Survival of Plant Growth Enhancing Root Fungi, Vesicular-Arbuscular Mycorrhizae, after Flooding and Extended Fallow

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Abstract

In 1993, large areas of the Midwest and Great Plains were inundated with water. Plant phosphorus (P) deficiency is often a problem after such an event. Soil and plant samples were collected from sites which had been flooded and fallowed in 1993 in Missouri and Iowa. Plants from soil which low levels of starter fertilizer applied were P deficient. The application of 80 lb P /A as starter fertilizer produced plants which were not P deficient. The flood and fallow problem was associated with the loss of the root colonizing vesicular-arbuscular mycorrhizal fungi (VAM fungi) which benefit the plant by increasing uptake of P. The VAM fungi are dependent upon the plant for growth and reproduction and loss of the host significantly reduced the VAM fungal population in the soil. Use of starter fertilizer was beneficial in compensating for the loss of VAM fungi. VAM fungal populations increased with the presence of a crop in 1994 and will help reduce the need for starter fertilizer next year.

Introduction

Large areas of the Midwest and Great Plains were inundated with water in 1993, as well as large areas in Georgia in 1994. When flooded in 1993, crops were killed, creating a fallow period before the next crop was planted. In the Australian Darling Downs area, when fields are left fallow for long periods of time, a "long fallow disorder" developed with symptoms of P and zinc (Zn) deficiency. Thompson (1987) found the absence of a mycorrhizal plant host during the fallow period and subsequent decrease in mycorrhizal colonization potential for the succeeding crop caused the P and Zn deficiencies. Mycorrhizal fungi require a host plant in which to grow and reproduce and VAM populations decrease during times when plants are not present. Mycorrhizal fungi (also known as VAM, VAMF, and vesicular-arbuscular mycorrhizal fungi) are a beneficial plant fungi that colonize roots of almost all agriculturally important plants. The fungal hyphae (hair-like growth of fungus) can be a 100 times longer than roots (Frey and Ellis, unpublished data). Hyphae can act like an extension of the root system to extend the zone of nutrient absorption. Mycorrhizal fungi have been found to affect uptake of nitrogen (N), P, sulfur (S), Zn, potassium (K), magnesium (Mg), manganese (Mn), copper (Cu), aluminum (Al) , silicon (Si), calcium (Ca), iron (Fe) and water by the plant (Safir, 1987). In a fumigation study in Nebraska involving corn (*Zea mays* L.), plants were stunted and showed severe P deficiency symptoms after fumigation (Jawson et al., 1993). However, when mycorrhizal fungi were inoculated into soil at the time of planting, plant growth and yields were comparable to that for the non-fumigated plot area (Ellis, unpublished data).

The first objective of this study was to determine if mycorrhizal fungal colonization potential was decreased after flooding and fallow in fields affected by the 1993 flood in Iowa and Missouri. The second objective was to determine if the loss of mycorrhizal inoculum produced the "long fallow disorder" problem of decreased crop P uptake after the flood/fallow period.

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Methods

Location

Three sites which were flooded in 1993 were chosen to study the flood and fallow effect on VAM fungi. The first site was near Mound City, Missouri and the other sites were located in Polk County, Iowa. Most of the fields were flooded more than once (Table 1).

Table 1. Field site description of flooding and cropping sequence.

Field	Crop		Flood duration		Crop	Notes
	1993	1994	number	total wks.	effect	
			Mound City, MO			
1	Corn	Corn	0	0		
2	Corn	Corn	2	6	Killed	
			Polk County, IA, Site 1			
1a	Soybean	Corn	0	0		Yield 10 Bu/A
1b	Soybean	Corn	2	4	Killed	Grass growth.
2a	Corn	Corn	0	0		
2b	Corn	Corn	2	4	Killed	Weeds controlled
3	No Crop	Corn	2	4	No crop	Weeds controlled
			Polk County, IA, Site 2			
1a	Soybean	Corn	0	0		Weeds controlled
1b	Soybean	Corn	1	2	Killed	Weeds controlled
2	Corn	Corn	2	3	Killed	Weed growth

The first flood occurred in early July and a second flood event occurred in mid-August. The soils were flooded a total of 2 to 6 weeks. The sites were managed by the farmers and a variety of fertilizer treatments were used (Table 2). Each of the flooded fields sampled had an adjacent field or a part of the field which had not been flooded. In each case, except for Polk county Site 2 Field 2, both the non-flooded and flooded fields were managed by the same farmer.

Table 2. Fertilizer application

Location	Fertilizer	
	Fall 1993	Spring 1994
Mound City, MO	None Applied	Liquid - 150 lb/A liquid N Starter - 10 lb/A N, 25 lb/A P and 25 lb/A K
Polk County, IA, Site 1 Fields 1-3	None applied	Liquid - 190 lb/A N as 32% liquid Starter - 80 lb/A P
Polk County, IA, Site 2 Field 1	Broadcast -150 lb/A NH_4N w/ N-Serve, 40 lb/A P and 60 lb/A K	Starter - 10 lb/A N, 26 lb/A P, 11 lb/A K, 15 lb/A S, 2 lb/A Zn and 1 lb/A B
Polk County, IA, Site 2 Field 2	None Applied	Broadcast - 190 lb/A N Starter - 60 lb/A P and 60 lb/A K

Sample collection and analysis

Soil samples were taken from the top six inches of soil on April 27-28 for soil pH, Electrical Conductivity (EC), nitrate (NO_3-N) and phosphorus (P) analysis and for bioassay to determine soil VAM fungal colonization potential. In the greenhouse, corn was seeded to eight inch pots containing soil from each field. Samples from the top six inches of soil were collected for VAM evaluation on May 25-26 and July 15-16 and shoot samples were collected for analysis on July 15-16.

The soil was analyzed for pH of soil-water slurry (1:1 weight:volume; McLean, 1980), extractable P (Knudsen, 1980) and NO_3-N (Keeney and Nelson, 1982), and plants for P, S, Zn, K, Mg, Mn, Cu, Al, Si, Ca and Fe (Knudson et al., 1981) and plant biomass. VAM colonization, VAM arbuscule formation, and colonization intensity were determined on stained roots (Koske and Gemma, 1989).

Results and discussion

There was no statistical difference in soil chemical properties because of flooding or previous crop planted in the fields (Table 3). However, the bioassay did determine that there was a significant decrease in VAM colonization potential in soils flooded the previous year. Both VAM fungal colonization potential and activity were decreased, based on percentage colonization and arbuscule formation

Table 3. Bioassay for vesicular-arbuscular mycorrhizal colonization potential and analysis of preliminary soil samples taken April 26-27, 1994.

Field	Flooding	Crop	pH	EC	NO_3	P	VAM Colon.	Arbuscules
		1993		mmhos cm^{-2}	ppm	ppm	%	%
				Mound City, MO				
1	NF*	Corn	6.81	1.13	128	88	26	12
2	F	Corn	5.94	0.53	35	74	7	1
				Polk County, IA, Site 1				
1a	NF	Corn	6.09	1.49	156	269	10	2
1b	F	Corn	5.39	1.05	102	68	10	5
2a	NF	Soybean	6.58	1.26	119	265	55	46
2b	F	Soybean	5.58	1.29	130	65	19	17
3	F	None	5.51	1.31	123	63	16	13
				Polk County, IA, Site 2				
1a	NF	Soybean	5.89	0.69	24	49	48	46
1b	F	Soybean	6.35	0.78	34	47	9	5
2	F	Corn	6.95	0.76	32	69	35	25
Pr>F								
Flood			0.29	0.20	0.13	0.74	>0.01	>0.01
Previous Crop			0.95	0.72	0.78	0.85	>0.01	>0.01

* NF = not flooded, F = Flooded

Arbuscules are a specialized mycorrhizal structures produced in cells which look much like a capillary system. In all cases, the low colonization rate of the plants grown in flooded soils during the bioassay indicated that flooded and fallowed soils could have affected P and Zn uptake by corn, if soil concentration of Zn was low. However, the test for extractable P indicated P was high in the soil and P should not be limiting.

When plant and soil samples were taken on May 25-26 (Table 4), plant root colonization by VAM fungi was significantly reduced in flooded fields. Although starter fertilizer was used on all fields, plants from the flooded area at Polk County Site 2 had 0.17 and 0.20 % P and were deficient in P. The plants had a purple color and were low in P even though all soils were considered high in P, ranging from 57-268 ppm Bray extractable P. At Polk county Site 2, starter P application did not overcome the flood-fallow syndrome effect of P deficiency as plants taken from the flooded fields had purple color and plant P was deficient. Field 1b had only 26 lb/A P applied as starter fertilizer and Field 2 had 60 lb/A. In contrast, the Field 1a was at the lower limit of adequate plant P and had mycorrhiza and some starter fertilizer. At Polk County Site 1, although VAM colonization, arbuscule formation and intensity of colonization were low, none of the plants were deficient in P because 80 lb P/A as starter fertilizer was applied. The concentrations of Ca, K and Mg were affected by flood and location. Potassium was decreased and Ca and Mg increased with flooding. However, K, Ca and Mg were not deficient in any of the crops. Other nutrients, such as Zn were not affected by flooding.

Table 4. Vesicular-arbuscular mycorrhizal colonization of corn and plant nutrient concentration of samples taken May 25-26, 1994.

Field	Flooding	Crop	VAM Colon.	Arbuscules	VAM Intensity	P	K	Ca	Mg
		1993	%	%	0-3	%	%	%	%
				Mound City, MO					
1	NF *	Corn	51	34	1.5	0.38	4.71	0.45	0.18
2	F	Corn	17	8	0.5	0.40	4.54	0.50	0.14
				Polk County, IA Site 1					
1a	NF	Corn	48	25	1.7	0.45	4.99	0.52	0.19
1b	F	Corn	8	4	0.5	0.44	4.91	0.57	0.21
2a	NF	Soybean	36	27	0.8	0.54	5.36	0.43	0.17
2b	F	Soybean	20	7	0.6	0.40	4.71	0.60	0.29
3	F	None	15	8	0.5	0.40	5.18	0.54	0.24
				Polk County, IA Site 2					
1a	NF	Soybean	59	48	2.1	0.30	3.72	0.60	0.37
1b	F	Soybean	25	21	0.5	0.17	2.72	0.86	0.46
2	F	Corn	28	24	0.4	0.20	3.10	0.70	0.25
P>F Flood			>0.01	>0.01	>0.01	0.09	0.05	>0.01	0.40

* NF=not flooded, F=Flooded

When samples were collected in July, none of the plants were P deficient (Table 5). Root samples collected had significantly less root colonization from Polk county Site 2 Fields 1b and 2, compared to non-flooded Field 1a. Root colonization was also less in plant roots from Polk county Site 1 which was affected by flooding and fallow. Both VAM colonization and arbuscule formation were greater in July than in May. However, colonization intensity was still low in roots from flooded and fallowed soils. Thus VAM activity would be still be less in plants grown in flooded and fallowed soil than plants grown in non-flooded soil. Concentrations of Ca, K and Mg were affected by flood and location. Potassium was decreased and Ca and Mg increased with flooding. Potassium, Ca and Mg were not deficient in the plant. However, shoot dry weight from the flooded fields was less than from non-flooded probably because of the effects of mycorrhiza loss during the early stages of development and resulting in plants with lower P concentrations.

Table 5. Vesicular-arbuscular mycorrhizal root colonization, plant biomass, and nutrient concentration of corn plants harvested July 15-16, 1994.

Field	Flood	Crop	VAM Colon.	Arbuscules	VAM Intensity	Shoot Dry wt	P	K	Ca	Mg
		1993	%	%	0-3	gms/plant	%	%	%	%
					Mound City, MO					
1	NF	Corn	45	34	1.8	360	0.47	2.10	0.45	0.17
2	F	Corn	44	38	1.6	195	0.38	1.52	0.55	0.28
					Polk County, IA, Site 1					
1a	NF	Corn	51	39	2.2	202	0.38	1.78	0.45	0.14
1b	F	Corn	14	10	1.6	139	0.38	1.65	0.45	0.27
2a	NF	Soybean	78	59	2.2	226	0.41	1.85	0.55	0.19
2b	F	Soybean	27	22	1.1	195	0.40	1.30	0.51	0.33
3	F	None	26	16	1.3	167	0.38	1.52	0.54	0.21
					Polk County, IA, Site 2					
1a	NF	Soybean	65	59	2.3	195	0.44	1.68	0.62	0.39
1b	F	Soybean	44	36	1.8	124	0.43	1.80	0.58	0.37
2	F	Corn	52	37	1.8	178	0.43	1.69	0.52	0.24
Pr>F										
Flood			0.05	0.09	0.33	0.07	0.07	>0.01	0.06	>0.01
Previous Crop			>0.01	0.02	0.13	0.48	0.53	0.35	0.03	0.21

* NF=not flooded, F=Flooded

Discussion and Conclusions

Early in the 1994 growing season, fields of purple and stunted corn could be seen throughout the areas flooded and fallowed in 1993. The flood and fallow period of 1993 significantly decreased the population of VAM fungi similar to the problem of "long fallow disorder" discovered in Australia. When lower levels of starter fertilizer was applied, corn plants were stunted, purple, and P deficient. When 80 lb/A P starter fertilizer was applied there were no

visual P deficiency symptoms and there was adequate plant P. However, even when starter P was applied at planting, plants did not attain the early level of plant P of plants from soils which had not been flooded. As the season progressed, VAM fungal root colonization of plants grown in flooded and fallowed soil increased to a level similar to plants which were not flooded and plant P was not deficient.

Several observations support the conclusion that the flood and fallow disorder is associated with the loss of VAM fungi in soil. A farmer in Polk county replanted part of his field after the flood water receded in 1993 and found the area of the field which had been replanted did not show P deficiency symptoms in 1994. In the Polk county Site 1, Field 1 there was a large regrowth of grass in the field after flooding which aided in VAM fungal survival. Therefore, the data from this study supports the concept that the flood and fallow problem is very similar to the "long fallow disorder". The establishment of a crop for one year should allow for re-establishment of VAM fungi in adequate numbers for the following year and thus decrease the need for starter fertilizer. However, extreme loss of VAM fungi may require more time to rebuild the population. At the present time, a VAM fungal inoculant is not readily available and would be prohibitively expensive for most field crops. Thus, maintaining vegetative cover is important in maintaining VAM populations.

Recommendations

The application of 60-80 lb P/A of starter fertilizer should be applied with the planter after a flood and fallow problem to help offset mycorrhiza loss and maximize corn yield. The flood and fallow problem is not resolved with broadcast fertilizer treatments as Dr. Hoeff of the University of Illinois (personal communication) found that broadcast P at recommended rate is not effective in meeting P requirements of corn following flood and fallow.

An alternative to starter fertilizer application would be to consider planting a crop which is less dependent on VAM fungi. Soybean is more tolerant to decreased VAM fungal colonization and sorghum has even greater tolerance. In general, the shorter and coarser the root system, the greater the dependence of the host plant on mycorrhiza (Saif, 1987).

Because of VAM fungal loss, if Zn analysis of the soil is not in the high range, consider adding Zn to starter program.

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