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Nitrogen Response of Maize to Fresh and Composted Manure

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ABSTRACT

Growth traits and yields of maize (*Zea mays*) are described for varying fertilizer treatments (fresh cow manure, composted manure, inorganic NPK). Relative N-uptake is 9, 28, and 46% for compost, fresh manure and NPK, respectively. Growth rate and yields are correlated significantly with plant tissue nitrate at 30 days, which diminished in the order NPK>fresh manure>control>compost. Similarly, leaf nitrate at silking stage of maize decreases in the same order, with compost giving lowest soluble N levels.. Total-N in grain at harvest does not differ significantly between the treatments, however. It is concluded that rapid early nitrogen release contributes to a high yield but elevated plant nitrate and nitrate remaining in soil after harvest are consequences which must be weighed against it. The difficulties inherent in estimating N-release from organic sources are discussed.

INTRODUCTION

Field trials comparing the performance of conventional and organic fertilizers have limited validity since the fate of the organic materials in the soil and their nutrient release may be largely unknown. Attempts to clarify characteristic traits for such differing fertilizer practices must distinguish organic materials on broader grounds than analysis and crop yields alone. In our experiment we investigate the nitrogen release from various types of fertilizers and their physiological effects on maize.

Very little information is available outside of estimates from various farmers which describes the type of nutrient release and crop response to be expected from natural fertilizers (Flaig *et al.*, 1977). Of the published reports, widely varying indices of N availability from organic manures are found (Pratt *et al.*, 1973; Willrich *et al.*, 1974; Mathers & Goss, 1979; Castellanos & Pratt, 1981). Consequently, growers wishing to meet soil nutrient requirements from organic sources have no reliable data at hand to aid in choosing correct rates (Brinton, 1981). This may partially explain the lower than average yield reported for organic farming practices (German Ministry for Nutrition, Agriculture and the Environment, 1977; Lockeretz *et al.*, 1980). On the other hand it may encourage wasteful use of organic fertilizers.

Fresh plant and animal residues contain many labile organic compounds that upon addition to typical soil decay to release nutrients–in particular nitrogen–fairly rapidly. Normally, it is thought that if the N content is greater than 1.5%, or if a large amount of microbial proteins are present, the nitrogen release will be rapid (Allison, 1973; McCalla *et al.*, 1977). Theoretically, it is possible that the effects of rapid release organic fertilizers on soils and crops may not differ from those of soluble inorganic fertilizers. For example, the use of fresh poultry manure on pastures in the U.S. has increased the incidence of nitrate poisoning of cattle (Viets, 1974). Nitrate accumulation in crops has long been recognized to be a serious hazard (Wilson, 1949).

By controlled composting of fresh organic wastes, excessively rapid release of nitrogen to soils and crops may be avoided, since some of the potentially available forms of N such an ammonia, amines, and urea have been diminished by volatilization or have been transformed by chemical and biological steps to more stable polymerized humic compounds (Golueke, 1972; Flaig *et al.*, 1977). Therefore, subsequent further decomposition in soil will release nitrogen, but at a slower rate (Schudel *et al.*, 1979; Castellanos & Pratt, 1981). In addition, phenolic compounds which can be formed during composting may act to inhibit nitrification (Bundy & Bremner, 1973; Flaig, 1976). There is increasing evidence that nitrogen released in a slow manner may fit more closely the requirements of growing plants than that from highly available sources (Vaughn *et al.*, 1979; Power, 1979).

MATERIALS AND METHODS

A field experiment with maize (*Zea mays*, Doebler 78x) was set up to test differences in growth, nutrient content and yields from fresh and composted manure of similar origin alongside a standard inorganic NPK treatment. The field experiment was located on Hedge Hill Farm in the south-eastern Piedmont region of Pennsylvania, elevation 32 m, lat. 40°07', long. 75°30'. The mean annual temperature for the year of the experiment was 11.1°C and mean precipitation 114 cm. These values are 0.2°C less and 8 cm more, respectively, than the 30-year mean.

The soil type is Readington loam (fine-loamy, mixed, mesic, Typic fragiudalf), with 52% sand, 42% silt and 6% clay for the top 20 cm of soil. The soil pH was 5.5 in water and the relative saturation of Ca, Mg and K was 32%, 12% and 1.8%, respectively. Bray P1 and P2 phosphorus were 31 and 40 ppm, respectively. Organic matter was 2.3% and total N 0.136% giving by calculation a C:N (OM × .58=C) of 9.8. P and K levels were interpreted as moderate and N release for the sod plow-down estimated at 53-70 kg/ha, which is low since the N requirement is approximately 150 kg/ha for the estimated maximum yield potential for this soil and region of 7.85 t/ha.

The field on which the experiment was situated had no recent fertilizer history. The soil was plowed, disced and subsequently fertilized and rototilled just prior to planting maize on 90 cm rows (final plant population was 47,000/ha).

Fertilizer treatments and rates are shown in Table 1. The rate of N for the inorganic treatment was initially taken from the state soil testing lab. recommendation based on this soil and region; however, we subtracted the estimated quantity of N expected to be released from the soil. Rates for organic manures were taken by approximating the total N supply for the inorganic treatment; however, the compost rate was adjusted upwards due to very low soluble N present. The total N contents for fresh and composted manure were comparable at 2.0 and 2.3%, respectively. The composted manure was taken from a biodynamic (organic) dairy farm and the fresh manure from a neighboring farm which did not compost manure. The respective ages were 4 months and 3 weeks.

TABLE 1

Application rates for the various treatments.

Treatment	Dry matter kg/ha	Total N kg/ha	Total P kg/ha	K kg/ha
Composted Manure	6590	148	75	69
Fresh Manure	4730	101	56	40
Inorganic Manure	899	108	47	89

Plot Lay Out

A randomized complete block design incorporating 3 replications was employed. Individual parcels were 13 x 8.5 m.

Sampling and Analyses

Samples of maize were taken for whole plants at seedling stage (27 days after planting), ear node leaves at silking stage (60 DAP) and grain at harvest. Material was oven dried and ground before analysis. Total N was performed by the Kjeldahl method and non-protein N by the Schutzer and Barnstein method (Penn State Forage Testing Procedures, Penn State Lab, 1976).

Nitrate N was determined with an ion selective electrode (Orion Methods Manual, 1978). Free amino N was determined on water extracts after the AOAC method (AOAC, 1975). All tests were conducted in duplicate.

RESULTS

Physiological traits of maize at seedling stage (27 day) and silking stage (60 day) growth are shown in Table 2a and b. Net growth rate (NGR) as height gain per day at 20 days shows a gradient of NPK > fresh manure > composted manure > control. Plants with fresh manure treatment show significantly higher levels of total N than compost treatment, but were not significantly different from NPK treatment. Similarly, NO_3-N levels are significantly higher with fresh manure than with composted manure, and not significantly different from NPK treatment. In fact, compost treatment apparently depresses NO_3-N levels for they are lower than the control samples at the $p < 0.1$ level. The fraction of total N made up by NO_3-N decreases in the gradient NPK > fresh manure > control > composted manure. This data provides some evidence for a rapid early N release from fresh manure in contrast to composted manure.

The pattern of growth response may be explained as a stimulation from soluble N. Net growth rate (NGR) correlates very significantly with non-protein nitrogen (NPN) ($r = 0.80^{**}$) and NO_3-N ($r = 0.75^{**}$). NGR was also greater with increasing tissue K ($r = 0.72^{**}$) but tissue K does not correlate to K supplied in the fertilizer ($r = 0.30$), rather it increases with increasing relative nitrate levels ($r = 0.72^{**}$) in the plant tissue. Apparently the rate of nitrate reduction diminishes with increasing NO_3^-, for the amount of nitrate relative to total N increases highly significantly with increasing NO_3-N levels ($r = 0.99^{***}$). For 27 day plants the gradient of total N content from the lowest (3.35%) to the highest (4.5%), a change of 34%, is accompanied by a 2.6-fold elevation of NO_3-N. Thus there may be some argument to limiting the available N rate based on health considerations alone, depending on what stage of growth the crop is to be fed. In our samples we can not explain why the compost treatment has diminished the nitrate levels even compared to the control. Compost treatment of plants can result in NO_3-levels disproportionately low relative to the amount of N applied (Schudel *et al.*, 1979). This is in contrast to fresh manure, as in our samples fresh manure behaves more typical of inorganic NPK than of compost.

Analyses of ear node leaves are shown in Table 2b. NGR is greatest with NPK and differs significantly from the compost and control treatments, but not from fresh manure treatment. Total N levels decrease in the gradient NPK > fresh manure > compost > control, all treatments showing above-sufficiency levels. NO_3-N and NPN levels are again lowest in compost, but not

TABLE 2

Maize Physiological Traits.

Treatment	NGR* mm/day	Total N % dm	NO_3-N % dm	NPN % dm	NO_3-N/ Total-N	NO_3-N/ NPN
a) 27 days, whole plants						
Control	13.06 a[1]	4.13ab	0.48a	0.73a	11.6ab	65.8a
Composted Manure	14.15ab	3.96a	0.35a	0.75a	8.8a	46.1a
Fresh Manure	15.34bc	4.35c	0.56bc	1.05a	12.9bc	53.1a
Inorganic NPK	16.21c	4.29bc	0.64c	1.06c	14.9c	60.0a
b) silking stage, ear node leaves						
Control	34.93a	3.21a	0.021ab	0.29a	0.65ab	7.0a
Composted Manure	34.38a	3.25ab	0.016a	0.22a	0.49a	7.3ab
Fresh Manure	38.00ab	3.35ab	0.024ab	0.30a	0.72ab	8.0ab
Inorganic NPK	40.60b	3.49b	0.044b	0.33a	1.26b	13.4b

*NGR (net growth rate) measured at 20 and 45 days, respectively
[1]Values followed by the same letter in each column do not differ significantly at $p<0.05$ using Duncan's multiple range test.

significantly different from the fresh manure treatment. Similar trends are seen between the two sampling periods. For example, NGR correlates highly significantly between the 20 and 45 day determinations (r = 0.91***). Similarly, significant or very significant correlations between the two sampling periods are seen with regard to NO_3-N, NO_3-N relative total N, and NPN (r = 0.69*, 0.85**, 0.80**, resp.). Total N, however, correlates poorly (r = 0.31) between the samplings.

Grain Yields and Composition

Maize grain yields and composition are shown in Table 3. The yield gradient is similar to the total N gradient observed from earlier samplings of tissue, as well as from grain tests. Yields correlate significantly (r = 0.60*) with grain total N. Similar observations have been made by Pierre *et al.* (1977) who used the grain N%: yield % relationship to estimate N sufficiency and N requirements to reach maximum yield. Apparently, the nitrogen supplying capability of the soil was very good, as the control shows high N relative to yields and the differences in N content for all treatments are not significant.

TABLE 3

Maize Grain Yield and Composition.

Treatment	Shell corn yield, t/ha*	1000-kernel wgt., g**	Total N, % dm	Free amino N, % dm
Control	6.86a[1]	334a	1.39a	0.032a
Composted Manure	7.66a	336ab	1.39a	0.042b
Fresh Manure	8.23ab	352ab	1.44a	0.042b
Inorganic NPK	9.28b	366b	1.47a	0.045b

*15.5% moisture basis
**Dry basis
[1]Values in the same column followed by the same letter do not differ significantly at $p<0.05$ using Duncan's multiple range test

Nitrogen Use

By determining the nitrogen uptake for the control treatment we arrive at estimations of net N uptake for the treatments. Possible sources of error in this means of calculation are twofold: 1) if there is a "priming action" (Oberländer, 1973) by addition of organic materials then the calculations will tend to over-estimate the N release from organic manures, and 2) if there is inhibition of mineralization caused by inorganic N (Megušar, 1968) then calculations would under-estimate N-use from inorganic sources. Since N use efficiency from inorganic treatment is used to estimate the N release from organic manures, then error (2) tends to compensate for error (1). We believe both error sources may be safely ignored here, particularly as all fertilizer rates are very moderate.

Table 4 shows data on nitrogen use for the different treatments. Calculated efficiency of N utilization for the inorganic treatment is 46%, which compares well with the value reported by Bartholomew (1971). N uptake for organic treatments as a fraction of total N supplied is 9.2% and 28.5% for compost and fresh manure, respectively. Assuming the same efficiency of N use as found in the inorganic treatment, then the fraction of total N mineralized is 20% and 62% for compost and fresh manure, respectively . Castellanos & Pratt (1981) show data confirming a diminishing of N availability from composting, both with hen and dairy cow manure. With such differences in N release existing for manure, it becomes imperative to understand more clearly the aging process and by what means N release may be predicted in advance.

TABLE 4

Net Yield, N uptake and N release

Treatment	Net yield t/ha[1]	Net N uptake kg/ha	N uptake, % of total supplied	N release % of total[2]
Composted Manure	0.83	13.7	9.2	20
Fresh Manure	1.39	28.5	28.2	62
Inorganic NPK	2.42	49.6	46.0	-

[1]yield difference over control
[2]the values assumed 46% efficiency

TABLE 5

Nitrate-N Content of Top- and Sub-soil samples

Treatment	NO_3-N, ppm dry soil	
	Topsoil (0–20cm)	Subsoil (20–40cm)
Control	4.75	4.15
Composted Manure	6.12	3.85
Fresh Manure	6.38	6.50
Inorganic NPK	12.00	9.05

[1]Samples taken at harvest. Replications combined for analysis, therefore no statistics are available.

Fate of Nitrogen

NO_3-N in topsoil and subsoil samples was determined at harvest, as shown in Table 5. NO_3-N levels decrease in the order NPK>fresh manure>composted manure>control and correlate significantly with the calculated available N supply (r=0.97*). Thus, increasing levels of fertilizer N will increase the relative amount of N remaining in the soil after harvest in soluble form. By accounting for the quantity of nitrogen contained in the harvested portion and stover residues, as well as that remaining as soluble N in the soil to a depth of 40 cm, and subtracting it from the amount of N assumed available from the different treatments, we arrive at an estimation of N lost, or otherwise unaccounted for, as seen in Table 6. Fresh manure and inorganic NPK show similar losses (23% and 24% resp.) and compost least (9%), as a fraction of the total N applied. The values for fresh manure and NPK agree closely with volatilization losses

TABLE 6

Fate of Nitrogen

Treatment	Gross N unaccounted for, kg/ha[1]	Nitrate-N in soil profile kg/ha	Net N unaccounted for, (lost) kg/ha[2]	N loss, % of total supplied[3]
Composted Manure	15.7	2.2	13.5	9.1
Fresh Manure	33.2	11.2	22.0	22.6
Inorganic NPK	58.3	32.5	25.8	24.0

[1]available N minus N in crop (grain and stover)
[2]column 1 minus column 2
[3]column 3 divided by total nitrogen applied

reported by Badzhov & Ikonomova (1971) and Hauck (1971). Nitrogen we report as lost is not necessarily volatilized, since some nitrate could have leached beyond the 40 cm depth to which excess soluble N was taken into account. It is unlikely that immobilization into soil organic matter could account for any losses (aside from the portion already in resistant organic form in the organic manures), as the initial C:N ratio for this soil was 9.8.

CONCLUSIONS

Comparative studies of organic and conventional maize production in the U.S. midwest show that organic maize may be nitrogen limited (Lockeretz *et al.*, 1980; Wolfson & Shearer, 1981). Similar conclusions might be drawn for other crops based on European studies (German Ministry for Nutrition, Agriculture and Environment, 1977; Dlouhý, 1977, 1981; Pettersson & Wistinghausen, 1979).

Limitations of nitrogen in organic farming are twofold: 1) insufficient total N applied, most likely due to limited quantities of on-farm fertilizer materials, and 2) availability factors which restrict N release to crops. The availability of nitrogen from organic sources may be unknown, but it is certainly less than that from inorganic sources, excepting those adulterated to be slow releasing. In addition, N availability from organic sources may vary tremendously depending on the condition of the material, as in this study, or climate (Patriquin *et al.*, 1981).

The nitrogen limitation conclusion can be oversimplified, however. For example, a limitation of N availability, such as shown here for compost treatment, implied conversely an increase in soil nitrogen from resistant organic N in the manure. This may explain why in all the above cited comparative studies, organic treatment results in increases in soil organic matter and total N, many of the increases being significant. Therefore, with continued organic treatment a point may be reached where adequate N is made available each year from the 2-5% decomposition rate normally found for soil organic matter.

High available N rates may involve the trade-off of greater nitrate content of crops and increased N losses, either in volatilized form or as leached nitrate. N losses from organic treatment may be similar to those from inorganic treatment if the N release is very rapid, as shown by our data.

Yield differences that may be significant between conventional and organic production merit less attention if discrepancies can be shown with regard to the fate of the nitrogen applied. This would apply also to different forms of organic production,

Finally, in view of the rather large discrepancy of nitrogen supply from composted vs fresh manure, it would appear imperative to understand more completely the mechanisms which govern N-release from organic materials.

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