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FALLOW VERSUS WHEAT CROPPING OF UNAMENDED AND MANURE-AMENDED SOILS RELATED TO MYCORRHIZAL COLONIZATION, YIELD, AND PLANT NUTRITION OF DRY BEAN AND SWEET CORN

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ABSTRACT

Previous studies reported manure application to eroded Portneuf silt loam soil (Coarse-silty, mixed, superactive, Durinodic Xeric Haplocalcid) improved dry bean (*Phaseolus vulgaris* L., cv. Viva) yield to levels of topsoil. These yield increases only correlated with whole-plant zinc (Zn) concentration and soil organic matter. This might be related to enhanced arbuscular mycorrhizal (AM) colonization stimulated by manure application. A greenhouse study with dry bean suggested a relationship between manure application, increased AM colonization, and whole-plant Zn uptake, while field studies with wheat (*Triticum aestivum* L.) and sweet corn (*Zea mays* L.) did not. To clarify the apparent contradiction of manure application on AM relationships, the

present field study with dry bean and sweet corn was conducted in subsoils on the same experimental site established in 1991 and used in previous studies. The existing rotation also allowed the study of the effects of previously fallowed versus wheat cropped subsoils on yield, AM colonization and nutrition of dry bean and sweet corn. Average mycorrhizal root colonization in dry bean was greater on unamended than on manure-amended soils but was not related to increases in yield, Zn concentration, or Zn uptake. Average colonization of sweet corn roots was generally greater in unamended than manure-amended soils, but yields were greater in manure-amended soils. Colonization of sweet corn roots measured over time was consistently greater in subsoils previously cropped to wheat than fallowed, but yields were similar. Previous wheat-cropping resulted in leveling off of colonization beginning 7 July (second sampling) in dry bean, while previous fallow resulted in continuously increasing colonization throughout the five sampling periods. Bean yields were greater on subsoils previously cropped than fallowed; thus yields were generally not related to AM colonization. Results of our study confirm other field results where AM colonization was greater in unamended than manure-amended soils and in cropped than in fallowed soils. Any yield increases observed were not closely related to AM colonization.

INTRODUCTION

Organic Matter, Manure, and Mycorrhizal Colonization

Soil erosion has removed highly productive topsoil on millions of hectares around the world, exposing less fertile subsoil which reduces potential productivity. Robbins et al. (1) restored crop productivity on subsoil to topsoil levels in dry bean by high manure application (but not by application of other organic amendments), and the improved yield correlated only with soil organic matter and whole-plant Zn concentrations. This could be due to improving various soil chemical, physical, and/or biological properties (2, 3). Dry bean is known to be susceptible to Zn deficiency under conditions that reduce mycorrhizal development (4, 5). Thus, mycorrhizal infection stimulated by organic matter is a potential explanation for the increased yields in dry bean. Sweet corn and dry bean form AM relationships and may benefit from enhanced Zn uptake by the AM association since both crops are susceptible to Zn deficiency (4, 5, 6, 7, 8, 9). Boswell et al. (10) found the degree of AM infection

of corn positively correlated with growth and yield. Tarkalson et al. (11) observed increased AM colonization of dry bean roots from dairy manure applied at time of planting to freshly exposed subsoil samples in the greenhouse but decreased colonization in field-grown sweet corn and wheat from manure applied to soils six years earlier (12). Increases in nutrient uptake and yield from arbuscular mycorrhizal (AM)-plant symbiosis are well documented (13, 14, 15, 16). Mycorrhizal extension of the effective root surface area may facilitate plant uptake of phosphorus (P), Zn, copper (Cu), nitrogen (N), potassium (K), calcium (Ca), molybdenum (Mo), sulfur (S), magnesium (Mg), manganese (Mn), and/or silicon (Si) (13, 17, 18, 19).

Organic matter-AM fungi interactions are complex and difficult to predict (20). Manure or other organic amendments may either increase (12, 21, 22, 23) or decrease root colonization by AM fungi (11, 24, 25). St. John et al. (26) reported that soil organic matter enhanced the length and branching of AM hyphae. Kitt et al. (27) found that soils low in organic matter had reduced mycorrhizal growth compared to soils with higher organic matter. Increased AM colonization of wheat by organic matter (garbage compost) application was attributed to increased rooting density (23). In contrast, Tarkalson et al. (12) found that dairy manure additions depressed AM colonization in field-grown wheat and sweet corn. Ellis et al. (25) found that AM colonization was greater in plants when neither manure nor fertilizer was added to soils and that plants grown in soils that received manure additions exhibited the lowest colonization levels. Brechelt (24) reported red pepper yield was highest in soils that received the lowest rates of manure application and that high rates of manure application led to decreased AM efficiencies.

This experiment was conducted to clarify the observed contradiction in the role of manure application on AM relationships in subsoils observed in sweet corn and wheat under field conditions (12) compared to greenhouse studies on dry bean (11). Sampling plants in a way similar to Tarkalson et al. (12), AM colonization was measured during the growing season five times on dry bean and six times on sweet corn. The purpose of this study was to determine the effect of previously applied high rates of manure (applied four years previously) to topsoil and to subsoil (exposed eight years previously) on AM colonization, yield, and nutrition of dry bean under field conditions. Sweet corn was included to confirm the 1997 observations and to relate yield, previously unobtainable in 1997 (12), to AM colonization and Zn nutrition.

Fallowing Versus Cropping and Mycorrhizal Colonization

Fallowing reportedly leads to declines in AM colonization and to plant nutrient deficiencies (28, 29, 30, 31, 32, 33). Kabir et al. (34) found that AM

efficiency and plant content of P and Zn decreased with increasing length of fallow. Leggett and Westermann (4) found that dry bean grown on Portneuf topsoil showed symptoms of Zn deficiency when previously cropped to sugarbeet (*Beta vulgaris* L.) or fallowed. Dry bean grown on soils previously cropped to corn exhibited no Zn deficiency symptoms. Sugarbeet is non-mycorrhizal (13) and could consequently have the same effect of reducing the levels of AM fungi as does fallowing. Hamilton et al. (5) reported higher AM colonization in dry bean grown after corn than after fallow. Accordingly, AM fungi may have formed sufficient relationships in dry bean following corn to provide adequate Zn uptake, while reduced mycorrhizal colonization following sugarbeet or fallow may have resulted in low Zn uptake (4). No one has reported the development of AM infection over the growing season in either sweet corn or dry bean following wheat cropping or fallow conditions. Neither has anyone reported AM colonization in either crop grown in previously fallowed or cropped subsoil. The specific objective of this part of the study was to follow, over the length of the growing season, the impact of previous bare fallow versus wheat cropping in manure-amended and unamended subsoil on AM colonization, yield, and nutrient uptake of dry bean and sweet corn.

MATERIALS AND METHODS

This experiment was conducted on previously established plots at the Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho. Robbins et al. (1) established field plots to study crop rotation and manure amendment effects on reclamation of exposed subsoils of Portneuf silt loam (Coarse-silty, mixed, superactive, Durinodic Xeric Haplocalcid). Field plot locations and descriptions can be found in Robbins et al. (1) and Tarkalson et al. (12). Previous amendment treatments are summarized in Table 1. Long-term crop rotation had no effect on dry bean yield or nutrient uptake in 1994 (1). Plots used in 1998 were previously in a three-year rotation of either barley, bean, fallow or barley, alfalfa, wheat. Manure effect studies were conducted by planting dry bean and sweet corn into manure-amended or unamended (not manured) topsoil and subsoil plots. Topsoil plots had been previously cropped to wheat and subsoil plots had been previously cropped to either wheat or fallowed. The study of previous cropping effects was conducted on subsoil either cropped to wheat or fallowed the previous year. Topsoil and subsoil strips and previous crop treatments ran lengthwise and parallel to the field slope while manure (added in the fall of 1994) and conventional fertilizer plus Zn (not manured) treatments ran across the plots. The original field plot design was a split block (1). For this experiment, the plots were split lengthwise to accommodate sweet corn into a rotation design originally slated for dry bean only. Dry bean and sweet corn strips were planted the full

Table 1. Treatment History of Field Plots Located at the USDA-ARS Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho (Robbins et al., 1997; Tarkalson et al., 1998b)

Year	Date	Treatment
1991	18 April	conventional subsoil plots received 135 kg P ha ⁻¹ as triple superphosphate and 245 kg N ha ⁻¹ as urea
	19 April	subsoil + manure 1991 plots received 44 Mg ha ⁻¹ dairy manure (on air dry basis)
	2 May	conventional subsoil plots received 100 kg N ha ⁻¹ as urea
	21 May	all plots received 1.5 kg Zn ha ⁻¹ as Zn-EDTA
	17 October	conventional subsoil plots received 130 kg P ha ⁻¹ as triple superphosphate
1992	18 October	subsoil + manure 1991 plots received 93 Mg ha ⁻¹ dairy manure (on air dry basis)
		no additional fertilizer or amendments added
1993	14 April	subsoil conventional plots received 110 kg N ha ⁻¹ as ammonium nitrate
1994	15 November	selected subsoil and topsoil plots received 74 Mg ha ⁻¹ dairy manure (on air dry basis)
1995	10 April	conventional subsoil plots received 168 kg N ha ⁻¹ as urea
1996	15 March	topsoil and conventional subsoil plots received 8.4 kg Zn ha ⁻¹ as ZnEDTA
1997		no additional fertilizer or amendments added

length of the field. In the year of experimentation, all plots were treated with 2.3 L of Roundup ha^{-1} and 2.3 L 2,4-D ha^{-1} on 28 April and plowed to a depth of 0.3 m on 22 May 1998. Corn plots received 168 kg N ha^{-1} and dry bean plots received 56 kg N ha^{-1} as surface applied urea on 1 June. Lasso herbicide was also applied 1 June to all plots at a rate of 7.0 ha^{-1} . Dry bean "Viva Pink" and sweet corn "Jubilee" were planted 8 June at a rate of 147 kg ha^{-1} and 19 kg ha^{-1} , respectively. Plants were furrow irrigated as needed. Each crop-soil-amendment treatment was repeated four times.

Bean root samples were collected on 30 June, 7 and 21 July, and 4 and 18 August, 1998. Sweet corn root samples were collected on 6, 13 and 20 July, 3 and 17 August, and 14 September, 1998. A hand-operated soil core sampling device was used to obtain five, 534 cm^3 soil cores plot^{-1} to a depth of 15 cm at each sampling event. The five cores were combined. Sample cores were centered immediately above a single plant. Roots and soil were placed on a screen and gently washed with a stream of water to remove soil from the roots the same day as sampled. The roots were cut from the plant tops after washing and total wet root weight per volume of soil was recorded. The tops were discarded without weighing. The roots were mixed and randomly separated into two portions. Half was placed in a pre-weighed paper bag, weighed wet, dried at 65°C and weighed again. The other half of the roots was placed in a plastic zip lock bag and stored in a freezer (−20°C) to await mycorrhizal colonization analyses. Dry bean and sweet corn roots were stained with analine blue and percent mycorrhizal colonization was determined using a point intersection method (35, 36).

Dry bean trifoliolate leaves (uppermost fully developed) were sampled from each plot on 27 July (R1 stage) and whole-plant samples (above ground parts) were obtained 21 July (V8 stage), 27 July (R1 stage), and 31 August (R8 stage). Sweet corn leaves were sampled from each plot on 13 August (VT stage, leaf below whorl) and 20 August (R1 stage, ear leaf). Sweet corn whole-plant samples (above ground parts) were obtained 20 July (V9 stage) and 20 August (R1 stage). Samples were rinsed with distilled water, dried at 65°C, and ground in preparation for mineral analysis. Zinc, Fe, Mn, Cu, Ca, Mg, and K concentrations were determined using dry ashing (37) and atomic absorption spectrometry (Perkin Elmer, Norwalk, Connecticut). Phosphorus was determined colorimetrically (38). Dry bean yields were obtained 22 and 23 September and sweet corn yields were obtained on 14 and 15 September.

Statistical Procedure

Field data was analyzed as a split-block design using analysis of variance output from SAS (39). Mean comparisons were made using F-test values from SAS analysis of variance. Orthogonal comparisons were used to analyze topsoil

and subsoil treatment differences (subsoil previously cropped to wheat vs. subsoil previously fallowed; subsoil vs. topsoil). Mean separation using the Student-Newman-Keuls (SNK) procedure identified differences among sampling dates for mycorrhizal colonization.

RESULTS AND DISCUSSION

Manure and Non-manured Effects on Topsoil and Subsoil

Mycorrhizal Colonization

Mycorrhizal root colonization was seldom greater on unamended (not manured) than manure-amended soils on individual sampling dates (data not shown). However, mean root colonization over all sampling dates was higher on unamended (not manured) than manure-amended soils for dry bean and sweet corn in the field (Figure 1, left; note different y-axis scale for each crop species). This confirms observations by Tarkalson et al. (12) with sweet corn and wheat in 1997. However, results with dry bean in the field were opposite those from the greenhouse pot experiment using freshly exposed subsoil (11). The conflicting accounts of greenhouse and field colonization for dry bean could be due to a decreased effectiveness of manure over time. Manure was freshly applied to the recently exposed subsoils used in the greenhouse study at the time of planting, whereas application of manure on field plots was last made in spring of 1994 (four years previous). Differences in colonization could be also related to recent manure application covering adsorption sites (40), making nutrients more available and reducing mycorrhizal dependence. Less biological and chemical weathering of the freshly exposed subsoil used in the greenhouse compared to subsoil used in the field also could explain the discrepancy in colonization. The subsoils in the field had been exposed for eight years in this experiment compared to only a few weeks in the greenhouse. Lower colonization in manure-amended soils also might be associated with increased microbial competition in the rhizosphere (26, 41) or decreased mycorrhizal efficiencies from the high nutrient content in manure (24).

There was a significant interaction between manure amendment and soil in both dry bean and sweet corn. The interaction for each crop was different (Figure 1, right). With dry bean, manure-amended and unamended soils were equally colonized only following subsoils previously cropped to wheat, but in sweet corn they were equal only on topsoil. In all other cases, manure amendment always produced significantly lower mycorrhizal colonization than unamended soils. We have no explanation for the observations where manure and unamended soils are equal in percent AM colonization.

Figure 1. Percent mycorrhizal colonization of dry bean and sweet corn in soils amended or unamended with manure. In all graphs, NS is not significant, + is significant at the 0.10 level, * is significant at the 0.05 level, and ** is significant at the 0.01 level. There was a significant interaction between manure amendment and soil treatment at the 0.10 level.

Topsoil Versus Subsoil

A significant sampling date by soil interaction resulted in similar percent AM colonization of dry bean roots grown on topsoil and subsoil for the first two sampling dates (30 June and 7 July) and greater AM colonization in dry bean grown on subsoil than topsoil thereafter (Figure 2). The interaction resulted in greater percent colonization of sweet corn in topsoil than subsoil for the first two

Figure 2. Percent mycorrhizal colonization of dry bean and sweet corn over time as affected by growth on subsoil or topsoil. In all graphs, NS is not significant, + is significant at the 0.10 level, * is significant at the 0.05 level, and ** is significant at the 0.01 level. Points for either subsoil (capital letters) or topsoil (lowercase letters) followed by the same letter are not significantly different at the 0.05 level. There was a significant interaction between sampling date and soil at the 0.001 level.

sampling dates, equal colonization on 20 July, and lower colonization in topsoil than subsoil thereafter (Figure 2). In both species, percent AM colonization in topsoil generally leveled off after 6 or 7 July, whereas colonization in subsoils increased through the later sampling dates. This could result if higher fertility topsoils decreased the need for the mycorrhizal relationship. Higher colonization rates in crops grown on low fertility soils like subsoils should benefit more from mycorrhizae than crops grown on highly fertile soils (24). When averaged over sampling periods, dry bean roots were colonized at higher percentages in subsoil than topsoil (data not shown). Tarkalson et al. (12) observed a similar trend of higher colonization in subsoil than topsoil in wheat, but an opposite trend with dry bean in the greenhouse (11). Mean root colonization of sweet corn for all sampling dates combined over the length of the growing season was similar in topsoil and subsoil (data not shown), confirming average colonization results reported in sweet corn the previous year (12).

Yield

Yield was similar in dry bean grown on manure-amended and unamended soils (averaged 3.1 Mg ha^{-1}) and consequently was not related to differences in mycorrhizal colonization or nutrient uptake (Figure 3, top). This lack of yield response to manure application is contrary to the original observations of Robbins et al. (1) where yield increases in dry bean were observed in manure-amended (3.4 Mg ha^{-1}) compared to unamended (2.0 Mg ha^{-1}) soils and the increases were correlated closely to soil organic matter and to whole-plant Zn concentrations. Cooler climatic conditions in the early growing season resulting in late planting or slower growth may have been involved in 1998 observations. The mean daily air temperature for June 1994 was 65.9°F compared to 59.3°F for June 1998. The lack of yield response in 1998 compared to four years earlier could be also associated with the effectiveness of manure diminishing over the four-year period since the previous manure application, chemical and biological weathering of the exposed subsoils over time, diminishing effects of adsorption site reduction (40), or impacts of cropping over time may have decreased the effect of fresh subsoil on growth reduction. But yields of sweet corn in 1998 were positively influenced by manure application (Figure 3, bottom), which confounds the validity of these explanations. Yield of dry bean did not differ between topsoil and subsoil (Figure 3, top), also contrary to Robbins et al. (1). Thus, increased mycorrhizal colonization observed in subsoil compared to topsoil (Figure 2) did not contribute to improved yields nor increased total Zn uptake (Table 2) compared to topsoil. Time may have decreased the impact of removing the topsoil on subsoil plots through increased root residue, chemical and biological weathering, or improved physical conditions.

Figure 3. Sweet corn and dry bean yields as affected by amendment with or without manure and growth in subsoil or topsoil. NS is not significant and + is significant at the 0.10 level. There was no significant interaction between treatment and soil at the 0.10 level.

Table 2. Total Uptake (Above Ground Parts) of Eight Essential Nutrients in Dry Bean and Sweet Corn Grown in Subsoil or Topsoil

Nutrient	Total Uptake ^a					
	Subsoil			Topsoil		
	21 July ^b			31 August ^b		
Dry bean ($\mu\text{g plant}^{-1}$)						
Zn		125		701	*	880
Mn		411		2707	**	2122
Cu	32	**	51	266	*	310
Fe	566	**	957	6198	*	9220
Dry bean (mg plant^{-1})						
P	14	**	20		127	
K	155	**	216		1072	
Mg		31			151	
Ca	82	**	114		448	
		20 July ^b			20 August ^b	
Sweet corn ($\mu\text{g plant}^{-1}$)						
Zn	268	**	794	4461	**	9488
Mn	488	**	854	9014	*	12541
Cu	51	**	100		1508	
Fe		1162		9543	**	17303
Sweet corn (mg plant^{-1})						
P	25	**	46	402	**	663
K	255	**	445	4016	*	5504
Mg	22	**	34	422	+	523
Ca	25	**	43	473	*	709

^a+ is significant at 0.10, *is significant at 0.05, and **is significant at 0.01.

^bOnly one value in column indicates not significant at 0.10 level so the average value is reported.

Sweet corn yield increases were associated with manure additions (Figure 3, bottom), and correlated positively to early, but not late, season mycorrhizal colonization (data not shown, $r = +0.38$, $p < 0.10$) and to soil organic matter ($r = +0.38$, $p < 0.10$). The only factor that negatively correlated with yield of sweet corn in non-manured soils was late season mycorrhizal colonization (data not shown, $r = -0.36$, $p < 0.10$). Thus, manure additions to subsoils improved sweet corn yields to comparable levels of topsoil as was previously observed in dry bean and wheat (1, 12). However, the correlation between soil organic matter, Zn uptake, and yield in dry bean previously observed by Robbins et al. (1) was not observed for sweet corn or

dry bean. Sweet corn yields were similar in subsoils and topsoils (Figure 3, bottom).

Nutrient Uptake and Crop Effects

A factor originally linked to increased yield of dry bean in manured soils was whole-plant Zn concentrations (1). Whole-plant concentrations and total uptake of Zn in dry bean were significantly higher in manure-amended than unamended soils on the 21 July sampling date, but by 31 August whole-plant concentrations were higher in unamended soils and plant uptake was similar in the two soils (Tables 3 and 4). Mycorrhizal colonization was greater in unamended soils (Figure 1). Thus, total Zn uptake was not linked to AM colonization, but must be related to some other factor associated with organic matter. The results are opposite observations with dry bean grown in greenhouse soils (11), where higher colonization in manure-amended soils led to enhanced Zn uptake. Unamended plots received Zn additions in 1996 (Table 1) and this might account for differences in colonization, plant nutrition, and yield between 1994 and 1998 (1). However, DTPA-extractable Zn concentrations did not differ significantly in spring 1998 on manure-amended and unamended soils (data not shown). Also, in earlier studies Zn additions to artificially exposed Portneuf subsoil did not produce significant yield improvement in dry bean (1, 42).

No impact of manure amendment on Zn uptake of sweet corn was observed on either sampling date (Table 4) despite increases in yield from manure

Table 3. Concentrations of Zn in Dry Bean (Whole-Plant) and Sweet Corn (Leaf) Grown in Manure-Amended and Unamended Soils

Crop	Zn, mg kg ⁻¹ ^a			
	Manure-Amended		Unamended	
Whole-plant	21 July ^b		31 August ^b	
	32	+	29	18
	13 August ^b		20 August ^b	
Leaf				
	29		21	
Sweet corn				

^a+ is significant at 0.10, *is significant at 0.05, and **is significant at 0.01.

^bOnly one value in column indicates not significant at 0.10 level so the average value is reported.

Table 4. Total Uptake (Above Ground Parts) of Eight Essential Nutrients in Dry Bean and Sweet Corn Grown in Manure-Amended and Unamended Soils

Nutrient	Total Uptake ^a					
	Manure-Amended		Unamended		Manure-Amended	
	21 July ^b		31 August ^b		20 August ^b	
Dry bean ($\mu\text{g plant}^{-1}$)						
Zn	135	**	103		761	
Mn	465	*	373	2713	*	2311
Cu	41	*	36		280	
Fe	774	**	618		7205	
Dry bean (mg plant^{-1})						
P	18	**	13		126	
K	203	**	148	1217	*	912
Mg	34	**	27		152	
Ca	102	*	85		433	
Sweet corn ($\mu\text{g plant}^{-1}$)						
Zn		443			6136	
Mn	735	+	485		10189	
Cu	84	*	50		1301	
Fe		1292			12130	
Sweet corn (mg plant^{-1})						
P	44	*	20	579	*	399
K	429	*	208	5231	+	3794
Mg	33	+	19		456	
Ca	40	*	22		552	

^a+ is significant at 0.10, *is significant at 0.05, and **is significant at 0.01.

^bOnly one value in column indicates not significant at 0.10 level so the average value is reported.

application (Figure 3) and lower mycorrhizal colonization when manure was applied (Figure 1). Corn leaf Zn concentration was similar on the 13 August sampling date, but by 20 August leaf concentration was higher in unamended than manure-amended soils (Table 3). Tarkalson et al. (12) observed the same effect of manure application on mycorrhizal colonization in sweet corn and reported increased Zn concentration in leaves on unamended soils.

All nutrients measured in dry bean and all nutrients except Zn and Fe in sweet corn were taken up in greater amounts from manure-amended than

unamended soils on the July sampling dates even though AM colonization rates were generally higher in soils not amended with manure (Table 4, Figure 1). These manure application effects were largely gone by the second sampling date (except for Mn and K with dry bean and for P and K with sweet corn; Table 4). Significant positive correlations ($p < 0.05$) between mycorrhizal colonization measured during early sweet corn growth and plant uptake of Zn, Cu, Fe, P, and Ca calculated at the end of the growing season (data not shown) were observed. However, only early season mycorrhizal colonization correlated with yield increases and none of the plant uptake values correlated with increased yields. These results strongly suggest that factors other than mycorrhizal colonization are involved in the improved yields and nutrient uptake observed with manure applications.

Topsoil Versus Subsoil

When topsoil or subsoil influenced total nutrient uptake, nutrients were generally higher in both dry bean and sweet corn grown on topsoil (Table 2). The only nutrient in greater amounts in plants grown on subsoil than topsoil was dry bean Mn on 31 August. Tarkalson et al. (12) reported similar results with Mn concentrations in wheat tops and sweet corn leaves in subsoils. All nutrients, except Fe, were taken up by sweet corn in greater amounts from topsoil than subsoil on 20 July, but colonization rates on this same date were similar in both soils (Table 2, Figure 2). This effect generally remained consistent through 31 August with sweet corn. Thus, mycorrhizal colonization was not closely related to plant nutrition in either dry bean or sweet corn grown in subsoil or topsoil.

Previous Fallow or Wheat Crop Effects

Mycorrhizal Colonization

For dry bean there was a significant sampling date by previous crop interaction (Figure 4) for AM colonization. Dry bean grown in previously fallowed soils exhibited a linear increase in mycorrhizal colonization, while dry bean grown in soils previously cropped to wheat exhibited a quadratic-type increase. Consequently, root colonization was not different for sampling dates one and three, lower for fallowed soils for the second sampling date and finally higher for all sampling dates for fallowed soils thereafter. The leveling off of colonization of dry bean roots grown in soils previously cropped to wheat could be related to allelopathy of wheat on the dry bean/mycorrhizal fungus relationship.

Figure 4. Percent mycorrhizal colonization of dry bean and sweet corn over time as affected by previous cropping to fallow or wheat. In all graphs, NS is not significant, + is significant at the 0.10 level, and * is significant at the 0.05 level. Points for either previous fallow (capital letters) or previous wheat (lowercase letters) cropping followed by the same letter are not significantly different at the 0.05 level. There was a significant interaction between sampling date and previous cropping at the 0.001 level for dry bean only.

While dry bean eventually showed higher percent colonization in previously fallowed subsoils, percent AM colonization in sweet corn was consistently lower at each sampling date in formally fallowed subsoils than in subsoils previously cropped to wheat (Figure 4). Mean percent colonization was significantly greater in sweet corn grown in subsoils previously cropped to wheat (52%) than fallowed (40%) at the 0.001 level. This observation supports other research reporting that fallowing leads to declines in AM colonization (28, 29, 30, 31, 33). However, none of these reports involved subsoils as the growth medium nor measured colonization over the growing season.

Yield

The only dry bean yield increases observed in this experiment were associated with prior cropping history (Figures 3 and 5). Dry bean grown in subsoils previously cropped to wheat yielded more than previously fallowed subsoils. These yield increases positively correlated with early season mycorrhizal colonization ($p < 0.05$) and with uptake of Zn, Cu, and P on 31 August (Table 5; $p < 0.10$). The only factor negatively correlated with yield of dry bean in subsoils previously fallowed was late season mycorrhizal colonization ($p < 0.05$). Early AM colonization may have facilitated nutrient uptake leading to increased yields in dry bean grown on subsoils previously cropped to wheat. Unlike dry bean, sweet corn grown on previously cropped or fallowed subsoils produced similar yields (Figure 5; note difference in y-axis scale for the two crops).

Nutrient Uptake and Crop Effects

Whenever significant differences in total nutrient uptake between cropping systems were observed (all but Fe on 21 July and Mn, Fe, Mg, and Ca on 31 August), dry bean uptake was higher from subsoils previously cropped to wheat than fallowed (Table 5). These increases correlated positively with mycorrhizal colonization early in the growing season (Figure 4; $p < 0.10$). This supports the findings of Hamilton et al. (5) who suggested that mycorrhizae enhanced the uptake of Zn, Cu, and P in pre-cropped soils compared to fallowed soils. Nutrient uptake in sweet corn was similar in subsoils previously cropped to wheat and fallowed for all measured nutrients on both 20 July and 20 August (Table 5).

Table 5. Total Uptake (Above Ground Parts) of Eight Essential Nutrients in Dry Bean and Sweet Corn Grown in Soils Previously Cropped to Wheat or Fallowed

Nutrient	Total Uptake ^a			
	Previous Crop		Previous Crop	
	Fallow	Wheat	Fallow	Wheat
	21 July ^b		31 August ^b	
Dry bean ($\mu\text{g plant}^{-1}$)				
Zn	60	*	578	*
Mn	376	*	2707	
Cu	24	*	224	**
Fe		566		6198
Dry bean (mg plant^{-1})				
P	11	**	104	**
K	125	**	936	**
Mg	23	**		155
Ca	68	*		402
	20 July ^b		20 August ^b	
Sweet corn ($\mu\text{g plant}^{-1}$)				
Zn		268		4461
Mn		488		9014
Cu		51		887
Fe		1550		9543
Sweet corn (mg plant^{-1})				
P		25		402
K		255		4016
Mg		22		422
Ca		25		473

^a*is significant at 0.05, and **is significant at 0.01.

^bOnly one value in column indicates not significant at 0.10 level so the average value is reported.

CONCLUSIONS

The results from this field experiment suggest mycorrhizal root colonization in dry bean was greater in unamended than in manure-amended soils, but this difference in colonization was not generally related to yields or Zn concentrations or uptake. These findings are in contrast to those of the greenhouse pot experiment (11) where mycorrhizal root colonization and Zn uptake were greater in manure-amended soils. Also, unlike the previous dry bean field trial in 1994

Figure 5. Dry bean and sweet corn yields as affected by previous cropping to wheat or fallow. NS is not significant and * is significant at the 0.05 level. There was no significant interaction between previous cropping and soil or manure at the 0.10 level.

(1), yields were unaffected by manure amendments, possibly due to a cooler season, the effectiveness of manure diminishing over time, increased biological and chemical weathering of the exposed subsoils over time, or effects of cropping over time may have decreased the impact of fresh subsoil on growth reduction. This reasoning might also explain the conflicting accounts of mycorrhizal

colonization in the greenhouse and field, because manure was freshly applied when planting into freshly exposed subsoil. Mycorrhizal root colonization in sweet corn was generally greater in unamended soils compared to manure-amended soils, but yield was greater in manure-amended soils. This was similar to the results of wheat field trials in 1997 where increases in wheat yields were associated with manure additions, but not to enhanced Zn concentrations by mycorrhizae (12). Since increases in sweet corn, wheat, and dry bean yield are not correlated with greater mycorrhizal colonization, perhaps other factors associated with organic matter (manure) dominate. Manure could increase the solubility of nutrients via chelating properties or cover soil adsorption sites (40), making nutrients more available.

Mycorrhizal root colonization in sweet corn was consistently greater in subsoils previously cropped to wheat than fallowed, yet yields were similar in the two. The previous crop's impact on mycorrhizal colonization in dry bean varied with time. Notably, previous wheat cropping resulted in leveling off of colonization after 7 July while previous fallow resulted in a continuously increasing mycorrhizal colonization pattern throughout the five sampling periods. Dry bean yields were greater in subsoils previously cropped to wheat than fallowed, but because of the variable nature of the colonization with time, only one early measurement correlated with yield.

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