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EFFECT OF COMBINED CATTLE MANURE AND MINERAL NITROGEN ON MAIZE N UPTAKE AND GRAIN YIELD

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ABSTRACT

The effectiveness in increasing N recovery by maize (*Zea mays* L.) of N fertiliser (0, 60, 120 kg N ha^{-1} annum^{-1}) and aerobically composted cattle manure (0, 12.5 Mg ha^{-1} annum^{-1} or 37.5 Mg ha^{-1} applied only in the first year) was determined when the two N sources were applied separately or in combination. A field experiment was established on a moderately leached sandy loam soil (Typic Kandiustalf) over three seasons, and N uptake was determined fortnightly from 4 weeks after planting (WAP) until harvest. Net N recovery during plant growth increased with N application rate (up to 90 kg N ha^{-1} in first season and up to 60 kg N ha^{-1} in second and third seasons). Net N recovery from manure during the growing period was relatively poor. There was no net recovery (up to 12 WAP) from annual application of manure during the first season and from first year application of the large rate of manure in the second season. Combined application of manure and N fertiliser increased net N recovery in all growing seasons (up to 120 kg N ha^{-1}) above that achieved by separate applications of both N sources. There was a manure by N fertiliser interaction that enhanced N recovery, in two treatment combinations during the first season (low manure rate) and in the second season, and this was attributed to some non-N nutrient effects of the manure. Highest percentage increases in total N recovery at harvesting were observed when manure was combined with the low N fertiliser rate (60 kg N ha^{-1}) (av. 58% in first season, 63% in third season) and limited further increases were recorded when the N fertiliser rate was doubled (120 kg N ha^{-1}) (av. 15% in first season, 32% in third season). It was concluded that aerobically composted cattle manure from the smallholder farming areas of Zimbabwe was a poor source of N for maize growth in the short-term, even at high application rates. Combined application of manure with judicious use of N fertiliser can be positively exploited by smallholder farmers in Zimbabwe and other countries of sub-Saharan Africa, to increase yields through enhanced efficiency of use of scarce nutrient resources.

Key Words: Aerobic composting, N mineralisation, N recovery, *Zea mays*

RÉSUMÉ

L'efficacité dans l'augmentation de N du rétablissement du ma¿s (*Zea mays* L.) de fertilisant N (0, 60, 120 kg N ha^{-1} annum^{-1}) et le fumier de vache aérobicallement composté (0, 12,5 Mg ha^{-1} appliqué seulement en première année) était déterminée quand les deux sources de N étaient appliquées séparément ou en combinaison. Une expérience sur le terrain était établie sur un filtre de terre de sol sable (Typic Kandiustalf) au delà de trois saisons, et la consommation de N était déterminée bimensuellement á partir de quatre semaines après la plantation (WAP) jusqu'à la récolte. Le rétablissement net de N pendant la croissance de la plante a augmenté avec le taux d'application de N (jusqu'à 90 kg N ha^{-1} en première saison et jusqu'à 60 kg N ha-1 en seconde et troisième saisons). Le rétablissement net de N á partir du fumier durant la période de croissance était relativement pauvre. Il n'y avait pas rétablissement (jusqu'à 12 WAP)á partir de l'application annuelle durant la première saison et á partir de la première année d'application du large taux de fumier dans la seconde saison. L'application combinée du fumier et du fertilisant N a augmenté le rétablissement net dans toutes les saisons de croissance (jusqu'à 120 kg N ha-1) au delà de celui accomplit par les applications séparées de deux sources de N. Il y avait un fumier par l'interaction du fertilisant N qui a amélioré le rétablissement de N, dans deux combinaisons de traitement pendant la première saison (faible taux de fumier) et dans la seconde saison, et ceci était attribué aux non effets des substances N du fumier. Les augmentations élevées du pourcentage dans le rétablissement total de N á la récolte étaient observées quand le fumier était combiné avec le faible taux de fertilisant N (60 kg N ha-1) (av. 58% en première saison, 63% en troisième saison) et davantage augmentations étaient enregistrées quand le taux de fertilisant était doublé (120 kg N ha-1) (av. 15% en première saison, 32% en troisième saison). Il était conclu que le fumier de vache aérobicállement composté des fermiers des petites surfaces du Zimbabwe était une pauvre source de N pour la croissance de ma¿s à court terme, même aux taux d'application élevés. L'application combinée du fumier avec un usage judicieux du fertilisant N peut être positivement exploitée par les petits fermiers au Zimbabwe et autres pays de l'Afrique sub-Saharienne, pour augmenter les rendements à travers l'efficacité améliorée de l'usage des rares ressources des substances.

Mots Clés: Compost aérobic, minéralisation de N, rétablissement de N, *Zea mays*

INTRODUCTION

The inherent poor fertility of most soils in the tropics and subtropics constitutes a major constraint to sustainable smallholder crop production in sub-Saharan Africa (SSA) (Myers *et al.*, 1994; Smaling *et al.*, 1997). Use of both organic and mineral fertilisers is often limited and this has resulted in a gradual depletion of soil nutrients in SSA (Smaling *et al.*, 1997). In 1990, the average fertiliser use in SSA was only 8.4 kg ha^{-1}, compared with 81 kg ha^{-1} in other developing countries, and 75% of the fertiliser use was limited to only 6 countries (Gerner and Harris, 1993). There is potential to increase crop yields while maintaining soil organic matter through combined use of organic and inorganic fertiliser (Palm *et al.*, 1998), but reliable recommendations for use by smallholder farmers are not yet available in most SSA countries. Organic fertilisers such as cattle manure remain the major sources of nutrients for production of staple cereal crops in Zimbabwe where most smallholder farmers can not afford recommended mineral fertiliser rates (Campbell *et al.*, 1998). However, the amount of cattle manure available per household has declined since 1990 due to persistent droughts which have reduced the number of cattle owned (Mugwira and Murwira, 1997). Livestock manure is also an important source of plant nutrients in countries of the West African Sahel (Powel *et al.*, 1996).

Nitrogen is the most limiting plant nutrient in most soils in Zimbabwe (Grant, 1981) and elsewhere in Africa (Giller *et al.*, 1997). Most of the N fertiliser is applied to maize (*Zea mays* L.), the staple food crop. Nitrogen in mineral fertiser is immediately available for plant uptake, but it is susceptible to loss in gaseous forms or by leaching if added at the wrong time or in excess of plant demand. Manure contains both mineral N (NO_3^- and NH_4^+) that is immediately plant available and organic N which is gradually available because it has first to be mineralized. Jokela (1992) reported from the USA that the effect of farm yard manure on yield was often greatest in the second or third year.

Manures from the smallholder farming areas of Zimbabwe generally mineralise N slowly due to aerobic composting which causes stabilization of C and N (Murwira and Kirchmann, 1993a; Nyamangara *et al.*, 1999). Aerobic composting occurs while the manure is still in the cattle pens where it is aerated by the trampling effect of the animals as they move around the kraal. The manure is generally of poor quality (low in N) due to inadequate and low quality grazing (Mugwira and Mukurumbira, 1984; Mugwira and Murwira, 1997), and inappropriate handling of the manure which results in both excessive NH_3 volatilisation and mixing with soil in the kraals (Khombe *et al.*, 1992; Murwira, 1995). Mugwira (1984) reported 57.4% soil content in manures collected from Chihota and Svosve smallholder farming areas. Thus, most of the aerobically composted manures in Zimbabwe are poor sources of N for crop production.

Nitrogen deficiency has been widely reported in maize during early plant growth (up to 6 weeks after planting) when manure is used as the sole N source (Mugwira and Murwira, 1997; Mugwira, 1984; Murwira and Kirchmann, 1993b).

The concept of 'integrated nutrient management' utilising all available organic and mineral nutrient resources has become a dominant paradigm for research in smallholder agriculture systems of sub-Saharan Africa to ensure both efficient and economic use of scarce nutrient resources (Smaling *et al.*, 1997; Vanlauwe *et al.*, 2001). However, there are few studies to date that examine N use from combinations of cattle manure and mineral N fertilisers over several seasons. Given the limited quantities of manure available, which mineralise N slowly, and the limited quantities of mineral fertiliser available to smallholder farmers, the effectiveness of the two fertiliser sources can potentially be increased when applied in combination. Most of the yield benefits reported on the combined use of cattle manure and mineral N in field experiments were based on short-term experiments (1-2 years) (Giller *et al.*, 1997; Palm *et al.*, 1997; Giller, 2001; Nhamo, 2001).

The aim of this study was to determine the effectiveness of aerobically composted solid cattle manure, mineral N fertiliser, and their combined application, on maize N uptake and grain yield over three cropping seasons.

MATERIALS AND METHODS

A field experiment was carried out at Domboshawa Training Centre (T.C.), ca. 35 km north of Harare, Zimbabwe (31°09E; 17 °36S). The experiment was established in October 1995 and was run for three years. The soil was a moderately weathered and leached Typic Kandiustalf (USDA) derived from granodiorite gneiss (Table 1) (Nyamapfene, 1991).

The experimental site, which had been under a grass fallow for at least six years, was disc ploughed at the beginning of the experiment. Domboshawa T.C. average rainfall is 880 mm, 95% of it during summer (November - April). Mean temperature is 18.8°C (Anon., 1977).

Aerobically composted manure refers to manure that is composted under conditions of unlimited oxygen, a traditional method of composting manure in Zimbabwe. The manure had total C and N contents 8.4 and 0.93%, respectively, and total soil N content of 83.3%. The C and N contents corrected to a soil-free basis were 41.9 and 4.64%, respectively (Nyamangara *et al.*, 1999).

Three manure rates (0, 12.5 Mg ha^{-1} annum^{-1}, and 37.5 Mg ha^{-1} applied the first year) and three N fertiliser rates (0, 60, 120 kg N ha^{-1} annum^{-1} as NH_4NO_3) were used in a 2-factor randomised complete block design with three replications. Nitrogen fertiliser was spot-applied in 3 equal split applications; at planting, 6 weeks after planting (WAP) and 12 WAP. Plot size was 6 m by 5 m. Annual basal applications of 30 kg K ha^{-1} as muriate of potash, 30 kg P ha^{-1} and 30 kg S ha^{-1} as single super phosphate were made. Manure and basal fertiliser were incorporated into the 0-20 cm soil layer using hand hoes. After application of the amendments, all plots were planted with maize (local variety R215) at a population of 41 667 plants ha^{-1}. The experiment was weeded by hand throughout the season. At the beginning of the second and third seasons, aboveground maize stover was removed before ploughing to simulate smallholder farming systems in Zimbabwe where stover is collected and fed to cattle during winter.

TABLE 1. Selected properties of the experimental soil at Domboshawa Training Centre

Soil depth (cm)	Soil texture	Organic C(%)	Total N (%)	C/N ratio	†KCl-N (mg kg^{-1})
0 - 10	Loamy sand	0.40	0.030	13.3	23
10 - 27	Loamy sand	0.17	0.015	11.1	21
27 - 40	Sandy loam	0.13	0.012	10.9	17
40 - 70	Sandy clay loam	0.13	0.013	9.8	16
70 - 130	Sandy clay loam	0.08	0.009	9.2	17

†KCl - extractable N

Rainfall was recorded throughout the growing season using a rain gauge.

Three replicate samples (two plants per sample) of maize shoots were taken every 2 weeks from 4 to 12 WAP (up to 16 WAP in the first season), to determine N accumulation. Sampling was limited to the 3 outer rows on either sides of each plot in a structured manner so that the net plot in the centre of each plot was not affected. Alternate plants were sampled to minimise border effects in subsequent sampling stages. A stainless steel knife was used to cut the maize plants at ground level. The plant samples were rinsed in distilled water, oven-dried at 65°C and dry matter yield determined by weighing. The air-dried samples were ground to pass through a 2-mm sieve and analysed for N content using the semi-micro-Kjeldahl method (Bremner and Mulvaney, 1982). At harvesting, (ca. 20 WAP), grain yield and total N uptake (grain plus stover) were determined using twenty-four plants taken from a 9 m^2 area at the centre of each plot. To determine net N recovery by maize during plant growth, the amount of N uptake in the control treatment (no manure or N fertiliser applied) was subtracted from the N uptake in the manure and fertiser treatments. It was assumed that there was equal uptake of soil N with or without manure or N fertiliser, i.e., there was no priming effect (Kirchmann, 1991; Jokela, 1992).

A two-way analysis of variance was used to test the significance of grain yield and N uptake between the treatments and for possible interactions (MSTAT, 1988). Means were separated using the least significant difference ($LSD_{0.05}$) method (Steel *et al.*, 1997).

Net N recoveries from manure and mineral N treatments were summed and compared with net N recovery from the combined treatment applications of both manure and mineral N. The aim was to determine whether farmers with limited resources of manure and N fertiliser would increase total N recovery by maize (and hence yield) by applying the two resources separately to different crops or in combination to the same crop.

RESULTS

Soil and weather conditions. Rainfall during the first season was well distributed and totalled 865 mm, which was within the seasonal average for the area. The second season was wetter (1395 mm). Rainfall during the third season was near average (840 mm) but it was poorly distributed and periods of moisture stress were experienced. Soil organic C and N contents were low (Table 1) and typical of the poorest granitic sandy soils in Zimbabwe. The amount of mineral N (KCl-extractable) in the top soil at the beginning of the first season was relatively small (20-30 mg N kg^{-1}) according to the criteria used to assess nutrient status in arable fields in Zimbabwe (Nyamangara *et al.*, 2000).

Nitrogen uptake during the growing season. Net N recovery increased significantly ($P<0.05$) with N fertiliser rate during the three growing seasons (Figs. 1, 2 and 3). During the first season, application of the full rate of manure in the first year (MH) significantly ($P<0.05$) increased net N recovery from 10 to 16 WAP compared with annual application of small amounts of manure (ML). However, in the second season net N uptake was significantly higher (4-12 WAP) in the annual application treatment (ML), and there was no net N recovery from the first year application (MH) treatment (Fig. 2). In the third season uptake was similar with the two manure rates until the end of the season when final N uptake was significantly higher in the MH treatment (Fig. 3).

The combined application of manure and N fertiliser significantly ($P<0.05$)increased net N uptake when compared with manure only treatments (Figs. 1,2 and 3). The largest increase in net N recovery was observed when fertiliser was combined with first-year (MH) manure application. Except in the first season, net N recovery from combined manure and N fertiliser application was significantly greater than that from N fertiliser only treatments at the end of the growing season.

Grain yield. Maize yield in the unamended control plots decreased from 2.59 t ha^{-1} in the first season to only 0.45 t ha^{-1} in the third season (Table 2). Grain yield was not obtained in the second season due to crop damage by cattle. The addition of cattle manure and mineral N significantly ($P<0.05$) increased grain yield compared with the control during both the first and third growing seasons (Table 2). Supplementing the cattle manure with mineral N significantly ($P<0.05$) increased grain yield compared to sole manure treatments. Overall, there was no significant ($P<0.05$) increase in grain yield when manure was supplemented with 60 kg N ha^{-1} mineral N compared with when the mineral N rate was doubled.

Above ground N recovery at harvesting. Total aboveground N recovery by the maize crop at harvesting decreased from 46.5 kg N ha^{-1} in the first season to only 8.5 kg N ha^{-1} in the third season (Table 3). There **was a significant ($P<0.05$)** interaction in total N uptake between manure and N fertiliser only during the first season (Table 3). The greatest percentage increase in N recovery was recorded when manure was combined with the 60 kg N ha^{-1} (60N) mineral N rate, and a much smaller further increase was recorded when the mineral N rate was doubled (120 kg N ha^{-1}). Total N recovery (at harvesting) was not obtained in the second season again due to crop damage by cattle.

As no final measurements were taken in the second season due to cattle damage in the plots, values were calculated for the 12 week harvest

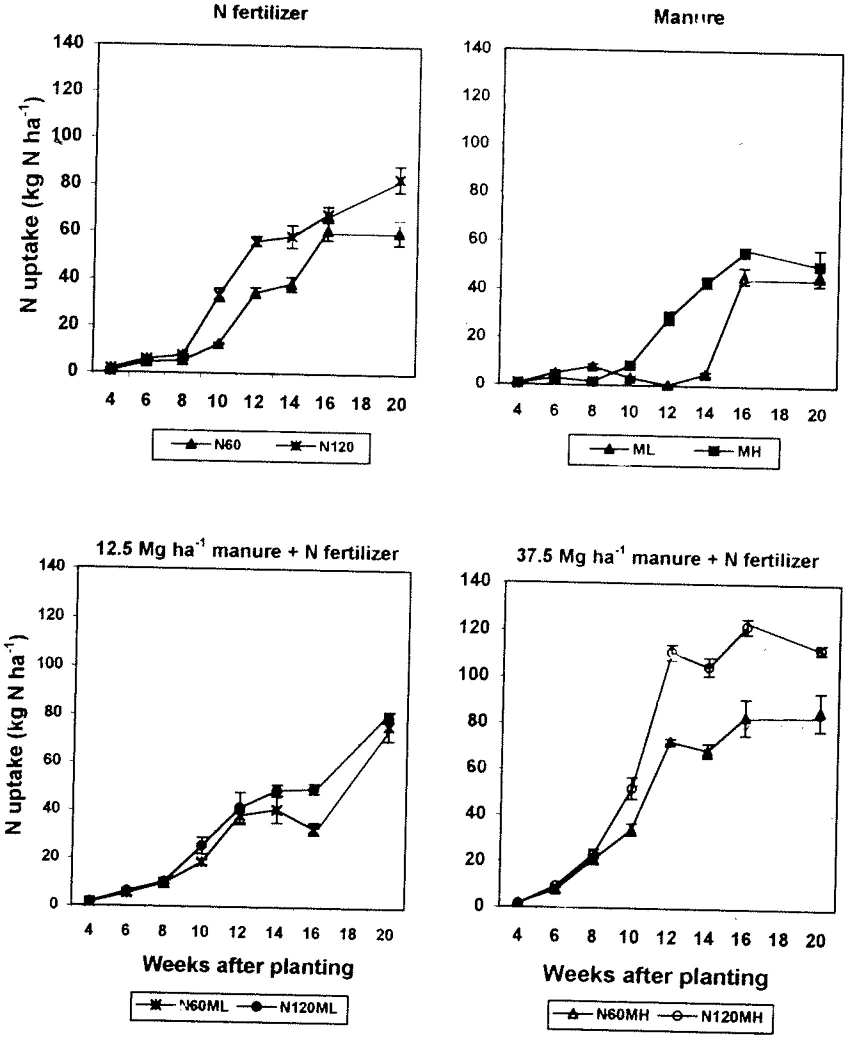

Figure 1. Net N uptake pattern of maize against time in plots amended with manure and N fertiliser treatments during the **first growing** season.

when N accumulation appeared to have reached a maximum in several treatments (Fig. 2). There were significant ($P<0.05$) differences in N recovery between the two systems in the first and second seasons (Table 4). In the first season N recovery was higher when manure (ML) and N fertiliser (both N60 and N120) were applied separately, and in the second season N recovery was higher when both rates of manure and N fertiser were applied in combination.

DISCUSSION

The efficiency of N capture depends on both the supply of N in the correct quantity and timing in relation to the crop demand and ability of the crop to capture the available N (Giller, 2001). It is thus, important that crop growth and uptake of N is not limited by other constraints such as water availability or deficiencies of other nutrients; otherwise available N in the soil may be susceptible to losses through leaching or as gaseous N, especially during heavy rainfall episodes.

Efficiency of mineral fertiliser as N source. The marked increase in N uptake with increasing N fertiliser rate during all three seasons indicates that N fertiliser was readily absorbed by the crop. In the first season, net grain yield per amount of N fertiliser applied was highest in the 60 kg N ha^{-1}

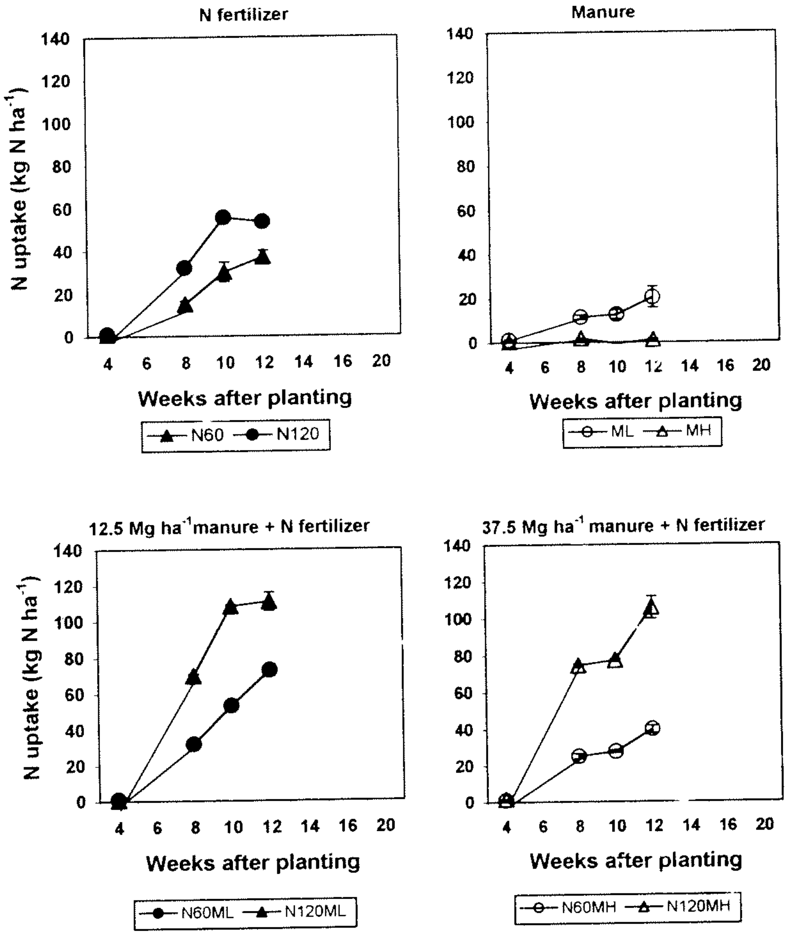

Figure 2. Net N uptake pattern of maize against time in plots amended with manure and N fertiliser treatments during the second growing season.

treatment (49.4 kg grain per kg N applied) compared with 31.5 kg grain per kg N applied in the 120 kg N ha^{-1} treatment. This indicates that the efficiency of N utilisation was highest in the low N treatment (Fig. 1). However, in the third season the utilisation efficiency was highest in the high N fertiliser treatment (28.3 kg grain per kg N applied) compared with the lower N fertiliser treatment (17.4 kg grain per kg N applied) (Fig. 3). The utilization efficiencies of applied N fertiliser were lower in the third season partly because of poor plant growth caused by poor rainfall distribution (Tables 2 and 3). Although smallholder farmers typically spot-apply N fertiliser, (Piha, 1993) the utilisation efficiency of the applied N by maize tends to be lower because of poor weed control due to labour constraints. Piha (1993) reported that with proper weed control, broadcasting N fertiliser, which is faster and less labour-intensive, can result in significantly higher N uptake, yield and profit margins in the smallholder farming areas of Zimbabwe.

Efficiency of manure as N source. The relatively poor N recovery from the manure only treatments, compared to the N fertiliser only treatments, especially in the first and second seasons, was

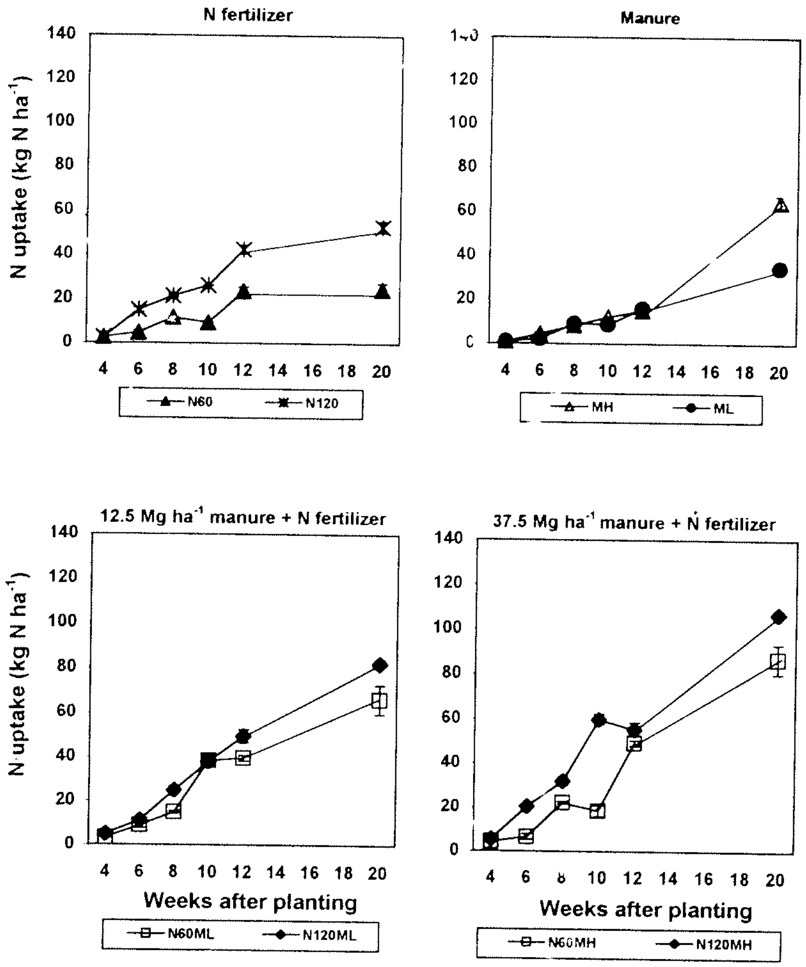

Figure 3. Net N uptake pattern of maize against time in plots amended with manure and N fertiliser treatments during the third growing season.

TABLE 2. Maize grain yield (t ha^{-1}) at harvesting in the first and third growing season

Manure (mg ha^{-1})	N fertiliser (kg N ha^{-1})			
	0	60	120	Mean
		1995/96 season		
0	2.59	5.55	6.36	4.83
ML	4.95	6.73	6.48	6.05
MH	5.47	6.84	8.04	6.78
Mean	4.34	6.37	6.96	
SED		0.766		
		1997/98 season		
0	0.45	1.49	3.85	1.93
ML	2.31	3.84	4.66	3.61
MH	4.06	4.71	5.42	4.73
Mean	2.27	3.35	4.64	
SED		1.011		

ML = 12.5 mg ha^{-1} annum^{-1}; MH = 37.5 mg ha^{-1} applied only in the first year

TABLE 3. Total N uptake by maize (above ground parts) at harvesting in first and third growing seasons

Manure (mg ha^{-1})	N fertiliser (kg N ha^{-1})			
	0	60	120	Mean
		1995/96 season		
0	46.5 (129.5)*	106.7 (21.5)	129.6	94.3
	(88.4)	(14.8)	(-2.6)	(18.9)
ML	87.6 (39.8)	122.5 (3.0)	126.2	112.1
	(8.3)	(8.1)	(26.0)	(SED=2.4)
MH	94.9 (39.5)	132.4 (20.1)	159.0	(14.9)128.8
Mean	76.4 (57.9)	120.5 (14.7) (SED=3.05	138.3	
		1997/98 season		
0	8.5 (288)	33.0 (85.8)	61.3	34.3
	(405)	(126)	(48.1)	(102)
ML	42.9 (73.9)	74.6 (21.7)	90.8	69.4
	(70.4)	(27.7)	(27.0)	(SED=1.5)
MH	73.1 (30.4)	95.3 (21.0)	115.3	(36.3) 94.6
Mean	41.5 (62.9)	67.6 (31.8) (SED=1.83)	89.2	

ML = 12.5 mg ha^{-1}annum^{-1}; MH = 37.5 mg ha^{-1} applied only in the first year

*Figures in brackets are percentage increases in N recovery between the adjacent figures; i.e. $[(N_2-N_1)/N_1 \times 100\%]$

attributed to the slow N mineralisation from this poor quality manure. The depressed N uptake in the treatment where all the manure was applied in the first season (MH), compared with annual application (ML), during the second season may be attributed to the presence of a small fraction of mineral or readily mineralisable N fraction in the manure, although this was not measured. With first year manure application, all the readily decomposable and mineral N was presumably used up during the first season while with annual manure application some manure was applied every season. Presumably there was readily available N for plant uptake at the beginning of the second season in the ML treatment, while mainly stable organic material which mineralises slowly was predominant in the MH treatment during the second season (Muller-Sämann and Kotschi, 1994).

The slow rate of N mineralisation from aerobically composted manure, as shown by very low N uptake response until 12 WAP (Fig. 1), has been observed elsewhere and attributed to a high degree of C and N stabilisation in the soil (Kirchmann, 1985; Murwira and Kirchmann, 1993a; Muller-Sämann and Kotschi, 1994). In a laboratory incubation experiment using the same manure, there was slight immobilisation of N over the first twenty one days, after which, there was limited N remineralisation over a 60 day period of the incubation (Nyamangara *et al.*, 1999). Similar patterns were found by Murwira and Kirchmann (1993b) who observed depressed N uptake up to 8 weeks after the application of a similar type of poor quality manure. Depressed N uptake after application of aerobically composted low-N manure has also been reported in Zimbabwe (Mugwira and Mukurumbira, 1984; Mugwira, 1984; Tanner and Mugwira, 1984). In our study, no negative effects of manure addition on crop N recovery was observed during early crop growth, although there was little benefit seen from manure addition during the first 12 weeks of crop growth (Figs. 1-3).

Combination of manure and mineral N fertiliser. Increased N uptake during all seasons in the combined manure/N fertiliser treatments

TABLE 4. Comparison of net N uptake by maize when manure and N fertiliser were applied separately or in combination

Manure	N fertiliser	Application of method		
		Separate	Combined	Significance
		1995/96 season		
ML	N60	101.3	76.0	*
ML	N120	124.2	79.7	*
MH	N60	108.6	85.9	NS
MH	N120	131.5	112.5	NS
		1996/97 season[b]		
ML	N60	39	74	*
ML	N120	57	110	*
MH	N60	58	40	NS
MH	N120	76	106	*
		1997/98 season		
ML	N60	58.9	66.1	NS
ML	N120	87.2	82.3	NS
MH	N60	89.1	86.8	NS
MH	N120	117.4	106.8	NS

ML = 12.5 mg $ha^{-1}annum^{-1}$; MH = 37.5 mg ha^{-1} applied only in the first year

[b] Results presented from the harvest 12 weeks after planting as final harvest was destroyed by cattle

N60 = 60 kg $ha^{-1}annum^{-1}$; N120 = 120 kg $ha^{-1}annum^{-1}$

compared with the manure only treatments confirms the hypothesis that N fertiliser can be used to overcome the negative effects caused by the addition of low-N manure. There were significant ($P<0.05$) interactions between the manure and N fertiliser (in the N60ML and N120ML treatments during the first season), and in the second cropping season. This implies that the presence of small quantities of manure increased N recovery from mineral N fertiliser.

The interactions were strongest in the second season when heavy rainfall was experienced. This can be explained by the possibility that improved root growth increased the ability of the crop to capture fertiliser N that was otherwise lost by leaching. Since the interactions were evident where lower rates of manure were added, it is unlikely that the effects were due to improvements of soil physical properties. The effect could have been due to some other nutrients such as addition of P, Ca and Mg that are known to limit crop growth in these sandy granitic soils (Grant, 1981). However, a parallel study at the Domboshawa site showed that both first year (MH) and annual (ML) manure application significantly increased soil structural stability and water retention at low suction values after 3 years (Nyamangara *et al.*, 2001).

In the manure plus N fertiliser treatment combinations, the largest increase in total N uptake was observed in the 60 kg N ha^{-1} plus manure (ave. 58% in first season and 63% in third season). Doubling the N fertiliser rate (120 kg N ha^{-1}) in the combinations resulted in a limited further increase in N uptake (ave. 15% in 1995/96 and 32% in 1997/98), suggesting that the lower N fertiliser rate was the most efficient. In fact, N fertiliser rates of 90-120 kg N ha^{-1}, without manure addition, have been reported to be adequate for an average maize yield of 7 t ha^{-1} in Zimbabwe (Cooper and Fenner, 1981; Murwira and Kirchmann, 1993b).

Although there was no distinctive complementarity between manure and N fertiliser on N uptake and yield in our study, it has been reported elsewhere and attributed to the beneficial physical effects of manure on soil (Magdoff and Amadon, 1980; Nnoham and Odurukwe, 1987) and synchrony between N release and uptake by the crop (Rodel *et al.*, 1980; Murwira and Kirchmann, 1993b; Nleya and Mugwira, 1993). Murwira and Kirchmann (1993b) concluded that best synchrony between N availability and plant uptake was achieved when manure was supplemented with late-applied fertiliser N. Rodel *et al.* (1980) recommended a minimum annual application of 4.5 t ha^{-1} manure supplemented with 90 kg N ha^{-1} for maize production.

CONCLUSION

Application of aerobically composted cattle manure from smallholder farming areas of Zimbabwe and related farming systems in SSA, even at high rates, is not adequate to supply the N requirements for maize production due to the low rate of decomposition of the manure, especially during the season of application. Nitrogen fertiliser is required during early plant growth to prevent temporary N deficiency caused by the manure. The recovery of N by maize (and hence yield) can effectively be increased by the application of manure in combination with some mineral N in the smallholder farming areas of Zimbabwe and similar farming systems of SSA.

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