

The Effects of Four Organic Cropping Sequences on Soil Phosphorous Cycling and Arbuscular Mycorrhizal Fungi

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Abstract—Organic farmers across Saskatchewan face soil phosphorus (P) shortages. Due to the restriction on inputs in organic systems, farmers rely on crop rotation and naturally-occurring arbuscular mycorrhizal fungi (AMF) for plant P supply. Crop rotation is important for disease, pest, and weed management. Crops that are not colonized by AMF (non-mycorrhizal) can decrease colonization of a following crop. An experiment was performed to quantify soil P cycling in four cropping sequences under organic management and determine if mustard (non-mycorrhizal) was delaying the colonization of subsequent wheat. Soils from the four cropping sequences were measured for inorganic soil P (Pi), AMF spore density (SD), phospholipid fatty acid analysis (PLFA, for AMF biomarker counts), and alkaline phosphatase activity (ALPase, related to AMF metabolic activity). Plants were measured for AMF colonization and P content and uptake of above-ground biomass. A lack of difference in AMF activity indicated that mustard was not depressing colonization. Instead, AMF colonization was largely determined by crop type and crop rotation.

Keywords—Arbuscular mycorrhizal fungi, crop rotation, organic farming, phosphorous, soil microbiology.

I. INTRODUCTION

MANY organic farms across Saskatchewan (SK) face soil phosphorus (P) shortages. Phosphorus is often tied up with calcium compounds in Saskatchewan soils, making it largely inaccessible to plants and immobile within the soil profile [1], [2]. Organic farming does not allow the use of fertilizers, and in Saskatchewan the use of manure is limited due to large farm size [3]. Therefore organic farmers must rely on natural inputs for soil P fertility.

Crop rotation is very important in these systems. Cereal crops like wheat, barley, and mustard are heavy nutrient users that do not replenish the soil system, while legumes like pea, lentil, and alfalfa fix nitrogen (N₂) in the soil [4]. The benefits of legume crops will often carry over, and produce higher yields of cereals following them [5]. When legumes are plowed under as green manure, farmers may see many benefits including increased nutrient cycling, decreased nutrient losses, decreased erosion, and weed suppression [6]-[8]. Proper crop rotation means maintaining a balance between nutrient users and nutrient fixers.

Arbuscular mycorrhizal fungi (AMF) are also important for P in organic systems. They form a symbiotic relationship with

80% of terrestrial plants [9]. In exchange for carbon, AMF colonize and extend the root surface area of plants, allowing them to explore a larger area of the soil and increase plant P uptake [10]. A non-mycorrhizal (uncolonized) crop in rotation has been seen to depress colonization of a following crop [11], [12]. The degree of AMF colonization is also affected by its environment. Colonization is often decreased in high P environments [13], [14], indicating it will only perform in P-deficient systems.

For this experiment, AMF infection and other soil and plant P parameters were measured under differing cropping sequences from a long-term (18-year) organic system (Table I). Soil and plants were sampled from the Agriculture and Agri-Food Canada research station in Scott, Saskatchewan. They were taken from the Alternative Cropping Study (ACS), which is an existing experiment looking at different cropping sequences with three diversity levels and six phases (Table I). The diversity levels are named for the crops appearing in them (LOW =low diversity, DAG=diverse annual grain, DAP =diverse annual perennial), and each phase is present every year. The experiment consists of a high-input, reduced-input, and organic system, but only the organic system was sampled for this experiment. Samples were taken to represent each diversity level and to examine AMF colonization following a non-mycorrhizal crop (mustard) and a partial fallow period (lentil green manure). The cropping sequences were wheat-pea (WP), lentil green manure-wheat (LGrMW), mustard-wheat (MW), and wheat-barley (WB).

The study objectives were (i) to evaluate soil P dynamics in the four cropping sequences and (ii) to quantify the affects of a partial fallow period and non-mycorrhizal crop on AMF colonization.

TABLE I
SAMPLED PLOTS FROM SCOTT, SK 2012

Diversity Level	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
LOW	LGrM	W	W	LGrM	M	W
DAG	LGrM	W	P	B	LGrM	M
DAP	M	W	B	A†	A	A

†A=alfalfa

II. MATERIALS AND METHODS

Soils were taken at pre-seeding to measure inorganic soil P (P_i) and AMF spore density (SpD, number of AMF spores 100 g soil⁻¹), at pre-seeding and flowering for phospholipid fatty acid analysis (PLFA), and at flowering for alkaline

phosphatase (ALPase) activity [15]-[18]. Plant samples were taken at flowering for %AMF colonization and measured for plant P concentration and uptake [19]-[21]. Spore density and PLFA measurements (AMF biomarker 16:1 ω 5c) [22] were taken to assess potential AMF activity and AMF colonization and ALPase activity represented actual activity of AMF. Alkaline phosphatase has been related to AMF metabolic activity [23]-[25].

III. RESULTS AND DISCUSSION

Soil inorganic P levels did not vary between cropping sequences, but P_i in WB was lowest (Table II). Spore density of AMF was also not different between sequences (Fig. 1). The AMF biomarker 16:1 ω 5c was detected in greater amounts at flowering than pre-seeding, indicating its abundance increased in the presence of growing crops, but no statistical differences were detected (Fig. 2). Plant AMF colonization and ALPase activity were also not different at flowering (Figs. 3 and 4). Plant P concentrations of the above-ground biomass were lower in MW, and plant P uptake of the above-ground biomass was lower in WB (Table II). Factors other than P are affecting yield and P-uptake of WB, due to its high P concentrations and low P-uptake. However, this is beyond the scope of this project.

The lack of difference between SpD, AMF biomarker counts, AMF colonization, and ALPase activity of the cropping sequences indicates continuous AMF activity throughout the growing season. Despite previous studies to the contrary, mustard is not depressing the colonization of the wheat following it [11], [12]. Furthermore, plant P concentrations are average, despite low P_i levels [26]. It is possible that AMF is responding to the low P_i environment, and colonizing each plant equally. This has been seen previously [27]. In fact, decreased AMF colonization is often seen in systems where high amounts of P are added in the form of fertilizer [28], [29]. It is also possible that organic management is preserving mycorrhizal weed species, which promote colonization during fallow periods and the presence of non-mycorrhizal crops [30].

The combination of low soil P_i and the lack of P-input in this system may be promoting AMF colonization equally on all crops, and are more influential than any effects that non-mycorrhizal crops would have in a conventionally managed system. These conditions preserve spore counts and the living AMF DNA, allowing AMF to draw up its resources every growing season.

Crop rotation may also play a role for AMF activity and colonization. Although variations were not significant, the barley from WB had the lowest overall SpD, AMF biomarker counts, and AMF colonization, and WP had the highest SpD and AMF biomarker counts. To further understand these patterns, it is necessary to refer back to the crop rotation plan (Table I). In Phase 1, or 2010 for the sampled plot of barley, mustard was planted, followed by wheat in 2011 and barley in 2012. All three crops in this succession are heavy nutrient users. It is therefore unsurprising that by 2012, barley would grow in a relatively nutrient-depleted plot.

The higher SD and AMF biomarker counts in WP can also be attributed to crop rotation. Peas increase soil N levels through N₂ fixation. Despite the wheat that was planted in this plot in 2011, which would have depleted the soil somewhat, LGrM was grown there in 2010. The addition of organic matter and nitrogen by LGrM and pea outweigh the nutrient depletion caused by wheat, and promote conditions for AMF SpD and biomarker counts. The elevated AMF colonization in the MW rotation is less clear, but may be related to a carryover effect of alfalfa (N₂-fixer) from 2010. The lack of inputs in this organic system meant that LGrM, pea, and alfalfa are the only inputs available, and are more reliable determinants of plant AMF colonization than mycorrhizal or non-mycorrhizal crops. Crop rotation is the only factor that changes between rotations.

TABLE II
 SOIL PO₄ AND PLANT P CONCENTRATION AND UPTAKE

Cropping Sequence	Soil PO ₄ (kg ha ⁻¹)	Plant [P] (mg kg ⁻¹)	Plant P uptake (kg ha ⁻¹)
WP	17.0	4.1a‡	11.2b
LGrMW	18.4	3.5b	18.8a
MW	16.8	3.1b	16.5a
WB	14.1	3.6b	7.0b
LSD_{0.05}	ns†	0.7	4.7

†ns indicates non-significance. ‡Means followed by the same letter are not significantly different according to LSD_{0.05}

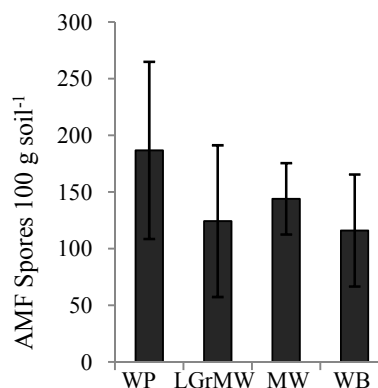


Fig. 1 AMF Spore Density of pre-seeding soil

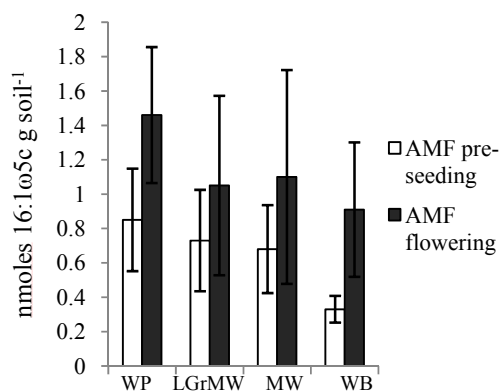


Fig. 2 AMF biomarker 16:1 ω 5c abundance at pre-seeding and flowering

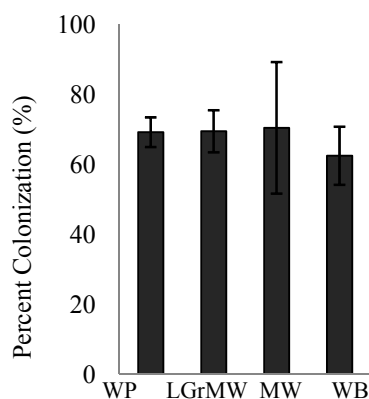


Fig. 3 AMF Colonization at flowering

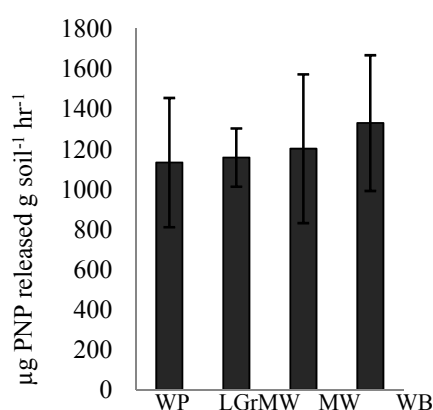


Fig. 4 Alkaline phosphatase activity at flowering

IV. CONCLUSIONS

In this organic system, low soil P_i and crop rotation are more important for AMF colonization than mycorrhizal and non-mycorrhizal cropping sequences. More specifically, the presence of mustard is not depressing the colonization of wheat following it, and it may be due to these conditions.

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