residues) from crop land without adequate nutrient replenishment can rapidly deplete the soil nutrient reserves and jeopardise the sustainability of agricultural production. Nutrient balances (i.e., input minus removal) are negative for many farming systems in sub-Saharan Africa (Stoorvogel and Smaling, 1990). Countries in East and Central Africa with a high annual rate of nutrient depletion (i.e., > 40 kg N ha^{-1} and > 30 kg K_2O ha^{-1}) include Ethiopia, Kenya, Malawi and Rwanda.

Parasitic weeds of the genus *Striga* establish preferentially in nutrient poor soils and fields which have been exhausted by continuous cropping (Vogt *et al*., 1991). Most *Striga* infested areas are characterised by agricultural production systems exhibiting low productivity. These areas tend to be managed traditionally with low inputs and continuous cereal cropping without crop rotation. The use of inorganic nitrogen (Mumera and Below, 1993; Pieterse, 1996) and organic fertilisers such as manure and compost have been reported to reduce *Striga* infestations (Ogborn, 1984; Bebawi, 1987). Manure applications have been shown to be as effective as fallowing in maintaining soil productivity. The positive benefits of applying manure include an increase in pH, water holding capacity, hydraulic conductivity, infiltration rate, and a decrease in bulk density. Manure is also an important source of N, P, and K (Haque *et al*., 1995; Murwira *et al*., 1995). To enhance the quality and hence the effectiveness of traditional soil fertility maintenance strategies such as manure application, a fertiliser augmented soil enhancement strategy (FASE) that involves the addition of limited quantities of inorganic fertilisers has been suggested (McCown *et al*., 1992; Probert *et al*., 1992). Such combined applications have been found to be superior to the application of manure alone (Agboola *et al*., 1975; Qureshi, 1991). This approach combines the short-term benefits of inorganic fertiliser with the long-term value of organic fertiliser (Murwira *et al*., 1995). Smaling *et al*. (1992) demonstrated the need for integrated nutrient management (INM), especially in areas of low soil fertility where farmers cannot afford to rely on mineral fertilisers alone. Such integrated soil fertility management systems can reduce the requirement and at the same time increase the efficiency of added inputs (Kang, 1989). The main objective of this study was to determine the optimum combination of manure and fertilisers for crop growth and *Striga* control in the northern Ethiopian highlands.

MATERIALS AND METHODS

Field experiments were established in the northern Ethiopian highlands at three sites, one near Mekele (on a farmer's field) and two near Sirinka (one on-station at the Sirinka Research Centre and one on a farmer's field). The field experiment near Mekele was sown in the Adi Bakel area on 7 June 1996 and early July 1997. The experiment consisted of a factorial combination of four levels of inorganic fertiliser, N from Urea (0, 40, 80 and 120 kg N ha^{-1}) and four rates of farmyard manure (0, 10, 20 and 30 t ha^{-1}) in a randomised complete block design (RCBD) replicated three times. The test crop was a *Striga* susceptible local cultivar of sorghum at a spacing of 75 cm x 15 cm. The experiments at Sirinka were sown on July 13, 1996 and July 15,1997. The experimental design of the field experiment was a split-plot layout consisting of maize and sorghum as main plots and a factorial combination of four levels of inorganic fertiliser N (0, 40, 80 and 120 kg N ha^{-1}) and four rates of farmyard manure (0, 10, 20 and 30 t ha^{-1}) as the sub-plots replicated three times. The test crops were *Striga* susceptible maize cultivar "A511" and sorghum cultivars "IS9302" in 1996 and "76Ti # 23" in 1997. In all trials, N was applied as Urea at sowing (half the N rate) and top-dressed after three weeks. Phosphorus as Triple Super Phosphate (TSP) was applied at sowing at the recommended rate (46 kg P_2O_5 ha^{-1}). Plot size was 3.75 m x 5 m.

Soil samples were collected from each plot at 0-20 cm, 20-40 cm and 40-60 cm depths at the beginning of every season for soil chemical analysis (i.e., pH, organic carbon and total N). The topsoil soil pH, organic carbon and total nitrogen were determined. *Striga* infestation was counted at weekly intervals from the time of emergence. Crop samples were taken at harvesting to determine grain, stover and cob yields. The samples were weighed fresh, dried at 60°C for 4 days, and then weighed for dry matter yields. Data were subjected to an analysis of variance using Genestat package. Before analysis, raw data for *Striga* counts were transformed to square roots to eliminate heterogeneity of variance.

RESULTS AND DISCUSSION

Soil analytical results. Soil analysis results indicate that the soils were slightly acidic and low in organic carbon and total nitrogen (Table 1). There were significant changes in soil pH and soil organic carbon during the two years. The mean soil pH and organic carbon increased by 0.6 units and 0.27 % respectively, but the mean soil total N did not change. Significant increases in soil organic carbon occurred in most manure treatments. However, application of urea and manure did not significantly change soil pH, organic carbon and total nitrogen (Table 1).

Table 1. Changes in topsoil (0 - 20 cm) soil pH, organic carbon (%) and nitrogen content (%) in response to integrated nutrient management factors at Sirinka (on-station) in 1996 and 1997

Treatment N(kg ha^{-1})	Manure (t ha^{-1})	Soil pH		Organic carbon(%)		Total nitrogen (%)	
		1996	1997	1996	1997	1996	1997
0	0	6.60	6.75	1.60	1.65	0.11	0.14
0	10	6.83	6.81	1.64	1.91	0.13	0.14
0	20	6.79	6.86	1.60	1.95	0.12	0.15
0	30	6.88	6.94	1.64	1.95	0.12	0.14
40	0	6.84	6.86	1.68	1.77	0.12	0.12
40	10	6.84	6.82	1.64	1.83	0.12	0.12
40	20	6.83	7.02	1.75	2.09	0.13	0.13
40	30	6.88	6.98	1.60	2.14	0.11	0.13
80	0	6.86	6.79	1.75	1.81	0.13	0.11
80	10	6.76	6.89	1.75	2.07	0.13	0.11
80	20	6.88	6.92	1.71	1.99	0.13	0.13
80	30	6.80	6.97	1.64	2.07	0.18	0.16
120	0	6.82	6.73	1.79	1.97	0.13	0.15
120	10	6.81	6.75	1.79	1.89	0.13	0.13
120	20	6.73	6.93	1.71	1.99	0.13	0.14
120	30	6.83	6.86	1.64	2.09	0.11	0.14
Mean		6.81	6.87	1.68	1.95	0.13	0.13
LSD (P<0.05)							
Year		0.14	-	0.22	-	NS	-
Treatment		NS	-	NS	-	NS	-

***Striga* emergence.** *Striga* emergence during the first season was significantly affected by crop species and nitrogen (N) levels at Sirinka (Table 2). *Striga* emergence was higher on sorghum than on maize despite poor sorghum germination at Sirinka in 1996 (Table 2). Addition of fertiliser N at all rates increased the mean *Striga* emergence on sorghum compared to maize. The increase in *Striga* emergence may be related to production of a more extensive sorghum root system which increased the root surface area and thus stimulated emergence of the parasite.

Table 2. Sorghum and maize stover and grain yields at Sirinka as affected by integrated nutrient management factors in 1996 and 1997

Treatment N (kg ha^{-1})	Manure (t ha^{-1})	Sirinka (on-station) 1996				Sirinka (on-station) 1997				Sirinka (on-farm) 1996			
		Striga emergence (Plants m^{-2})		Grain yield (kg ha^{-1})		Striga emergence (Plants m^{-2})		Grain yield kg ha^{-1})		Striga emergence (Plants m^{-2})		Stover yield (kg ha^{-1})	
		Sorghum	Maize	Sorghum	Maize	Sorghum	Maize	Sorghum	Maize	Sorghum	Maize	Sorghum	Maize
0	0	1.4	0.6	297	1727	1.1	1.6	1342	1044	0.7	0.8	370	1728
0	10	2.8	1.2	412	3144	2.9	2.7	2173	2030	1.5	2.6	1042	866
0	20	2.1	1.1	461	3401	2.0	2.3	2057	2351	1.5	1.8	1399	1563
0	30	2.8	0.9	737	5479	0.9	1.6	2358	2664	1.7	1.3	737	2645
40	0	2.0	1.1	423	2504	5.8	5.1	2131	1617	1.0	1.7	919	2163
40	10	2.3	1.2	597	3743	1.7	1.3	2387	3349	1.2	1.1	1086	1738
40	20	3.6	1.4	905	4530	2.8	2.3	3077	2922	1.3	1.3	1551	3127
40	30	1.8	0.7	552	4789	0.5	1.3	3189	4085	2.0	1.0	1853	3601
80	0	1.8	1.1	468	4379	1.2	3.3	2427	3514	0.8	0.6	731	3169
80	10	3.7	1.1	704	3972	5.2	1.5	3016	4654	1.3	0.6	742	3970
80	20	1.9	1.4	552	4946	1.0	0.8	2613	5382	1.8	0.6	880	3686
80	30	1.5	1.1	438	5729	0.4	0.5	2654	5913	0.5	0.4	1330	4155
120	0	1.2	0.4	386	5868	0.6	1.2	1634	3792	1.2	0.3	904	3504
120	10	1.3	1.3	318	5527	0.5	1.9	2775	5130	0.5	0.7	2461	4108
120	20	1.4	0.7	261	5340	0.7	0.3	2086	5865	0.8	0.4	762	4536
120	30	0.9	0.8	160	6298	1.2	0.7	2427	5800	0.6	0.7	913	3287
Mean		2.0	1.0	480	4461	1.8	1.8	2399	3757	1.1	1.0	1105	2991
LSD ($P<0.05$)													
Crop (C)		0.5	-	1222.6	-	NS	-	428.0	-	NS	-	820.8	-
Nitrogen (N)		0.6	-	462.6	-	1.1	-	338.2	-	0.4	-	511.3	-
Manure (M)		NS	-	462.6	-	1.1	-	338.2	-	NS	-	NS	-
C x N		NS	-	931.6	-	NS	-	466.4	-	NS	-	760.3	-
C x M		NS	-	931.6	-	NS	-	466.4	-	NS	-	NS	-
N x M		NS	-	NS	-	2.1	-	NS	-	NS	-	NS	-
C x N x M		NS	-	NS	-	NS	-	NS	-	NS	-	NS	-

Nitrogen, manure, and nitrogen with manure significantly affected *Striga* emergence during the second season at the Sirinka on-station site (Table 2). Manure treatments without inorganic nitrogen significantly increased *Striga* emergence on maize and sorghum at 10 t ha^{-1} but reduced infestation at 30 t ha^{-1} when compared to the control at Sirinka in 1997. Inorganic fertiliser N applied at 40 kg N ha^{-1} also increased *Striga* infestation. Pieterse and Verkleij (1991) suggested that, under depleted soil conditions, fertilisers may stimulate *Striga* infestation probably by increasing the biomass of host roots thereby encouraging more parasite seeds to germinate. However, a combination of 40 kg N ha^{-1} and manure at all rates reduced

Striga emergence (Table 2). The highest reduction in *Striga* density at 40 kg N ha^{-1} occurred with 30 t ha^{-1} manure. The greatest decrease in mean *Striga* density across all treatments was obtained with 120 kg N ha^{-1} and 20 t ha^{-1} manure for maize (Table 2). The N level had little effect on *Striga* during the early stages of crop development as there are no significant N effects on *Striga* emergence in the first few months after planting at Sirinka in 1997. Soil organic matter and N content in some treatments increased after one year based on soil analysis, although total N declined in the 80 kg N ha^{-1} treatments (Table 1). Sherif and Parker (1988) found no influence of organic matter on *Striga* in the absence of associated N fertiliser in pot studies. Other research has shown that when N fertiliser and organic matter were combined, *Striga* emergence declined over a three year period in field studies carried out in Kenya (Ransom and Odhiambo, 1994). Incorporation of crop residues combined with sufficient N fertiliser to allow for a reasonable rate of organic matter decomposition has been shown to decrease the *Striga* seed bank in the soil. Therefore, increasing the biological activity of the soil appears to enhance the natural demise of *Striga* seeds (Ransom, 1996).

Only N fertiliser effects were significant on the on-farm trial at Sirinka during the first season (Table 2). Fertiliser N at 40 kg N ha^{-1} enhanced *Striga* emergence whereas 120 kg N ha^{-1} reduced the infestation on maize. Addition of manure increased *Striga* infestation on both sorghum and maize in the first season at this site. The on-farm trial at Sirinka was discontinued during 1997.

Nitrogen and manure did not affect *Striga* emergence at Mekele in 1996 (Table 3), but both factors significantly affected *Striga* emergence in 1997. Compared to sorghum planted without manure and fertiliser, the application of 20 t ha^{-1} manure, 40 kg N ha^{-1} with 30 t ha^{-1} manure, 80 kg N ha^{-1} with 10 and 30 t ha^{-1} manure, and 120 kg N ha^{-1} with 20 and 30 t ha^{-1} manure significantly reduced *Striga* infestation on sorghum at Mekele in 1997 (Table 3). Application of 40 kg N ha^{-1} in combination with 10 and 20 t ha^{-1} manure and 80 kg N ha^{-1} with 20 t ha^{-1} manure did not significantly reduce the *Striga* infestation.

Table 3. Sorghum stover and grain yield at Mekele as affected by integrated nutrient management factors in 1996 and 1997

Treatment N (kg ha^{-1})	Manure (t ha^{-1})	1996			1997	
		Striga emergence (Plants m^{-2})	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Striga emergence (Plants m^{-2})	Stover yield (kg ha^{-1})
0	0	4.6	4462	553	2.0	2431
0	10	3.6	6544	572	2.1	3902
0	20	4.7	4554	567	0.6	5071
0	30	5.1	6035	499	1.8	5631
40	0	3.4	4277	370	1.2	4507
40	10	4.3	3984	317	1.5	4044
40	20	4.0	6033	583	1.1	4951
40	30	3.6	6429	1117	0.8	2844
80	0	3.8	5001	433	1.2	2858
80	10	3.2	8839	1053	0.5	5240
80	20	4.3	7312	1038	1.0	5747
80	30	4.3	6761	1074	0.8	5156
120	0	3.7	6363	721	1.2	5187
120	10	3.3	7619	670	1.0	5667
120	20	2.5	6453	805	0.2	6196
120	30	3.9	5395	504	0.6	5253
Mean		3.9	6004	680	1.1	4730
LSD ($P<0.05$)	NS	NS	NS	NS	1.1	NS

Striga counts at Sirinka and Mekele in the second season reflected a general decline in infestation with increasing N and manure rates. These results are in agreement with the results reported by Mumera and Below (1993) who found that *Striga* infestation declined with increasing N availability and the impact depended on the severity of the infestation. However, reducing *Striga* seed banks using fertiliser N is a slow process that requires long-term soil management strategies (Ransom and Odhiambo, 1994; Ransom, 1996). Farina *et al.* (1985) conducted long-term fertiliser trials using nitrate and ammonium N sources at 60, 120 and 180 kg N ha^{-1} and found that N significantly reduced the incidence of *S. asiatica* on maize in South Africa. Recent research in Western Kenya has shown that the *Striga* seed bank in the soil decreased by 90 %, where stover was applied with inorganic N and farmyard manure over a two year period (Ransom and Odhiambo, 1994; Odhiambo and Ransom, 1997). In addition, several other studies conducted in East and Central Africa have shown that the application of high rates of mineral fertilisers or farmyard manure reduces *Striga* infestation (Esilaba and Ransom, 1997).

Crop yields. Sorghum and maize biomass yields at the three sites (two in Sirinka and one in Mekele) for 1996 and 1997 are presented in Tables 2 and 3. There were significant crop, nitrogen, and manure main effects as well as crop by nitrogen, and crop by manure interaction effects on sorghum and maize biomass and grain yields at the Sirinka on-station site in 1996 (Table 2). Significant crop yield differences in the first season at this site was related to poor germination of the late maturing sorghum cultivar "IS9302". Sorghum grain yields were, therefore, not consistent and varied from 160 kg ha^{-1} to 905 kg ha^{-1}. Maize grain yields ranged from 1727 kg ha^{-1} (control) to 6298 kg ha^{-1} (120 kg N ha^{-1} with 30 t ha^{-1} manure), indicating that there was an increase in yield with increasing levels of manure and fertiliser. Among the manure treatments, the application of 10 to 30 t ha^{-1} significantly improved maize grain yield as compared to the control during the first season. Addition of fertiliser N at 40, 80 and 120 kg N ha^{-1} also significantly improved maize grain yield compared to the control (Table 3). Despite the absence of significant nitrogen by manure interaction effects, the combined application of N and manure increased maize grain yield. Thus, at 40 and 80 kg N ha^{-1}, all rates of manure increased grain yield, whereas only 120 kg N ha^{-1} increased yield with the application of manure at 30 t ha^{-1}.

There were significant crop, nitrogen, and manure main effects as well as crop by nitrogen, and crop by manure interaction effects during the second season at the Sirinka on-station site. Sorghum grain yields varied from 1342 (control) to 3189 kg ha^{-1} (40 kg N ha^{-1} and 30 t ha^{-1} manure). Application of farmyard manure at 10 t ha^{-1} and fertiliser at 40 and 80 kg N ha^{-1} significantly increased sorghum grain yield, but grain yield was severely depressed at 120 kg N ha^{-1} due to poor germination. There was no significant N by manure interaction but the combined application of N and manure increased grain yields during the second season (Table 3). The application of 40 kg N ha^{-1} with 20 and 30 t ha^{-1} manure significantly improved sorghum grain yield. Whereas only the combined application of 80 kg N ha^{-1} with 10 t ha^{-1} manure increased grain yield, all rates of manure application with 120 kg N ha^{-1} improved grain yield despite poor maize germination. Manure applied at 10 t ha^{-1} and urea applied at 40 kg N ha^{-1} may be the optimal rates of application of manure or urea alone for sorghum. Maize grain yields ranged from 1044 (control) to 5913 kg ha^{-1} (80 kg N ha^{-1} with 30 t ha^{-1} manure). Addition of manure increased maize grain yield from 1044 kg ha^{-1} (control) to 2030, 2351 and 2664 kg ha^{-1} at 10, 20 and 30 t ha^{-1} of manure. However, there were no significant differences between the 10 and 20 t ha^{-1} and also between the 20 and 30 t ha^{-1} rates of manure. Urea application significantly increased maize grain yields from 1044 (control) to 1617, 3514 and 3792 kg ha^{-1} at 40, 80 and 120 kg N ha^{-1}, respectively. However, yields at the 80 kg N ha^{-1} and 120 kg N ha^{-1} rates did not differ significantly (Table 2). Manure application at 10 t ha^{-1} and N rates between 40-80 kg N ha^{-1} were adequate for maize and sorghum at this site. Combined application of manure and N enhanced soil fertility (i.e., soil organic matter and total nitrogen) (Table 1), and increased crop yields at all rates of fertiliser application (Tables 2 and 3). These results confirm that the application of manure and nitrogenous fertilisers, provided that other major nutrients are not limiting, increases grain yield of the host crop even under *Striga* pressure. On infertile land, as in the current study, *Striga* infestation increased at the lower rates of manure and urea application. However, at the higher rates of application, *Striga* emergence declined, and this may result in complete suppression of the parasite in the long-term (Doggett, 1988; Pieterse and Verkleij, 1991; Parker and Riches, 1993).

There were significant crop and nitrogen main effects, and crop by nitrogen interaction effects on sorghum and maize stover yields at the Sirinka on-farm site in 1996 (Table 2). However, the grain yield was lost due to drought and damage by rodents and birds. This trial was discontinued during the second season due to management problems.

Nitrogen and manure did not affect sorghum biomass and grain yields at Mekele in the two seasons due to moisture stress and bird damage (Table 3). Sorghum grain yields in 1996 ranged from 317 to 1117 kg ha^{-1}. The highest yield was obtained at 40 kg N ha^{-1} in combination with 30 t ha^{-1} manure. However, there were higher but inconsistent sorghum grain yields at Mekele in 1997. Sorghum stover yields increased at all rates of manure application whereas combined application of manure and fertiliser increased stover yields at the 80 and 120 kg N ha^{-1} rates. Addition of manure also increased stover yield at 40 kg N ha^{-1} and 20 t ha^{-1} of manure during the second season (Table 3).

The conclusion from the current study is that crop yields responded to fertiliser N and farmyard manure even in the presence of moderate levels of *Striga* infestation when moisture was not limiting. Nitrogen inputs both from inorganic and organic sources are required for the long-term maintenance of cereal production. Improving the N status of the soil will also help suppress *Striga*. However, long-term studies are required to quantify these beneficial effects of N on *Striga* density.

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