Understanding Microbially Mediated Processes Involved in N, P and C Cycling in Wheat-Based Cropping Systems

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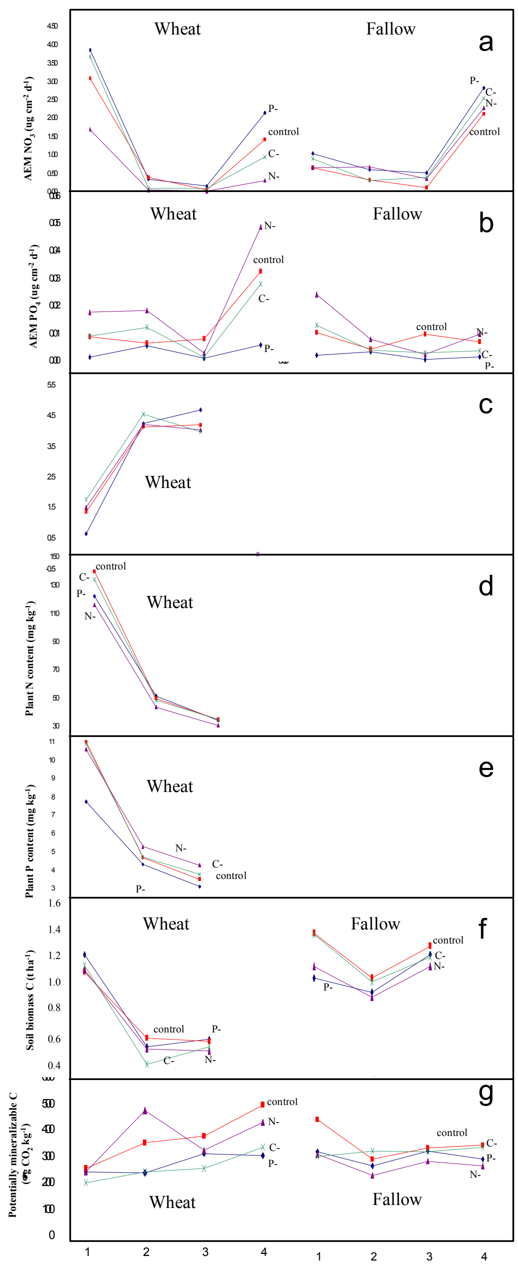

Fig. 1 Variables describing the wheat and fallow soil systems developed after 36 years of different N, P fertilization levels and fallow frequency (C). n=3. Sampling time 1, June 8; 2, July 4; 3, August 5; 4, September 16, 2003.

Introduction

The contribution of soil microorganisms to crop nutrition is undoubtly substantial, but how this contribution is made is still unclear. The soil of wheat plots, which received nitrogen and phosphorus or not and had more or less frequent fallow periods for the last 36 years, have reached different dynamic equilibrium and provided an ideal system to deepen our understanding of the impact of soil nitrogen, phosphorus and carbon inputs on the cycling of these nutrients. The objective of this study is to relate soil microbial biomass dynamics to soil fertility and plant competition in these systems. We report some data from the summer of 2003.

Methods

The experiment, which was established in 1967 on an orthic Brown Chernozen of the Swinton silt loam series, had four treatments: (1) a control where nitrogen and phosphorus fertilizers were applied as recommended to a Fallow-Wheat-Wheat rotation (F-W-W); (2) N-, where no nitrogen, but phosphorus fertilizer was applied as recommended on a F-W-W; (3) P-, where no phosphorus, but nitrogen fertilizer was applied as recommended on a F-W-W; and (4) C-, where nitrogen and phosphorus fertilizers were applied as recommended to a Fallow-Wheat rotation (F-W). These treatments had been applied for the last 36 years in a complete randomized block design with three blocks.

Plots in fallow and those in wheat after fallow were sampled. The top 0-7.5 cm soil layer and three plants, when present, were sampled on June 8, July 4, August 5 and September 16, 2003. Wheat, cv. AC Eatonia, was seeded at a rate of 71 kg ha^{-1}, on May 14, 2003, in plots

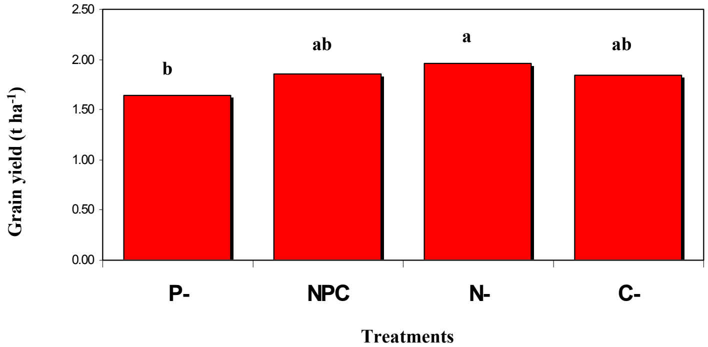

Fig. 2. Wheat grain yield is lowest in plots not fertilized with P, and highest in plots not fertilized with N for 36 years

that were in a wheat phase of the rotations. Plots under fallow were tilled on May 21, June 30 and July 21 with a heavy duty cultivator (16 cm sweep and 0-7.5 cm deep).

Soil moisture (gravimetric), available NH_4-N, NO_3-N (KCL extract) (Maynard and Karla 1993) and phosphorus (Olsen et al. 1954), soil microbial biomass carbon (fumigation-extraction; Voroney et al. 1993), and potentially mineralizable carbon (Bartha 1965), as well as plant biomass, plant nitrogen and phosphorus content (Thomas et al. 1967) were determined. Anion exchange membranes (AEM; Cooperband et al. 1999) were inserted into the soil (7.5 cm) to collect the NO_3 and PO_4 ions released by the soil over the periods of May 22 to June 23, June 27 to July 21, July 22 to August 12, and September 3 to September 30. The data was analyzed with Network Jump v. 3.2.6 and Systat v. 10.

Results and Discussion

The 2003 season was very dry with only 68.2 mm of precipitation from May to the end of July (data not shown).

Nitrogen and phosphorus dynamics in soil: Soil NO_3^- level, as determined by AEMs, seemed largely driven by the seasonal nitrogen fertilization, as it was lower under N- at the beginning of June, and by plant uptake, as shown by a larger residual amounts under P- (Fig. 1a), the low yielding treatment (Fig. 2), in September. Under fallow, there was no difference between treatments. AEM-NO_3 was low throughout the growing season and high on September 16 (Fig. 1a), probably due to enhanced mineralization; the soil was less dry at that date, and three tillage operations had been performed during the growing season. AEM-PO_4 levels, in contrast, revealed a residual effect of phosphorus fertilization, with higher amounts in N- plots and lower amounts in P- plots (Fig. 1b). Inorganic phosphorus seemed to be mobilized by the wheat crop as higher AEM-PO_4 levels were found after wheat than after fallow, within the phosphorus fertilized plots (Fig. 1b, sampling time 4).

Nitrogen and phosphorus uptake by wheat: Nitrogen fertilization increased plant nitrogen

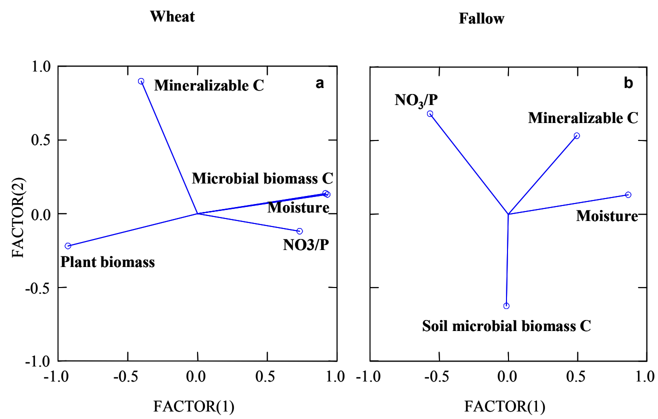

Fig. 3. Factor loading plots showing the relationship between soil microbial biomass C and other components of wheat and fallow soil systems. The models presented explain 83% of the variability (wheat) and 62% of the variability.

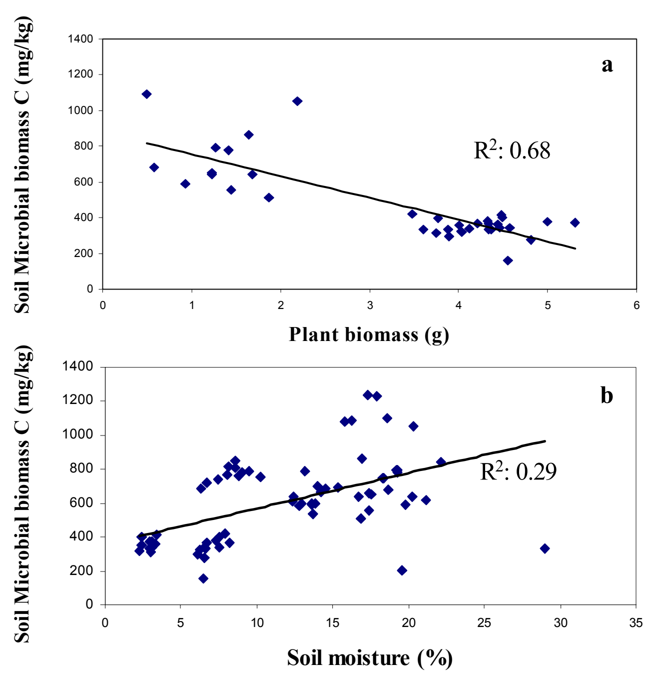

Fig. 4. Competitive relationship between soil microbial biomass C and wheat biomass (P<0.001). Soil microbial biomass C is positively correlated with soil moisture (P<0.001).

content at the first and second, but not at the third sampling time (Fig. 1d and Table 1). In contrast, phosphorus fertilization influenced plant phosphorus content at all sampling times (Fig. 1c and Table 1). Low phosphorus levels were found under P-, the low yielding treatment, suggesting that P availability controls yield, at least partially.

Soil microbial biomass carbon dynamics: Soil microbial biomass carbon (SMB-C) in the top 0-7.5 cm soil layer amounted to more than 1 t ha^{-1} on average, on June 8 (Fig. 1c). SMB-C abundance decreased dramatically with wheat growth (Fig. 3a). The close direct relationship between SMB-C and soil moisture, as well as the inverse relationships between plant biomass, and soil moisture and SMB-C, suggest that water uptake by plants had a large negative impact on soil microbial proliferation (Fig. 3a). Under wheat, soil moisture, but not mineralizable soil carbon influenced SMB-C significantly (Fig. 2 and Fig. 3b). The ratio of KCL-extractible NO_3^- to available phosphorus was also positively correlated with SMB-C under wheat (Fig. 4a). Under fallow, where water was in larger supply, SMB-C did not seem influenced by any of the variables measured, according to a Principal component analysis (Fig. 4b). This observation contrasts with the conclusion of Cruz et al. (2004) who studied the factors limiting the growth and activity of microbial communities in the same plots. This study revealed that limitation by carbon nitrogen and phosphorus was more frequent under fallow than under wheat. Under fallow, for example, carbon limited nitrogenase activity in control plots, phosphorus was limiting in C- plots, wherease carbon nitrogen and phosphorus were limiting in N- plots, and, finally, none of carbon nitrogen or phosphorus was found to limit nitrogenase activity in P- plots. At the light of all this, it seems that different microbial communities adapted to the specific soil conditions created by the treatments may exist in N-, P-, C-, and control plots. This hypothesis is being tested.

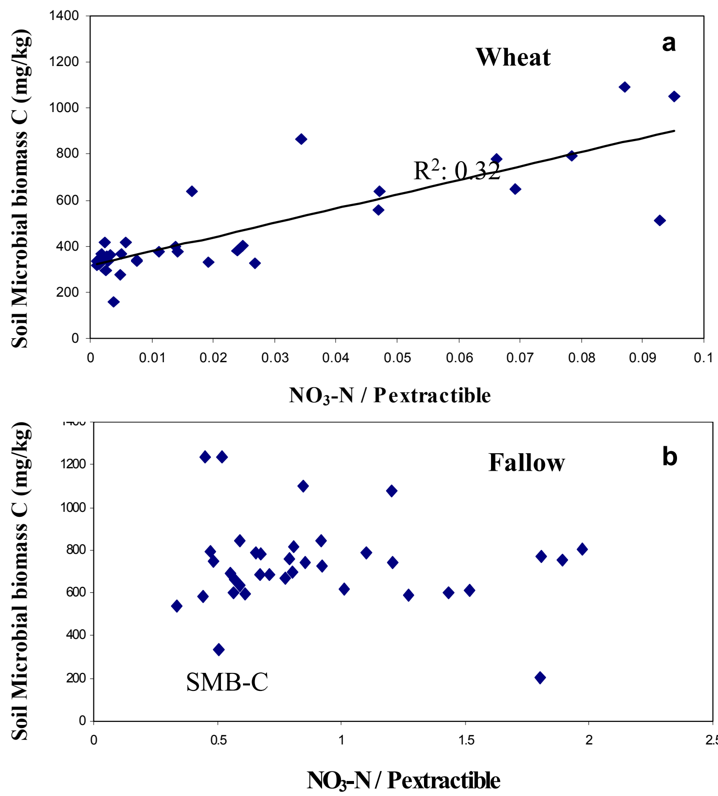

Fig. 5. Soil microbial biomass is correlated with soil NO_3 : available P ratio (P<0.001) under wheat, but not under fallow.

Factors limiting yield and soil microbial biomass C: Wheat grain yield was lowest in absence of phosphorus fertilization and highest in absence of nitrogen fertilization for 36 years (P=0.056; Fig. 2), suggesting than phosphorus rather than nitrogen is likely to limit wheat yield in the system studied. SMB-C was often lowest in absence of nitrogen fertilization (Fig. 1f; Table 2). Thus, while wheat is likely to be phosphorus limited in this systems, the size of the soil microbial community may be nitrogen limited. It appears clearly, however, that competition with plants for water was the major factor limiting SMB-C during this dry 2003 growing season.

Concluding Remarks

Water use by wheat negatively impacted the size of soil microbial biomass. The amount of nitrogen and phosphorus contained in this microbial biomass and released to the soil upon plant competition still need to be determined. The amount of phosphorus released from the soil microbial pool could be important since wheat yield seemed to be primarily limited by P, in this system. It is possible that different microbial communities have been selected in plots under N-, P-, C- and control treatments. It will be interesting to see if the treatments influenced the C/N and C/P ratio of these communities, as such adjustment could influence the quality of the soil microbial pool of nitrogen and phosphorus and, thus, the cycling of these nutrients in soil.

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Table 1 Anova table for soil microbial biomass carbon (SMB-C), potentially mineralizable carbon (Cmin), soil NO_3 flux (AEM-NO_3), PO_4 flux (AEM-PO_4), extractible NO_3 (NO_{3ext}), extractible P (P_{ext}), wheat biomass (W_{mass}), wheat N content (W_N), wheat P content (W_P).

Source of Variation	Cmin				SMB-C			AEM-NO_3				AEM-PO_4				NO_{3ext}			P_{ext}			W_{mass}			W_N			W_P		
Sampling time:	1	2	3	4	1	2	3	1	2	3	4	1	2	3	4	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Fallow frequency (FF)	*								*									*	*		*	*								
Phase of rotation (Ph)	*					*	*	*	*	*	*				*	*	*		*											
Ph*FF			*	*		*														*	*									
Fertilizer[FF]	*			*			*				*	*			*	*	*	*	*	*	*	*			*	*		*	*	*
Fertilizer*Ph[FF]				*					*						*	*	*	*												

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