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Nutrients Removed in Harvested Portion of Crop by Continuous Corn Receiving Organic and Inorganic Fertilizers*

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Abstract: A study was conducted to examine patterns of macro- and micro nutrient accumulation in corn grains in response to seven different levels of N amendments: no amendments, fertilizer (NH_4NO_3) at 100 and 200 kg N ha^{-1}, stockpiled and rotted manure at 50 and 100 Mg ha^{-1} (wet weight) application. Results indicate that over the study periods manure application increased most of biomass macro- and micro nutrient concentrations. There was no significant positive relationship between grain yield and macro- and micro nutrient concentrations. Data showed at 11 t ha^{-1} yield level, corn grain would remove on average the following amounts of nutrient elements: N, 126.5 to 174.9; P, 31.9 to 35.2; K, 34.43 to 37.62; S, 12.21 to 14.96; Mg, 10.08 to 10.65; Ca, 0.81 to 0.97; Fe, 0.24 to 0.33; Zn, 0.20 to 0.23; Mn, 0.048 to 0.054; Cu, 0.027 to 0.042 kg ha^{-1}, which are comparable to those reported in the literature: N, 120.8; P, 36.7; K, 44.7; S, 9.9; Mg, 14.4; Ca, 2.6; Fe, 0.33; Zn, 0.25; Mn, 0.045; Cu, 0.03 kg ha^{-1}. These values, however, do not take into account the quality and availability of nutrient reserves already in the soil. Because of this limitation, soil testing should still be the cornerstone of all fertility programs. Removal rates can be used in conjunction with soil testing to estimate the depletion of macro- and micro nutrient reserves. These data are very useful in comparing the nutrient demands of different crops.

Key words: Corn (*Zea mays* L.), Biomass, macro-and micro nutrient, stockpiled and rotted manure, organic and inorganic fertilizer

Introduction

In the efforts to achieve sustainable agricultural production while maintaining and preserving the environment, we have come to face crucial macro- and micro nutrient for life (Marschner, 1995). Agricultural producers increasingly rely on application of large quantities of inorganic and organic amendments to maximize yields, which may lead to potential macro-and micro nutrient crisis (Heckman *et al*., 2003). Therefore, an ideal nutrient management should provide a balance nutrient between inputs and outputs in the plant-soil-atmosphere ecosystem over the long-term (Bacon *et al*., 1990; Heckman *et al*., 2003). To do so, nutrient removed by crop harvest must be replaced annually or at least within the crop rotation cycles. If, nutrient inputs as a fertilizer, manure or any other sources like waste materials exceed crop removal over growing seasons, soils become an environmental concern (Daniel *et al*., 1998). An accurate measurement for macro- and micro nutrients removal by biomass part of crop is an important component for sustainable crop production and nutrient management. Macro-and micro nutrient fertilizers must be applied annually to avoid nutrient deficiencies, maintain a medium level of soil fertility and produce high-yielding crops.

Nutrient removal values are a key component of nutrient management planning as manure and fertilizer applications are being limited based on the expected level of crop potential yield of corn (Heckman *et al*., 2003; Sims, 1999; Sims *et al*., 1998). Ontario Ministry of Agriculture and Food

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regularly publishes values for crop nutrient removal through agronomy guide for field crops. Also, the values that were established in the past may reflect progress in current agronomic technologies such as improved hybrids, with higher plantation; yield potential, precision fertilizer management according to land type and soil conditions. In additions, the soils on the ECORC experimental station are typical of the Eastern Ontario crop area in regards to soil series, chemical and physical properties and crop rotations making it an ideal site for soil fertility research in relation with biomass nutrient uptake. Therefore, it is urgently need to evaluate biomass macro- and micro nutrients removal by corn for expected yield.

Many of the soils used for corn, soybean and wheat production in Eastern Ontario have high pH, low organic matter and low to medium levels of plant available nutrients (Baute, 2002). There is emphasis on short and long-term fertilization studies are conducted at the central experimental farm to examine corn crop physiology, rotation, hybrids, growth and yield response to N amendments (Ma and Dwyer, 2001, 1998; Ma *et al*., 1999, 2003). Crop nutrients removal has not been received greater attention. The objective of this study was to assess soil N amendments effects on corn grain and stover accumulation of macro- (N, P, K, S, Ca and Mg) and micro- (Fe, Mn, Zn and Cu) nutrients.

Materials and Methods

The Experiment

A long-term experiment on corn from 1992 to 2002 was conducted on Brandon loam soil (Orthic Humic Gleysol, in the Canadian classification) on the Central Experimental Farm at Ottawa, Ontario (45°22'N, 75°43'W) to evaluate the N changes in soil and plant after ten years of continuous corn receiving fertilizer and manure. The soil contained an average of 34% clay, 27% silt and 39% sand with a pH of 6.5 (1:1 in water). The treatment and design has been reported previously (Ma *et al*., 1999). Briefly, a randomized complete block design arranged with two factors. Seven different treatments (no amendments, N fertilizer (NH_4NO_3) at 100 and 200 kg N ha^{-1}, stockpiled manure at 50 and 100 Mg ha^{-1} (wet weight) and well rotted manure at 50 and 100 Mg ha^{-1} (wet weight) were assigned to the whole plot. Two corn hybrids, an older lower yielding hybrid (Pride 5) with demonstrated intolerance to stress conditions and a modern hybrid of the same maturity (Pioneer 3902), were the subplot. Each subplot was 8 m long and consisted of 12 rows with 0.762 m spacing. This study was focused on the modern hybrid plots.

Table 1: Chemical composition of stockpiled and rotted manure applied from 1998 to 2001

Year	Total C	Total N	Dry matter†	Total mineral N†	Total N†	C:N
	g kg^{-1}		Mg ha^{-1}	kg N ha^{-1}		
Stockpiled manure						
Spring 1998	427	22	12	60	260	20
Spring 1999	419	18	11	24	190	23
Spring 2000	401	19	14	43	260	21
Fall 1998	407	21	12	35	250	19
Fall 1999	443	21	11	46	220	21
Fall 2000	419	20	10	42	198	21
Fall 2001	419	20	12	85	308	21
Mean	419	20	12	48	236	21
Rotted manure						
Spring 1998	427	22	12	60	260	20
Spring 1999	326	24	14	52	330	14
Spring 2000	392	19	13	44	250	21
Fall 1998	362	22	20	58	440	16
Fall 1999	385	25	15	82	390	15
Fall 2000	378	20	13	55	266	19
Fall 2001	378	22	18	13	387	17
Mean	378	22	15	52	333	17

†Total amount in the manure applied at 50 Mg ha^{-1} (wet weight) and double the values to obtain the total amount applied at 100 Mg ha^{-1} (wet weight)

The fertilizer N (NH_4NO_3) was broadcast and incorporated into the soil shortly after planting each year. During the first year of the experiment stockpiled manure was the only manure applied. Manures were spread in the spring, before planting from 1998 to 2001, then prior to fall ploughing from 1998 to 2001. Manure characteristics are shown in Table 1. The year 1998 and 2002 was used to evaluate the changes in macro and micronutrient removed by harvested portions. These year 1998 and 2002 has been selected based on samples are available and the weather, which means there is no considerable influence on nutrient removal due to weather.

Sampling and Statistics

Ten consecutive plants from an area marked shortly after harvests were taken from each plot and these separated into leaves, stalks, other reproductive components and kernels. An additional 40 plants were harvested in each plot for determination of grain yield. All the components were dried at 70°C to a constant and dry weights were recorded prior to being chopped. Sub samples (kernel and stover) were taken and ground to pass a 1 mm screen for macro- and micro nutrient analysis. The kernel and stover samples digestion for total N was performed using a block digester. The total N in the digest was determined using the automated colorimetric method. Concentrations of macro-nutrients (K, Ca and Mg) and micro-nutrients (Fe, Mn, Zn and Cu) in kernel and stover samples were determined by atomic absorption spectroscopy (AAS) after samples were digested with nitric and perchloric acid ratio 2:1 (Jackson, 1975; Anderson and Ingram, 1993). Measurement of P (Olsen and Sommers, 1982) and SO_4-S concentration in the extracts by a turbidimetric procedure using barium chloride (Anderson and Ingram, 1993). All macro- and micro nutrient concentrations are expressed on a dry weight basis.

All the data were subject to analysis of variance. The treatment means were separated according to the *F*-protected LSD test ($p<0.05$). Regression analysis also used to examine between yield and plant nutrient concentration and co-relation between corn yield and grain nutrient concentration.

Results

Macro Nutrients

Nitrogen, Phosphorus and Potassium

The concentrations of biomass (corn and stover) N across both years under different N amendments varied significantly within different N levels but manure (both stockpiled and rotted manure at 100 Mg ha^{-1}) application remarkably increased biomass N concentrations. Surprisingly there is no difference between 100 and 200 kg N ha^{-1} but biomass N concentration significantly increased in 2002 (Table 2 and 3) with no relationship of yield (Fig. 1), suggesting that a significant amount of N accumulated in biomass part which was not responding in yield. Compared to high rated of mineral fertilizer treatment, a large portion of the N uptake by the crop was derived from the native soil organic

Table 2: Comparison between 1998 and 2002 macro-micro nutrients concentration in corn grain under different levels of N amendments

*Soil N amendments	N 1998	N 2002	P 1998	P 2002	K 1998	K 2002	S 1998	S 2002	Mg 1998	Mg 2002	Ca 1998	Ca 2002
	Macro-nutrients (g kg^{-1})											
Unfertilized	012.3a	10.8a	2.96a	3.11a	3.27a	3.31a	0.97b	1.23a	0.926a	0.930a	0.766b	0.100a
100 kg N ha^{-1}	14.1b	16.9a	2.69b	3.28a	2.92b	3.46a	1.22a	1.10b	0.916a	1.02a	0.076a	0.083a
200 kg N ha^{-1}	13.5b	17.6a	2.64a	3.10a	3.07a	3.19a	1.23b	1.49a	0.896a	0.936a	0.080a	0.076a
SM50	12.5a	14.6b	2.86b	3.39a	3.28b	3.69a	1.22b	1.40a	0.893a	1.02a	0.076b	0.093a
SM100	15.6a	16.2a	2.76b	3.33a	2.89b	3.59a	1.26a	1.26a	1.03a	0.940a	0.070a	0.076a
RM50	13.3a	11.9a	2.66b	3.43a	3.12b	3.74a	1.23a	1.24a	0.983a	0.813a	0.076a	0.083a
RM100	14.0b	16.6a	2.88b	3.56a	3.24a	3.56a	1.20a	1.22a	0.976a	0.956a	0.076a	0.066a
Mean	13.6	14.9	2.78	3.31	3.1	3.5	1.19	1.28	.946	0.945	0.076	0.083

Table 2: Continue

*Soil N amendments	Fe		Zn		Mn		Cu	
	1998	2002	1998	2002	1998	2002	1998	2002
	Micro-nutrients (mg kg^{-1})							
Unfertilized	23.6a	20.4b	19.6a	21.7a	4.00b	4.81a	1.50b	3.31a
100 kg N ha^{-1}	24.7b	29.9a	19.7a	19.7a	3.92b	5.64a	1.37b	4.05a
200 kg N ha^{-1}	27.2a	28.0a	17.5a	18.6a	4.03b	5.83a	2.77b	4.92a
SM50	23.7a	24.5a	17.9b	21.1a	3.76b	4.97a	2.08b	4.03a
SM100	33.5a	27.0b	18.2b	20.3a	4.69a	4.89a	1.12b	6.31a
RM50	31.9a	22.5b	19.5b	21.8a	3.73b	5.14a	1.83b	4.13a
RM100	34.6a	26.2b	17.4b	19.4a	4.45b	4.58a	1.78b	4.42a
Mean	28.5	25.5	18.5	20.3	4.1	5.1	1.8	4.4

*Soil N amendments: 100 and 200 kg N ha^{-1} applied as NH_4NO_3; SM50 = stockpiled manure at 50 Mg ha^{-1} (wet weight); SM100 = stockpiled manure at 100 Mg ha^{-1} (wet weight); RM50 = rotted manure at 50 Mg ha^{-1} (wet weight); RM100= rotted manure at 100 Mg ha^{-1} (wet weight), Under each nutrient element, means within soil N amendments followed by the same letter are not significantly different at p<0.05 according to LSD test

Table 3: Comparison between 1998 and 2002 macro-micro nutrients concentration in corn stover under different levels of N amendments

*Soil N amendments	N		P		K		S		Mg		Ca	
	1998	2002	1998	2002	1998	2002	1998	2002	1998	2002	1998	2002
	Macro-nutrients (g kg^{-1})											
Unfertilized	4.52a	4.39a	2.08b	2.40a	11.1a	7.84b	1.24a	1.33a	1.08b	1.25a	2.72b	3.32a
100 kg N ha^{-1}	4.63b	5.81a	0.97a	0.79b	8.67a	8.45a	1.23a	1.20a	1.21b	1.55a	3.28b	3.88a
200 kg N ha^{-1}	4.90b	7.46a	0.63a	0.61a	9.00b	10.9a	1.19b	1.27a	1.16b	1.59a	3.19b	3.90a
SM50	4.58a	5.07a	1.37b	2.00a	11.2a	11.7a	1.25b	1.32a	0.93b	1.11a	2.88b	3.52a
SM100	5.31b	6.08a	0.66b	0.97a	10.9b	12.0a	1.22b	1.57a	1.16b	1.23a	3.59b	3.91a
RM50	5.14a	4.50a	1.18b	2.44a	10.7a	11.4a	1.19b	1.30a	1.41a	1.27b	3.42a	3.57a
RM100	5.29b	6.12a	0.66b	1.46a	9.9b	14.0a	1.21b	1.31a	1.09b	1.20a	3.34a	2.26a
Mean	4.9	5.6	1.08	1.52	10.2	10.9	1.22	1.33	1.15	1.31	3.2	3.5

Table 3: Continue

*Soil N amendments	Fe		Zn		Mn		Cu	
	1998	2002	1998	2002	1998	2002	1998	2002
	Micro-nutrients (mg kg^{-1})							
Unfertilized	327b	599a	29.6b	56.8a	16.3b	28.3a	4.17b	5.92a
100 kg N ha^{-1}	408b	602a	26.9b	38.5a	20.5b	36.9a	5.20b	7.06a
200 kg N ha^{-1}	410a	432a	14.1b	20.7a	22.0b	33.1a	4.23b	8.16a
SM50	218b	325a	19.6b	39.9a	45.4a	21.2b	3.54b	6.86a
SM100	300a	227b	17.0a	16.2a	25.3a	17.9b	6.12b	7.72a
RM50	473a	302b	24.7b	46.5a	22.4a	18.9a	4.24b	8.08a
RM100	187a	257b	13.6b	22.2a	13.2a	13.9a	4.36b	7.15a
Mean	332	392	21.2	34.4	23.6	24.3	4.6	7.3

*Soil N amendments: 100 and 200 kg N ha^{-1} applied as NH_4NO_3; SM50 = stockpiled manure at 50 Mg ha^{-1} (wet weight); SM100 = stockpiled manure at 100 Mg ha^{-1} (wet weight); RM50 = rotted manure at 50 Mg ha^{-1} (wet weight); RM100 = rotted manure at 100 Mg ha^{-1} (wet weight), Under each nutrient element, means within soil N amendments followed by the same letter are not significantly different at p<0.05 according to LSD test

N when sub-optimum N (100 kg N ha^{-1}) was applied. Which also tends to confirm the indication above that yield was limited by a factor other than nitrogen as increase in very large biomass N concentration. The mean value we estimated for P and K varied more than twofold for P and by twofold for K, which was similar to report from different studies (Heckman *et al*., 2003; Sims, 1999; Sims *et al*., 1998; Lander *et al*., 1998; Zublena, 1991). However, compared to those in 1998, biomass P and grain K concentration was significantly increased in 2002 (Table 2 and 3), while within N amendments significant different observed only in manure treatment when compared with unfertilized treatments (Table 4 and 5).

Table 4: Comparison of macro-micro nutrients concentration in corn kernel within different levels of N amendments (mean of 1998 and 2002)

*Soil N amendments	Macro-nutrients (g kg^{-1})						Micro-nutrients (mg kg^{-1})			
	N	P	K	S	Mg	Ca	Fe	Zn	Mn	Cu
Unfertilized	11.5c	2.9b	3.30abcd	1.11c	0.9283a	0.0883a	21.96b	20.6a	4.41a	2.41a
100 kg N ha^{-1}	15.5a	3.0ab	3.20cd	1.19bc	0.9683a	0.0800ab	27.28ab	19.7ab	4.78a	2.71a
200 kg N ha^{-1}	15.6a	3.0ab	3.13d	1.36a	0.9166a	0.0733ab	27.58ab	18.0b	4.93a	3.85a
SM50	13.6abc	3.1ab	3.49a	1.31ab	0.9566a	0.0850ab	24.08ab	19.5ab	4.37a	3.06a
SM100	15.9a	3.0ab	3.24bcd	1.26abc	0.9850a	0.0733b	30.25a	19.2ab	4.79a	3.71a
RM50	12.6bc	3.0ab	3.42ab	1.23abc	0.9166a	0.0800ab	27.16ab	20.6a	4.44a	2.98a
RM100	15.3ab	3.2a	3.40abc	1.21abc	0.9667a	0.07167c	30.39a	18.4ab	4.51a	3.01a

*Soil N amendments: 100 and 200 kg N ha^{-1} applied as NH_4NO_3; SM50 = stockpiled manure at 50 Mg ha^{-} (wet weight); SM100 = stockpiled manure at 100 Mg ha^{-1} (wet weight); RM50 = rotted manure at 50 Mg ha^{-1} (wet weight); RM100 = rotted manure at 100 Mg ha^{-1} (wet weight), In column within N amendments by the same letter are not significantly different at p<0.05 according to LSD test

Table 5: Comparison of macro-micro nutrients concentration in corn stover within different levels of N amendments (mean of 1998 and 2002)

*Soil N amendments	Macro-nutrients (g kg^{-1})						Micro-nutrients (mg kg^{-1})			
	N	P	K	S	Mg	Ca	Fe	Zn	Mn	Cu
Unfertilized	4.46c	2.24a	9.45bc	1.29ab	1.17ab	3.02bc	463a	43.1a	22.3a	5.0a
100 kg N ha^{-1}	5.22abc	0.88b	8.56c	1.22b	1.38a	3.58ab	505a	32.7ab	28.7a	6.1a
200 kg N ha^{-1}	6.18a	0.62b	9.94abc	1.23b	1.37a	3.54ab	421ab	18.9cd	27.5a	6.2a
SM50	4.83bc	1.69a	11.41ab	1.28ab	1.02b	3.20ab	272bc	29.7bc	33.3a	5.2a
SM100	5.70ab	0.82b	11.4ab	1.40a	1.19ab	3.75a	264bc	16.6d	21.6a	6.9a
RM50	4.82bc	1.81a	11.02ab	1.25b	1.34a	3.50ab	387abc	35.6ab	20.6a	6.2a
RM100	5.71ab	1.06b	11.97a	1.27ab	1.15ab	2.80c	222c	17.8cd	13.5a	5.8a

*Soil N amendments: 100 and 200 kg N ha^{-1} applied as NH_4NO_3; SM50 = stockpiled manure at 50 Mg ha^{-1} (wet weight); SM100 = stockpiled manure at 100 Mg ha^{-1} (wet weight); RM50 = rotted manure at 50 Mg ha^{-1}(wet weight); RM100 = rotted manure at 100 Mg ha^{-1} (wet weight), In column within N amendments by the same letter are not significantly different at p<0.05 according to LSD test

It was noted that surprisingly no difference observed in P concentrations but a significant different observed in K concentrations between the two levels N fertilization treatment. This may be attributed to the higher composition of macro- and micro nutrient concentrations in stockpiled and rotted manures. Moreover, organic manures reduce the capacity of soil minerals to fix P and increase its availability through release of organic acids. Increase in biomass P concentration due to manure application was reported by Sims (1993) and Sims *et al.* (1998). The biomass K concentration was also significantly higher in the N amendments that had received fertilizer and manures. The manures supply K and solubilize K from K-bearing minerals by the organic acids released from the manures. Similar results were reported by Gill (1995). The positive effect of organic manures on uptake of P and K by the crop may be attributed to the chelation of Fe, Al, Mn, Zn, Ca and Mg preventing them from fixing P and K into soluble compounds (Antil *et al*., 1995).

Application of stockpiled and rotted manure application increased significant amount of K concentration in kernel (Table 2). The increase was more pronounced in the plants supplied with manure than in the plant supplied with N fertilizer. Maintenance of high K levels in kernel and stover could be an important factor influencing kernel and stover growth by acting as an osmoticum to maintain the tissue turgor pressure, regulating the opening and closing of the stomata and water uptake of roots (Marschner, 1995).

Calcium, Magnesium and Sulphur

There was no significant effect of corn kernel Ca and Mg concentration between 1998 and 2002, even within different N amendments with some exception of Ca but corn stover Ca and Mg concentration significant increased within year between 1998 and 2002, even within different N amendments as well. The results indicate that application of fertilizer and manure led to accumulating

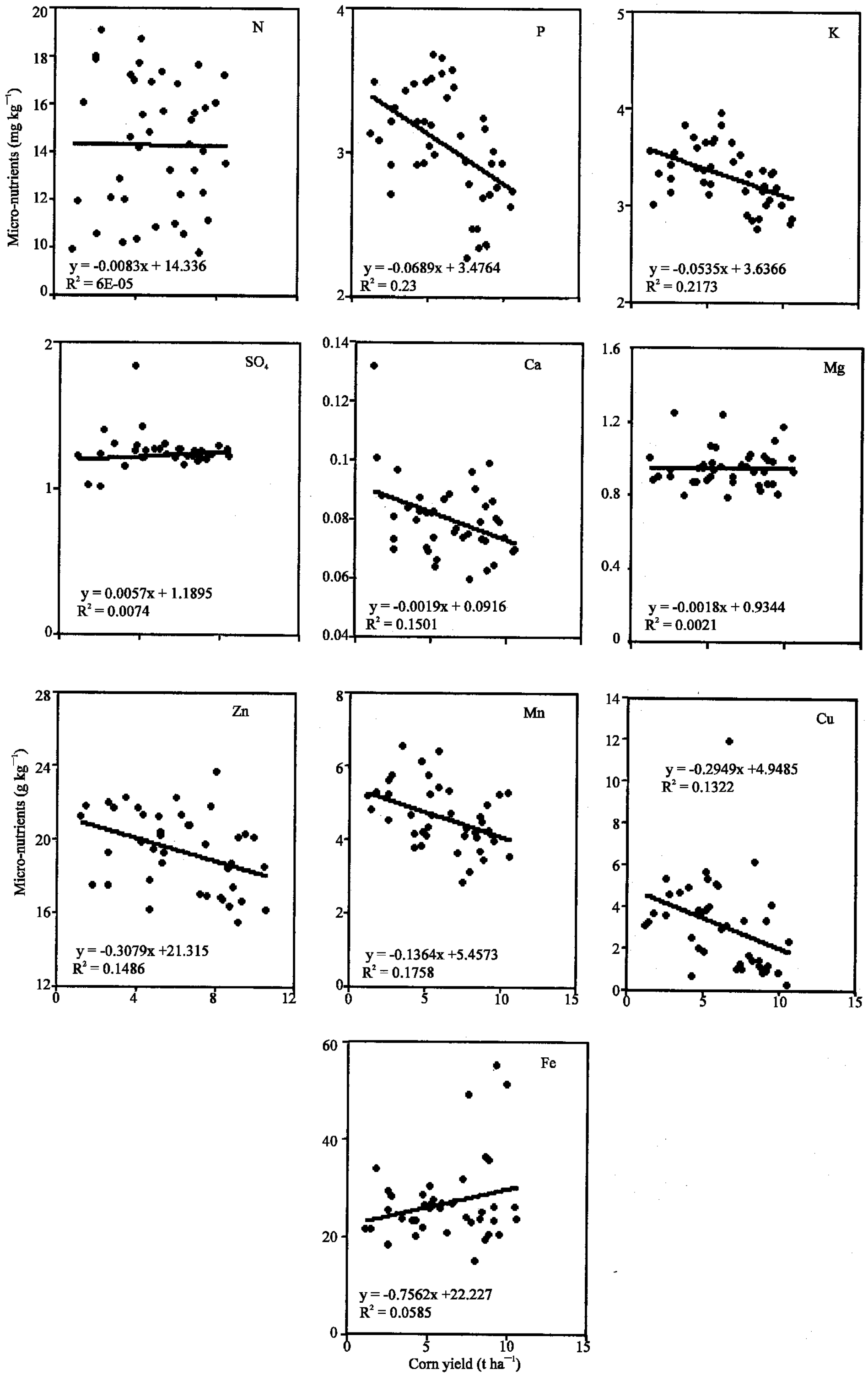

Fig. 1: Relationship between nutrient concentrations in corn grain and yield level

of significant amount of Ca and Mg in stover, not in grain. This result concerns with the report that application of Ca and Mg alone had no significant effect on yield, elemental composition of plant and uptake of macro- and micronutrients at harvest (Sahrawat *et al*., 1999). Plants in about the same quantity as phosphorus require Sulphur. Our results showed significant differences of sulphur in corn grain within N amendments but no difference within between 1998 and 2002 (Table 2 and 5). Literature shows about 10 pound S per acre is deposited annually by rainfall in surface soils is associated with organic matter (Zublena, 1991).

Micro Nutrients

Manganese and Iron

The concentration of Mn in the kernel of the corn plants grown in different N amendments was significantly increased in 2002 with some exception but no effect was observed within N amendments (Table 2 and 5). On the other hand, significant decreased stover N in 2002, where stockpiled manure was applied (Table 3) but difference was observed within N amendments (Table 5). In 2002, Fe concentration significantly increased in the kernel and stover portion of corn (Table 2 and 3) also significant difference was observed within different N amendments as well (Table 4 and 5).

Zinc and Copper

The concentration of Zn and Cu in the kernel and stover were significantly affected by manure application over the growing periods (Table 2 and 3), which is also reflected within different N amendments (Table 4 and 5). Accumulation of Zn and Cu in the corn plants increased by addition of potassium through organic manure or residue plant materials (Vasanthi and Kumaraswamy, 2000). Results indicated that the increase in the accumulation of Zn and Cu was negatively correlated with yield, although it was not significant.

Discussion

Grain yield ranged from 4 to 11 t ha^{-1} among all N amendments as reported elsewhere (Ma *et al*., 1999). Nutrient concentrations were not positively associated with yield (Fig. 1), may be yields were not reflecting the favorability of the growing environment; it is possible that sites were not favourable condition for corn growth also had no suitable conditions for the diffusion of nutrients from the soil to the root zone. The correlation co-efficient between P, K, Ca, Zn, Mn and Cu concentrations in grain and yield were negative, though it was not statistically significant (Fig. 1). Regression equations shown significant relationships only for Fe ($p<0.05$, Fig. 1).

The value represents in the Table 3 are estimates of nutrient removal or the quantity of nutrients removed in the harvested biomass portion of the crop. Based on these nutrient concentrations, if a corn grain harvest 11 t ha^{-1} would remove on average range within different N amendments the following nutrients amounts: N, 126.5 to 174.9; P, 31.9 to 35.2; K, 34.43 to 37.62; S, 12.21 to 14.96; Mg, 10.08 to 10.65; Ca, 0.81 to 0.97; Fe, 0.24 to 0.33; Zn, 0.20 to 0.23; Mn, 0.048 to 0.054; Cu, 0.027 to 0.042 kg ha^{-1}. These values are comparable to literature values (Heckman *et al*., 2003): N, 120.8; P, 36.7; K, 44.7; S, 9.9; Mg, 14.4; Ca, 2.6; Fe, 0.33; Zn, 0.25; Mn, 0.045; Cu, 0.03 kg ha^{-1}. However, in this stage it is very difficult to make a recommendation because lack of soil fertility status. Even though the existing values of corn grain macro- and micro nutrient removal in this study are similar to existence reference values, the variability seen in this study raises questions about the usefulness of average values for estimating crop nutrient removal across a range of conditions. It should not be confused with nutrient uptake, which refers to the total nutrients absorbed by the growing crop. Actual nutrient removal may vary by 30% or more depending on the specific growing conditions of the crop such as soil fertility, yield, soil moisture, crop vigor and limiting nutrients (interactions) as well as the actual crop variety and fertilizer program (Potash and Phosphate Institute, 2001). Changes of soil fertility may differ from the amount removed by the crop. In some instances, weathering of soil minerals and organic matter may compensate for part of the nutrient removal by crops. In other instances, nutrient may be chemically fixed by the soil or lost by leaching and loss of nutrients will exceed crop removal.

Phosphorus is evolved in the energy dynamics of plants, where as K is evolved in photosynthesis, sugar transportation, water and nutrient movement and protein synthesis. Phosphorus and potassium is not only the nutrients that may accumulate in soil from regular application of manure. Mineral supplementation of livestock feeds often enriches manures and soils to which they are applied with Cu and Zn (Mikkelsen, 2000). Nutrient removal values for Cu and Zn are relatively low compared with amounts of these nutrients that may be applied in the typical manure application. P is relatively immobile in soil, which quantity of available P in soils is the fraction that was also affected by plant removal.

Nutrients in plants that were left in the field will partially resupply nutrient reserves in the soil as they decompose. Estimates of nutrient depletion, therefore, should take into account only the nutrients removed with the harvested portion on the plant. Table 2 and 3 showed the mean concentration of various nutrients of both 1998 and 2002 that are removed by the corn crop for the yield level indicated. Values are not reported for B, Mo and Cl, because they were omitted due to lack of facilities, it does not mean that they were not removed or that they are unimportant.

Conclusions

Large variation of macro- and micro nutrient concentration implies that farmers may need regularly to obtain an analysis of their harvested crop to accurately assess nutrient removal. Nutrient management planners should take into account the increased crop removal of macro- and micronutrients at higher soil test levels and higher yield levels.

The current study provided baseline information on macro- and micro nutrient accumulation under different soil N amendments. These macro- and micro nutrient removal rates are useful in comparing the nutrient demands of different crops. These values, however, do not take into account the quality and availability of nutrient reserves already in the soil. Because of this limitation, soil testing should still be the cornerstone of all fertility programs. Removal rates can be used in conjunction with soil testing to estimate the depletion of macro- and micro nutrient reserves.

The macro- and micro nutrient concentrations variability of this study raises questions about the usefulness of average values for estimating crop nutrient removal across a range of conditions. Future research on nutrient removal should focus on identifying sources of variation in nutrient concentrations in corn grain to enable better monitoring of crop nutrient removal. Because the application of macro- and micro nutrients through fertilizer and manure varied from field to field and year to year, therefore, we could not evaluate whether any relationship existed between soil test level and concentrations of these nutrients in grain.

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