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ONE PLUS ONE EQUALS THREE: THE SYNERGISTIC EFFECTS OF CROP ROTATION ON SOIL FERTILITY AND PLANT NUTRITION [1]

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ABSTRACT

Corn grown under annual corn-soybean crop rotation has greater accumulation of certain mineral nutrients and higher yields than corn grown in monoculture. This study was conducted to determine if complex crop rotations (with legumes in the rotation as alfalfa hay as well as soybean row crops) and different levels of agriculture chemical input affect soil fertility and corn mineral nutrient composition. The effects of crop rotation [monoculture corn, corn-soybean 2-yr rotation, corn-soybean-wheat underseeded with alfalfa-alfalfa 4-yr rotation] and input level [high input (fertilizer application for 8.15 Mg ha^{-1} yield goal, prophylactic herbicide and insecticide application, fall moldboard plow/spring disk and cultivation operations), intermediate input (fertilizer application for 5.33 Mg ha^{-1} yield goal, pesticide applications based upon pest survey and IPM principles, fall chisel plow/spring disk and cultivation operations), and low input (no fertilizer, herbicide, or insecticide applications, fall chisel plow/spring disk and cultivation operations)] on soil fertility (pH, organic matter, NO_3-N, P, K, and total N) and on corn shoot dry weight, mineral nutrient (N, P, Ca, Mg) concentration and accumulation at tassel stage of development were investigated at Brookings, SD. Soil samples taken at the V6 stage of corn development indicated that crop rotation treatments reduced soil pH, increased soil NO_3-N level, and decreased soil P level when compared to corn monoculture. Shoots of plants grown under either 2-yr rotation intermediate input or 4-yr rotation no input treatments had greater dry weight, as well as greater P, Ca, and Mg accumulation than these same input treatments in other rotations. These results demonstrate a beneficial effect of crop rotation upon soil fertility and corn mineral nutrition. The results of this experiment are discussed in terms of nutrient synergisms whereby nutrient absorption proceeds at a faster rate than dry weight accumulation.

INTRODUCTION

Under conditions of high soil fertility, macronutrient (N, P, and K) and micronutrient (Zn) accumulation in corn tissue at physiological maturity, as well as grain yield, were greater in first year corn (after soybean) than in corn grown under monoculture (Copeland and Crookston, 1992). We were interested in confirming the above results as well as determining if these same results would occur under more complex crop rotations and diverse levels of agricultural chemical input. The

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objective of our experiment was to investigate the effects and interactions of complex crop rotations (with legumes in the rotation as hay as well as row crops) and different agricultural chemical input levels on soil fertility and corn mineral nutrient composition. Our experiment included crop rotations and input level treatments that mimicked agricultural production systems used by farmers in the northern portion of the US corn belt. Such a systems approach, which synthesizes scientific inquiry with real world agronomic situations, integrates research results for identification of gaps in our knowledge (Peterson et al., 1993) and improves the probability that experimental results will be applied by farmers to solve problems associated with crop production (Weiss and Robb, 1988).

MATERIALS AND METHODS

Crop rotation and input level treatments used in this experiment were established in the 1990 growing season on a Barnes clay loam soil at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD. Rotations included a continuous corn monoculture, a corn-soybean 2-yr rotation, and a corn-soybean-wheat underseeded with alfalfa-alfalfa 4-yr rotation. Three separate input level sub-plot treatments were superimposed upon the main plot rotation treatments. Input level treatments for the corn phase of the rotations included high input (fertilizer application for 8.15 Mg ha^{-1} yield goal, prophylactic herbicide and insecticide application, fall moldboard plow/spring disk and cultivation operations), intermediate input (fertilizer application for 5.33 Mg ha^{-1} yield goal, pesticide applications based upon pest survey and IPM principles, fall chisel plow/spring disk and cultivation operations), and low input (no fertilizer, herbicide, or insecticide applications, fall chisel plow/spring disk and cultivation operations). Additional information on treatments can be seen in a previous publication (Riedell et al., 1998).

Soil samples (0 to 30 cm depth, 2.5 cm diameter) were taken when the corn was in the 6th leaf stage (V6) and analyzed for pH, organic matter, NO_3-N, P (Olsen method), K, and total Kjeldahl N (Gelderman et al., 1987). At the tassel (VT) stage, corn shoots were sampled for dry weight and analyzed for N using the Kjeldahl method. Tissue concentrations of P, Ca, and Mg were also measured. Mineral nutrient concentration data was multiplied by the shoot dry weight to determine mineral nutrient accumulation by the shoots of plants. Data from the 1994 and 1995 growing seasons were analyzed using ANOVA and Fisher's restricted LSD values procedures in SAS (α = 0.1; Steel and Torrie, 1960). Qualitative relationships between plant dry weight, mineral nutrient accumulation, and mineral nutrient concentration were also examined using the method of Jarrell and Beverly (1981). A sequence of symbols representing differences (↑=increased, ↓=decreased, 0=no change) in these parameters between corn grown in monoculture and corn grown in either 2-yr or 4-yr rotation was generated. The patterns of the symbol sequences were used to determine potential response characteristics for these qualitative relationships.

RESULTS AND DISCUSSION

Treatment Effects on Soil Fertility

Soils under 4-yr rotation had significantly higher levels of NO_3-N as well as lower pH and P levels than those under continuous corn monoculture (Table 1). The soil pH and P level under the 2-yr rotation were also significantly lower than those seen under corn monoculture. Organic matter, K, and total N levels were not significantly affected by rotation. Input level had no significant effects upon any of the soil parameters measured at this sample date (data not shown). There were no significant rotation by input level interactions for any of the dependent variables.

Table 1. Influence of crop rotation upon soil pH, organic matter, and primary nutrient level as determined from 0-20 cm soil samples taken at the V6 stage of corn development.

Rotation	pH	Organic matter	NO_3-N	P	K	Total N
		g kg^{-1}	------------ mg kg^{-1} ------------			g kg^{-1}
Monoculture	6.9 a†	27 NS	11.2 b	6.3 a	132 NS	1.6 NS
2 Year	6.6 b	26	14.5 b	4.5 b	133	1.6
4 Year	6.6 b	26	23.8 a	4.1 b	142	1.6

† Means followed by same letter within columns are not significantly different (LSD, α=0.1).

Newly established alfalfa plantings have the potential to produce a large accumulation of NO_3-N in proportion to the total nitrogen present in the soil (Lyon et al.1924). Nitrogen in legume residue is rapidly mineralized (Power et al., 1986) which we believe resulted in the higher levels of NO_3-N in soil under the 4-yr rotation.

Treatment Effects on Corn Mineral Composition

Several significant rotation by input level interactions (P=0.01 for shoot dry weight, P=0.06 for P accumulation, P=0.03 for Ca accumulation, P=0.01 for Mg accumulation) were present. Plots of these data (Fig. 1) revealed that shoots grown under either 2-yr rotation intermediate input or 4-yr rotation low input treatments had greater dry weight, as well as greater P, Ca, and Mg accumulation than these same input treatments in other rotations. The similarities between shoot dry weight and mineral nutrient accumulations also suggest that the dry weight accumulation of the aerial portion of the plants is a major factor affecting mineral nutrient accumulation. Jarrell and Beverly (1981) noted that the concentration of mineral nutrients in plant tissue is a single-point measurement that results from the integration of two dynamic processes: mineral nutrient absorption and dry matter accumulation.

Because nutrient concentration is a result of the quantitative manner in which nutrient absorption and dry matter accumulation vary, it is reasonable to consider all three values when discussing the nutrient status of a crop (Table 2). N accumulation and N concentration were greater in corn grown under 2- and 4-yr rotation when compared with monoculture (Table 2). The defining characteristic of nutrient synergism is that nutrient absorption proceeds at a faster rate than dry weight accumulation. Important permissive factors thought to be involved in enhanced nutrient absorption include: higher ion concentrations in the soil solution, increased root growth, increased root activity, faster movement of ions to roots through mass flow of the soil solution, increased translocation of nutrients to shoots, and enhanced nutrient absorption mechanisms in the root (Jarrell and Beverly, 1981). Our soil analysis data suggest that there were higher NO_3-N levels in the soil under crop rotation which in turn could lead to greater rates of N absorption and accumulation by the crop. P nutrient accumulation was greater while P nutrient concentration was

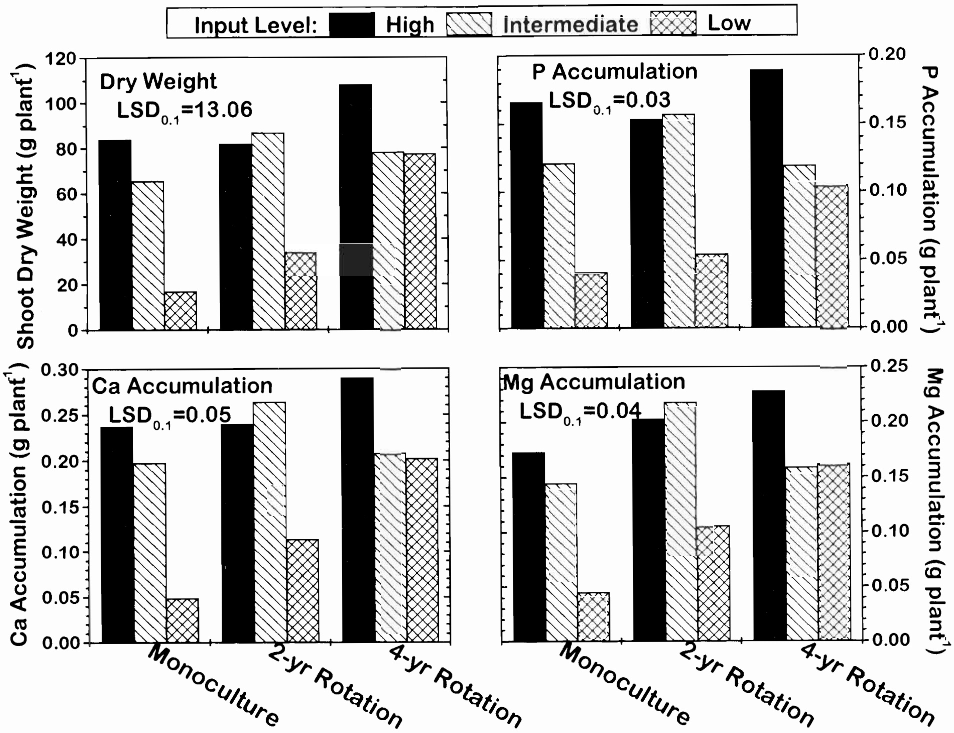

Figure 1. Shoot dry weight, P accumulation, Ca accumulation, and Mg accumulation of corn plants harvested from the rotation-input level treatments at the tassel stage of development.

less in corn grown under rotation when compared with monoculture. This relationship was consistent for all input levels under the 2-yr and 4-yr rotations (Table 2). The proposed mechanism that explains these responses in dry weight accumulation and P relations is dilution (Jarrell and Beverly, 1981). The characteristic that defines nutrient dilution is that crop dry matter accumulation proceeds at a faster rate than nutrient absorption. Such a situation would result when corn is grown in rotation and some negative factor slowed nutrient absorption or a positive factor increased dry weight accumulation. Factors that may slow the rate of nutrient absorption include: lower ion concentrations in the soil solution, decreased root growth, decreased root activity, decreased rate of movement of ions to roots through mass flow, reduced translocation of nutrients to shoots, and inhibition of nutrient absorption mechanisms in the root. The lower soil P levels under both crop rotation treatments (Table 1) could have been responsible for reduced rates of P absorption and accumulation. However, the P dilution seen under crop rotation may also have been the result of increased rate dry matter accumulation in the crop rotation treatments (Fig. 1). Factors leading to increased dry matter accumulation include: enhanced photosynthesis, lower respiration, improved translocation of photosynthate to points of need, greater turgor potential, less disease and pest pressure, lower rate of senescence, and better crop hormonal balance. Whether there were other factors involved in this P level dilution response, and the relative contribution of changes in nutrient absorption vs changes in dry matter accumulation under crop rotation cannot be determined from our

Table 2. Qualitative representation of differences in total mineral nutrient accumulation, dry weight accumulation, and mineral nutrient concentration between corn grown under monoculture and 2-yr or 4-yr rotation.

Input Level	Element	ΔAccumulation	ΔDry Weight	ΔConcentration	Response[‡]
			2-yr Rotation[†]		
High	N	↑[†]	0	↑	Synergism
	P	0	0	↓	Dilution
	Ca	0	0	0	None
	Mg	↑	0	↑	Synergism
Intermediate	N	↑	↑	↑	Synergism
	P	↑	↑	0	None
	Ca	↑	↑	0	None
	Mg	↑	↑	↑	Synergism
Low	N	↑	↑	↑	Synergism
	P	↑	↑	↓	Dilution
	Ca	↑	↑	↑	Synergism
	Mg	↑	↑	↑	Synergism
			4-yr Rotation		
High	N	↑	↑	↑	Synergism
	P	↑	↑	↓	Dilution
	Ca	↑	↑	↓	Dilution
	Mg	↑	↑	0	None
Intermediate	N	↑	↑	↑	Synergism
	P	0	↑	↓	Dilution
	Ca	↑	↑	↓	Dilution
	Mg	↑	↑	↓	Dilution
Low	N	↑	↑	↑	Synergism
	P	↑	↑	↓	Dilution
	Ca	↑	↑	↓	Dilution
	Mg	↑	↑	↓	Dilution

† Symbols represent more (↑), less (↓), or no change (0) between values obtained from corn grown under monoculture or rotation

‡ Proposed response involved as determined by sequence of the three qualitative symbols for each element (after Jarrell and Beverly, 1981)

data. It is interesting to note that the proposed mechanisms involved for Ca and Mg nutrient relations for corn grown under the 2-yr and the 4-yr rotations were different (Table 2). In just about every instance, the 2-yr rotation showed a synergism for Ca and Mg while the 4-yr showed a dilution. Such a situation would result if Ca and Mg under the 2-yr rotation were being absorbed at a faster rate than dry weight accumulation and/or dry matter accumulation was at a faster rate than Ca and Mg absorption under the 4-yr rotation. Although the specific reasons for the differences in the response mechanisms are not clear, our data suggest that there may be some factors that are promoting dry weight accumulation in the 4-yr rotation when compared with the 2-yr rotation.

CONCLUSIONS

Our data clearly demonstrate the beneficial effect of crop rotation on shoot dry weight and mineral nutrient accumulation in corn. However, the data collected in our study allow only speculation of the actual mechanisms involved in these responses. Additional studies (e.g. interactions of soil fertility, root growth, and nutrient use efficiency) using a more reductionist approach will be needed to reach a mechanistic understanding of crop rotations.

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