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NOTE AND UNIQUE PHENOMENA

Do we need to apply additional phosphorus for corn succeeding sugarbeet?

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Abstract

Supply of adequate P is critical at the early growth stages of corn (*Zea mays* L.), particularly under a cold environment like the northern Great Plains. The mutualistic relationship between arbuscular mycorrhizal fungi (AMF) and corn roots is responsible for supplying P. However, colonies of AMF drastically decline when corn follows a non-host crop like sugarbeet (*Beta vulgaris* L.) in rotation. Field experiments were conducted at two sites during 2018 and 2019 seasons to determine the corn grain yield response to six P management practices, (a) without P, (b) recommended P, (c) P_2O_5 at the rate of 112 kg ha^{-1}, (d) starter at the rate of 13.7 kg P_2O_5 ha^{-1}, (e) commercial mycorrhizal inoculant, and (f) starter and mycorrhizal inoculant. Corn grain yield did not respond to P application across 4 site-years. Application of 112 kg P_2O_5 ha^{-1} had significantly higher grain yield (15.6 Mg ha^{-1}) than mycorrhizal inoculant (13.5 Mg ha^{-1}) only at one site in 2018. Lowest soil available P was observed with only mycorrhizal inoculant. For one site, AMF population was significantly reduced under without P (0.79 µmol kg^{-1} soil) than recommended P application (1.79 µmol kg^{-1} soil). Higher than recommendation P rate, commercial mycorrhizal inoculant and starter P did not increase grain yield over without P application.

1 | INTRODUCTION

Corn (*Zea mays* L.) production is sensitive to the supply of plant available P in the northern Great Plains (Wortmann, Shapiro, Shaver, & Mainz, 2018). Cold soil temperature at the onset of early spring restricts plant access and uptake of soil P, therefore P fertilization has played a critical role in corn productivity in this region (Grant & Flaten, 2019). At the early corn growth stages, an effective hyphal network formed by arbuscular mycorrhizal fungal (AMF) appears to enhance early P absorption similar to P applied directly with the seed of corn (Miller, 2000). The AMF (members of *Glomeromycota* spp.) establish mutualistic associations with the most agricultural crops (Miller, 2000; Ryan & Graham, 2002). However, when corn follows non-mycorrhizal crops including canola (*Brassica napus* L.) and sugarbeet (*Beta vulgaris* L.), mycorrhizal colonization is delayed, reducing early-season P uptake, which might lead to yield reduction (Karasawa, Kasahara, & Takebe, 2001; Thompson, 1991). Shifts in resource inputs make a lasting effect on plant–soil–microbe interactions leading to soil-legacy effects (Wurst & Ohgushi, 2015). Due to the host preference, crop rotation may differentially promote or depress AMF species (Turrini et al., 2016).

Preceding crop and the host crop in rotation had the strongest effect on AMF assemblage (Benitez, Osborne, & Lehman, 2017; Gavito & Miller, 1998). Fertilizer-P rate and application method (Liu et al., 2015), tillage

Abbreviations: AMF, arbuscular mycorrhizal fungi; NLFA, neutral lipid fatty acid.

practices (Sheng, Lalande, Hamel, Ziadi, & Shi, 2012), and soil type (Oehl et al., 2010) also influenced the AMF population and community structure. Arihara and Karasawa (2000) reported increased corn grain yield after sunflower (*Helianthus annuus* L.), corn, soybean [*Glycine max* (L.) Merr.], and potato (*Solanum tuberosum* L. 'Danshakuimo') than after the rape (*Brassica napus* L.), fallow, and sugarbeet. Talukder and Germida (1993) found lentil (*Lens esculenta* L. 'Eston') had a higher percentage of colonized root and contained more arbuscules and vesicles than wheat (*Triticum aestivum* L.) roots, but no definite trend of AMF colonization on wheat roots were found. Greater fertilizer inputs might trigger increased competition among AMF communities due to the resulting decreased supply of photosynthates from the host plant (Liu et al., 2015). Liu et al. (2016) found that high P supply reduced root colonization while optimum P tended to increase fungal colonization on all sampling occasions. Interactions among plant–soil–AMF are complex, and adjusting crop rotation to favor abundance or diversity of AMF could not be widely recommended and gains in yields might be more easily achievable through soil nutrient management (Ryan & Graham, 2018).

Reduction in early-season P supply, due to delay in AMF infection of corn following a non-mycorrhizal crop, can be corrected with alternative P-management strategies: (a) application of fertilizer P higher than recommended rate (Bittman, Kowalenko, Hunt, Forge, & Wu, 2006), (b) starter fertilizer application (Miller, 2000), and/or (c) AMF inoculum addition (Karagiannifis & Hadjisavva-Zinoviadi, 1998). Fertilizer P management practices should be selected to optimize corn growth. Soil test P information provides a direct assessment of soil P status related to the probability of crop response to P, but cannot guarantee the response for a specific field and a specific year (Grant & Flaten, 2019). In Canada, Bittman et al. (2006) observed that application of both manure and starter P produced 58% more corn shoot biomass, corn took up 63% more P at V6 growth stage and resulted in 6% greater corn grain yield under well-colonized soils than poorly colonized soils, indicating AMF might facilitate corn roots to access starter P. Ammonium polyphosphate (APP), the most popular liquid phosphate fertilizer in North Dakota, supplies both N and P, mostly polyphosphate initially on application to the soil, but polyphosphate rapidly hydrolyzes into the readily plant available orthophosphate form. Ammonium polyphosphate is not as rapidly precipitated into more insoluble forms compared with granular fertilizers, thereby enhancing P availability (Grant & Flaten, 2019).

In the Red River Valley of North Dakota and Minnesota, it is common for corn to follow sugarbeet. These field experiments were conducted to determine the legacy effect of sugarbeet on corn production and corn yield response to fertilizer-P management practices. It was hypothesized that applications of either higher broadcast fertilizer-P rate, P-starter fertilizers, or mycorrhizal inoculation, or both starter and inoculum might supply enough P to overcome the low AMF activity following sugarbeet, and grain yield would not be reduced. The main objectives were to determine (a) the corn grain yield response to broadcast fertilizer-P rate, P-starter, and mycorrhizal inoculant; (b) the influence of P management practices on soil P availability; and (c) differences in AMF population for different P management practices.

Core Ideas

- Corn response to P following non-mycorrhizal crops was studied.
- Recommended P for corn is sufficient for corn succeeding sugarbeet.
- Commercial mycorrhizal inoculum did not increase yield over fertilizer P.
- Higher than recommended P and starter had no negative effect on mycorrhiza.

2 | MATERIALS AND METHODS

Field experiments were conducted with six treatments: (a) without P application (NoP), (b) recommended rate of fertilizer-P application (NPK), (c) fertilizer-P application at the rate of 112 kg P_2O_5 ha^{-1} (112P), (d) in furrow application of liquid starter (APP) at the rate of 28 L ha^{-1} containing 100 g kg^{-1} N and 150 g kg^{-1} P (supplying 4 kg N ha^{-1} and 13.7 kg P_2O_5 ha^{-1}) with only recommended N and K (starter), (e) mycorrhizae application with only recommended N and K (Myco), and (f) applications of mycorrhizae and starter with only recommended N and K (Myco+Starter), at two sites during 2018 and 2019 growing seasons (Table 1). Phosphorus fertilizer was applied in the form of mono ammonium phosphate or MAP ($NH_4H_2PO_4$) containing 110 g kg^{-1} N and 220 g kg^{-1} P. All treatments received recommended rate of N in the form of urea [$CO(NH_2)_2$] and K in the form of muriate of potash (KCl) based on the initial soil test values and according to North Dakota fertilizer recommendation (Franzen, 2018). Nitrogen application rates for different treatments were compensated for the soil nitrate-N within the 90-cm soil profile and N coming from the application of MAP. For the mycorrhizae treatment, a granular product, Xtreme Mykos (Reforestation Technologies International), was hand applied in planting row at the rate of 15 g for each 0.30 m length in 2018. As this mycorrhiza product did not

TABLE 1 Location, initial nutrient availability, crop and fertilizer management of experimental sites during 2018 and 2019 growing seasons

	2018		2019	
Soil and management indices	**Casselton, ND**	**Sabin, MN**	**Chaffee, ND**	**Downer, MN**
Location	46°56′0.5″ N, 97°11′56.3″ W	46°51′52.2″ N, 96°31′5.8″ W	46°56′89.5″ N, 97°12′10.5″ W	46°46′21.4″ N, 96°32′53.7″ W
Soil series	Kindred–Bearden	Wyndmere	Glyndon	Wyndmere
Soil organic matter, g kg^{-1}	50	26	42	35
pH (1:2.5)	7.4	8.7	7.9	7.5
Texture	Silty clay loam	Sandy loam	Sandy loam	Loamy fine sand
Soil NO_3–N,kg ha^{-1}[a]	27	12	13	15
Olsen P, mg kg^{-1}	17	7	14	11
Available K, mg kg^{-1}	207	89	193	170
Planting date	1 May	2 May	11 May	2 May
Harvesting date	26 Oct.	23 Oct.	15 Oct.	23 Oct.
Recommended fertilizers, kg ha^{-1}				
N	250	250	250	250
P_2O_5	10	87	58	58
K_2O	0	100	100	100

[a]Soil available NO_3 was measured for 90-cm depth.

have any influence on yield in 2018, a different commercial product, Myco Grow Soluble (Fungi Perfecti LLC) was used in 2019. This liquid product was applied at the rate of 30 ml (dissolved in 45 L water) per hectare using a hand sprayer before planting.

Treatments were arranged in a randomized complete block design with four replications. Each experimental unit was 3.35 m wide and 9.14 m in length and consisted of six 0.56 m wide rows. Before planting, dry fertilizers were hand broadcasted and incorporated using Triple K field cultivator that has an S-tine shank and double spiral roller behind at a depth of 12 cm. On the same day after fertilizer application, corn cultivars, Dekalb 36-28RIB, and Dekalb C35-88RIB in 2018 and 2019, respectively, were planted at 85,000 seeds ha^{-1} using 0.56 m wide row spacing. For controlling weeds, glyphosate [isopropylamine salt of N-(phosphonomethyl) glycine a.i.] at the minimum rate of 0.74 kg a.i. ha^{-1} (formulation 25 ml L^{-1}) and ammonium sulfate (Class Act, Winfeld Solutions, LLC) at 10 ml L^{-1} were sprayed on the last week of May. At physiological maturity, the middle three rows of each plot were harvested using the small plot combine harvester and the grain yield was calculated using 155 g kg^{-1} moisture content.

To determine initial nutrient availability, representative soil samples of 0- to 15- and 15- to 90-cm depths were collected using a probe truck. Composite samples collected from each site were analyzed using standard method for the north-central region (NCR 221, 1998). Briefly, soil organic matter content was determined using the loss-on-ignition method; soil nitrate-N was extracted using 2 M KCl and analyzed colorimetrically using an autoanalyzer; soil available P was determined using the Olsen method, and soil available K was determined using the flame photometry. At the seedling stage, stand count data was collected for the middle two rows of each plot. For soil available P, samples from 0- to 15-cm depth were collected after harvest in 2018, and on 19 June 2019 (close to V4 growth stage and 39 and 48 d after planting for Chaffee and Downer, respectively). For each plot, triplicate soil samples, from in-between two middle rows spaced across the whole plot length, were collected and composited for the analyses. In 2018, soil available P after harvest did not differ across treatments, so it was decided to collect soils at V3 growth stage for the 2019 growing season.

Soil samples (0–15 cm) were collected to determine the AMF population. Samples were collected on 19 June 2019 (the same day as soil sampling for available P). Triplicate soil samples, close to corn roots, spaced out evenly across the plot length were collected. Soil samples were immediately stored on dry ice in the field and then stored frozen (−20 °C) in the laboratory. Within 48 h, soil samples were lyophilized for 18 h and then sent to Microbial ID laboratory (Newark, DE) for phospholipid- and neutral lipid fatty acid (PLFA–NLFA) analyses (Martinez-Garcia, Korthals, Brussaard, Jorgensen, & De Deyn, 2018). For this manuscript, NLFA 16: 1ω9 biomarker was only compared for the AMF population (Ngosong, Gabriel, & Ruess, 2012; Olsson, 1999).

Corn grain yield, soil available P and NLFA concentration were statistically analyzed using Proc Mixed

TABLE 2 Corn grain yield (Mg ha^{-1}) in response to P treatments for fields with sugarbeet as preceding crop in the Red River of North Dakota and Minnesota during 2018–2019 seasons

	2018				2019			
Treatments	Casselton, ND		Sabin, MN		Chaffee, ND		Downer, MN	
NoP	13.57	(1.5[a])	14.01	(0.6)AB[b]	14.16	(0.8)	15.07	(0.8)
NPK	15.52	(0.8)	14.80	(1.2)AB	13.25	(0.9)	15.17	(0.3)
112P	14.96	(1.3)	15.62	(0.8)A	14.02	(0.5)	15.05	(0.4)
Starter	14.89	(1.3)	14.35	(1.1)AB	13.90	(1.1)	14.08	(1.1)
Myco	14.77	(2.1)	14.02	(1.0)AB	14.23	(1.0)	14.74	(1.0)
Myco+Starter	14.39	(2.3)	13.50	(0.3)B	12.87	(1.6)	15.36	(1.6)
$P > F$	.16		.04		.15		.44	

Note. NoP: Only recommended nitrogen and potassium without phosphorus; NPK: recommended nitrogen, phosphorus, and potassium fertilizers; 112P: P_2O_5 at the rate of 112 kg ha^{-1} with recommended N and P; Starter: in-furrow application of 10–34–0 at the rate of 28 L ha^{-1} with recommended NPK; Myco: mycorrhizae with recommended NPK.

[a]Values in bracket represent the standard deviation.

[b]Different capital letters indicate significant difference ($P < .05$) among treatments for the same site-year.

procedure within SAS 9.4 software (SAS Institute). Differences of least square means were adjusted using the Tukey–Kramer method at 95% significance level.

3 | RESULTS AND DISCUSSION

Rainfall distribution during the growing season was presented in Supplemental Table S1. Soil after planting was dry due to lower than average rainfall in May of 2018 and in June of 2019. However, stand density was similar across plots at the seedling stage (Supplemental Table S2). Endres, Franzen, Kandel, Ostile, and Schatz (2017) also reported the number of days from corn seed planting to emergence was similar among the untreated check, and band- and in-furrow application of P fertilizer.

Corn grain yield in response to P management practices are presented in Table 2. Phosphorus-fertilizer did not influence corn grain yield over NoP across 4 site-years. In 2018, recommended rate of P had the highest grain yield at Casselton; but at Sabin, 112P had the highest grain yield, significantly greater than only Myco+Starter, and similar to recommended P. The Sabin site had higher soil pH, lower soil organic matter content and available P than the Casselton site (Table 1), this might have resulted in the greater response with 112P. At Sabin, corn response to P might be due to low P mineralization, caused by low soil organic matter; moreover, fixation of P by Ca^{2+} or calcium ion in alkaline soil reduced the P availability.

The statistically similar yield of 112P and recommended P rates indicate that current fertilizer-P recommendation is sufficient to maximize the grain yield, even after sugarbeet. Instead of fertilizer P, the starter only treatment was statistically similar in grain yield to recommended P (NPK) application for all site-years. Mycorrhiza alone or with starter did not show any consistent response. In North Dakota, Endres et al. (2017) also found that only 3 out of 11 site-years, grain yield tended to increase with infurrow/banded P application but the increases were not statistically significant.

Significant differences in soil available P was observed at Chaffee and Downer in 2019 (Table 3). The lowest soil available P value was observed with Myco treatment, for all site-years. Application of Myco had the lowest soil available P, significantly lower than 112P at Chaffee, and Starter treatment at Downer. Bittman et al. (2006) reported that both AMF colonization and starter P improved early corn growth and, to a lesser extent, grain yield even on soils with high soil P.

Mycorrhizal population, measured by NLFA, significantly varied across P treatments at Chaffee during 2019 (Table 4). Downer had higher average NLFA concentration of 2.04 µmol kg^{-1} soil than Chaffee (1.26 µmol kg^{-1} soil). Diversity and richness of AMF is greatly affected by land use intensity and soil parameters; Oehl, Laczko, Oberholzer, Jansa, and Egli (2017) observed some AMF species were affected by soil organic matter, soil microbial biomass, nutrient availability, whereas other species were more affected by soil pH, soil texture, and base saturation. Downer had slightly lower soil pH and lighter texture than Chaffee (Table 1).

At Chaffee, NPK had the highest NLFA, and NoP had the lowest NLFA concentration. NPK had significantly higher NLFA concentration than NoP. Ryan and Angus (2003) reported that high colonization by AMF was not essential for major field crops grown on temperate red loam (Kandosol) soils even under P-limiting conditions. Previously many researchers (Faye et al., 2013; Tarbell & Koske, 2007)

TABLE 3 Soil available P (mg kg^{-1}) in response to P treatments for fields with sugarbeet as preceding crop in the Red River of North Dakota and Minnesota during 2018–2019 seasons

	2018		2019	
Treatments	**Casselton, ND**	**Sabin, MN**	**Chaffee, ND**	**Downer, MN**
NoP	8.07 (2.6[a])	6.69 (5.6)	36.5 (5.74)B[b]	15.5 (4.43)B
NPK	9.89 (4.5)	7.67 (3.2)	42.3 (10.3)AB	33.5 (12.2)AB
112P	12.1 (4.8)	6.76 (1.6)	55.0 (6.32)A	26.0 (10.3)AB
Starter	8.48 (5.3)	6.89 (1.4)	41.3 (13.6)AB	69.3 (39.1)A
Myco	5.85 (1.2)	6.69 (1.2)	35.8 (4.57)B	15.0 (2.94)B
Myco+Starter	7.13 (2.1)	6.79 (2.1)	46.3 (14.8)AB	31.5 (16.6)AB
P > *F*	.12	.91	.03	.01

Note. NoP: Only recommended nitrogen and potassium without phosphorus; NPK: recommended nitrogen, phosphorus, and potassium fertilizers; 112P: P_2O_5 at the rate of 112 kg ha^{-1} with recommended N and P; Starter: in-furrow application of 10–34–0 at the rate of 28 L ha^{-1} with recommended NPK; Myco: mycorrhizae with recommended NPK.
[a]Values in bracket represent the standard deviation.
[b]Different capital letters indicate significant difference ($P < .05$) among treatments for the same site-year.

TABLE 4 Arbuscular mycorrhizal fungal population as determined neutral fatty acid (NLFA) (μmol kg^{-1} soil) profile in response to phosphorus management practices of soil samples (0–15 cm) collected from on 19 June 2019 from two corn fields succeeding sugarbeet

Treatments	**Chaffee, ND**	**Downer, MN**
NoP	0.79 (0.11[a])B[b]	2.30 (0.60)
NPK	1.79 (0.52)A	1.31 (0.17)
112P	1.31 (0.36)AB	2.28 (0.62)
Starter	1.08 (0.07)AB	2.13 (0.32)
Myco	1.38 (0.76)AB	1.83 (0.53)
Myco+Starter	1.21 (0.33)AB	2.39 (0.81)
P > *F*	.03	.11

Note. NoP: Only recommended nitrogen and potassium without phosphorus; NPK: recommended nitrogen, phosphorus, and potassium fertilizers; 112P: P_2O_5 at the rate of 112 kg ha^{-1} with recommended N and P; Starter: in-furrow application of 10–34–0 at the rate of 28 L ha^{-1} with recommended NPK; Myco: mycorrhizae with recommended NPK.
[a]Values in bracket represent the standard deviation.
[b]Different capital letters indicate significant difference ($P < .05$) among treatments for the same site.

reported the lack of corn response to commercial mycorrhizal inocula. Tarbell and Koske (2007) found five out of the eight inocula failed to colonize roots when applied at the recommended rate and doubted the quality control practices implemented by many inoculum producers. Faye et al. (2013) did not find any correlation between inoculant mycorrhizal potential and its AMF propagule density and species diversity.

This study showed that sugarbeet, a non-AMF host crop had no negative effect on the grain yield of the following corn. Alternative to fertilizer P management practices, commercial mycorrhizal application and starter did not increase yield or soil P availability. Dry- or starter-P application had no negative effect on soil mycorrhizal population.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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REFERENCES

Arihara, J., & Karasawa, T. (2000). Effect of previous crops on arbuscular mycorrhizal formation and growth of succeeding maize. *Soil Science and Plant Nutrition*, *46*, 43–51. https://doi.org/10.1080/00380768.2000.10408760.

Benitez, M. S., Osborne, S. L., & Lehman, R. M. (2017). Previous crop and rotation history effects on maize seedling health and associated rhizosphere microbiome. *Scientific Reports-Uk ARTN*, *7*, 15709. https://doi.org/10.1038/s41598-017-15955-9.

Bittman, S., Kowalenko, C. G., Hunt, D. E., Forge, T. A., & Wu, X. (2006). Starter phosphorus and broadcast nutrients on corn with contrasting colonization by mycorrhizae. *Agronomy Journal*, *98*, 394–401. https://doi.org/10.2134/agronj2005.0093.

Endres, G., Franzen, D., Kandel, H.. Ostile, M., & Schatz, B. (2017). *Corn response to phosphorus starter fertilizer in North Dakota*. NDSU Extension Service, SF-882 (revised). Fargo, ND: North Dakota State University. Retrieved from https://www.ag.ndsu.edu/publications/crops/corn-response-to-phosphorus-starter-fertilizer-in-north-dakota/a1851.pdf

Faye, A., Dalpé, Y., Ndung'u-Magiroi, K., Jefwa, J., Ndoye, I., Diouf, M., & Lesueur, D. (2013). Evaluation of commercial arbuscular mycorrhizal inoculants. *Canadian Journal of Plant Science*, *93*, 1201–1208.

Franzen, D. W. (2018). *North Dakota fertilizer recommendation tables and equations*. NDSU Extension Service, SF-882 (revised). Fargo, ND: North Dakota State University. Retrieved from https://www.ag.ndsu.edu/publications/crops/north-dakota-fertilizer-recommendation-tables-and-equations

Gavito, M. E., & Miller, M. H. (1998). Changes in mycorrhiza development in maize induced by crop management practices. *Plant and Soil*, *198*, 185–192. https://doi.org/10.1023/A:1004314406653

Grant, C. A., & Flaten, D. N. (2019). 4R Management of phosphorus fertilizer in the northern great plains. *Journal of Environmental Quality*, *48*, 1356–1369. https://doi.org/10.2134/jeq2019.02.0061.

Karagiannidis, N., & Hadjisavva-Zinoviadi, S. (1998). The mycorrhizal fungus Glomus mosseae enhances growth, yield and chemical composition of a durum wheat variety in 10 different soils. *Nutrient Cycling in Agroecosystems*, *52*, 1–7. https://doi.org/10.1023/A:1016311118034.

Karasawa, T., Kasahara, Y., & Takebe, M. (2001). Variable response of growth and arbuscular mycorrhizal colonization of maize plants to preceding crops in various types of soils. *Biology and Fertility of Soils*, *33*, 286–293. https://doi.org/10.1007/s003740000321.

Liu, Y. J., Johnson, N. C., Mao, L., Shi, G. X., Jiang, S. J., Ma, X. J., … Feng, H. (2015). Phylogenetic structure of arbuscular mycorrhizal community shifts in response to increasing soil fertility. *Soil Biology & Biochemistry*, *89*, 196–205.

Liu, W., Zhang, Y. L., Jiang, S. S., Deng, Y., Christie, P., Murray, P. J., … Zhang, J. (2016). Arbuscular mycorrhizal fungi in soil and roots respond differently to phosphorus inputs in an intensively managed calcareous agricultural soil. *Scientific Reports-Uk ARTN*, *6*, 24902. https://doi.org/10.1038/srep24902.

Martinez-Garcia, L. B., Korthals, G., Brussaard, L., Jorgensen, H. B., & De Deyn, G. B. (2018). Organic management and cover crop species steer soil microbial community structure and functionality along with soil organic matter properties. *Agriculture, Ecosystems & Environment*, *263*, 7–17. https://doi.org/10.1016/j.agee.2018.04.018.

Miller, M. H. (2000). Arbuscular mycorrhizae and the phosphorus nutrition of maize: A review of Guelph studies. *Canadian Journal of Plant Science*, *80*, 47–52. https://doi.org/10.4141/P98-130.

NCR 221. (1998). *Recommended chemical soil test procedures for the north central region*. Retrieved from http://extension.missouri.edu/p/sb1001

Ngosong, C., Gabriel, E., & Ruess, L. (2012). Use of the signature fatty acid 16:1ω;5 as a tool to determine the distribution of arbuscular mycorrhizal fungi in soil. *Journal of Lipids*, *2012*, 236807. https://doi.org/10.1155/2012/236807.

Oehl, F., Laczko, E., Bogenrieder, A., Stahr, K., Bosch, R., Heijden, van der M., & Sieverding, E. (2010). Soil type and land use intensity determine the composition of arbuscular mycorrhizal fungal communities. *Soil Biology & Biochemistry*, *42*, 724–738. https://doi.org/10.1016/j.soilbio.2010.01.006.

Oehl, F., Laczko, E., Oberholzer, H., Jansa, J., & Egli, S. (2017). Diversity and biogeography of arbuscular mycorrhizal fungi in agricultural soils. *Biology and Fertility of Soils*, *53*, 777–797.

Olsson, P. A. (1999). Signature fatty acids provide tools for determination of the distribution and interactions of mycorrhizal fungi in soil. *Fems Microbiology Ecology*, *29*, 303–310. https://doi.org/10.1111/j.1574-6941.1999.tb00621.x.

Ryan, M. H., & Angus, J. F. (2003). Arbuscular mycorrhizae in wheat and field pea crops on a low P soil: Increased Zn-uptake but no increase in P-uptake or yield. *Plant and Soil*, *250*, 225–239.

Ryan, M. H., & Graham, J. H. (2002). Is there a role for arbuscular mycorrhizal fungi in production agriculture? *Plant and Soil*, *244*, 263–271. https://doi.org/10.1023/A:1020207631893.

Ryan, M. H., & Graham, J. H. (2018). Little evidence that farmers should consider abundance or diversity of arbuscular mycorrhizal fungi when managing crops. *New Phytologist*, *220*, 1092–1107. https://doi.org/10.1111/nph.15308.

Sheng, M., Lalande, R., Hamel, C., Ziadi, N., & Shi, Y. C. (2012). Growth of corn roots and associated arbuscular mycorrhizae are affected by long-term tillage and phosphorus fertilization. *Agronomy Journal*, *104*, 1672–1678. https://doi.org/10.2134/agronj2012.0153.

Talukdar, N. C., & Germida, J. J. (1993). Occurrence and isolation of vesicular-arbuscular mycorrhizae in cropped field soils of Saskatchewan, Canada. *Canadian Journal of Microbiology*, *39*, 567–575. https://doi.org/10.1139/m93-082.

Tarbell, T. J., & Koske, R. E. (2007). Evaluation of commercial arbuscular mycorrhizal inocula in a sand/peat medium. *Mycorrhiza*, *18*, 51–36.

Thompson, J. P. (1991). Improving the mycorrhizal condition of the soil through cultural practices and effects on growth and phosphorus uptake by plants. In C. Johansen, K K. Lee, & K L. Sahrawat (Eds.), *Phosphorus nutrition of grain legumes in the semi-arid tropics* (pp. 117–138). Patancheru, India: ICRISAT. Retrieved from http://oar.icrisat.org/474/

Turrini, A., Sbrana, C., Avio, L., Njeru, E. M., Bocci, G., Barberi, P., & Giovannetti, M. (2016). Changes in the composition of native root arbuscular mycorrhizal fungal communities during a short-term cover crop-maize succession. *Biology and Fertility of Soils*, *52*, 643–653. https://doi.org/10.1007/s00374-016-1106-8.

Wortmann, C., Shapiro, C., Shaver, T., & Mainz, M. (2018). High soil test phosphorus effect on corn yield. *Soil Science Society of America Journal*, *82*, 1160–1167.

Wurst, S., & Ohgushi, T. (2015). Do plant- and soil-mediated legacy effects impact future biotic interactions? *Functional Ecology*, *29*, 1373–1382. https://doi.org/10.1111/1365-2435.12456.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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