Long-Term Impact of Wheat-Based Cropping Systems on Soil Biological Activity

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Key Words: Soil enzymes, lentil, fall rye, flax, soil quality

Introduction

Cropping systems have a large impact on soil quality. In southwest Saskatchewan, low precipitations limit yields and fallow is commonly practiced to improve profits on the short-term. Economical reasons also support the practice of wheat monoculture. Water deficit results in high wheat grain protein content, a quality which is worth a premium on the grain market. The benefit of N- and P-fertilization under the condition of water deficit prevailing in this region and has sometimes been questioned. Furthermore, the negative effect of monoculture also needed to be assessed. Therefore, a long-term experiment was set up in 1967, in southwest Saskatchewan. We examined, with this experiment, the effects of fallow frequency, absence of N- and P-fertilization and crop diversification on soil biological activity in a Brown Chernozem, under a semiarid climate.

Materials and Methods

The experiment was arranged in a randomized complete block design with three blocks, on an orthic Brown Chernozen of the Swinton silt loam series, at the South Farm of the Semiarid Prairie Agricultural Research Centre, in Swift Current. All plots had been planted with wheat (cv. AC Eatonia) at a rate of 71 kg ha^{-1}, on May 14, 2003. The different treatments (Table 1) had been applied on the same field plots for the last 36 years, when soil samples were taken in triplicate, on September 12, 2003, from the 0-7.5 cm and 7.5-15 cm soil layers. Replicate samples were pooled to produce one composite sample per plot, for each soil depth.

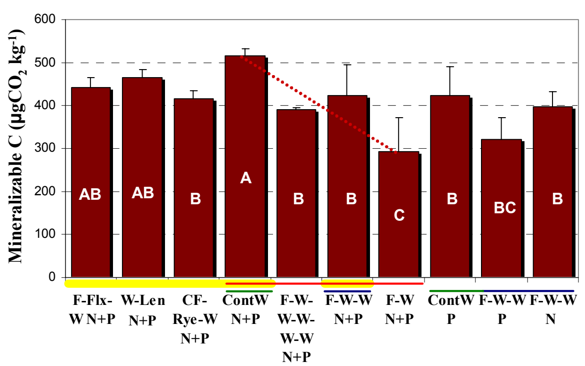

Fig. 1. Soil mineralizable C measures the relative capacity of soil to mineralize C. *n=3*, error bars are standard deviations. Bars with the same letter are not different, according to least significant intervals. Red underline facilitate the comparison of fallow frequency; blue and green underline facilitate the comparison of the N and P fertilization treatments; and the yellow underline, that of crop diversification.

Soil samples were sieved (2 mm) and soil moisture (gravimetric) was determined. Potentially mineralizable C (Bartha 1965), and potential dehydrogenase (Casida et al. 1964), arylsulfatase, ß-glucosidase (Tabatabai 1982) and phosphatase (Eivazi and Tabatabai 1977) activities were measured on fresh soil samples. The significance of treatment effects was analyzed by ANOVA using Network Jump v. 3.2.6.

Results and Discussion

Only the results obtained from the 0-7.5 cm soil depth are presented (Fig. 1 to 5). The data obtained from the 0-7.5 and 7.5-15 cm soil depths had the same trends, with stronger treatment effects in the 0-15 cm depth, except in the case of phosphatase and arylsulfatase activities the extent of which was remarkably similar at the two soil depths (data not shown). The absence of difference in phosphatase and arylsulfatase in the 0-7.5 and 7.5-15 cm soil depths suggests that the production of these enzymes by roots is relatively important in the system, as soil microbial biomass is usually more important in the first 7.5 cm of the soil. Soil microbial biomass is currently being measured to confirm this hypothesis. While the ability of plant roots to produce phosphatase is well documented (Alexander 1977; Paul and Clark 1996), the plant origin of arylsulfatase is unreported, to the best of our knowledge.

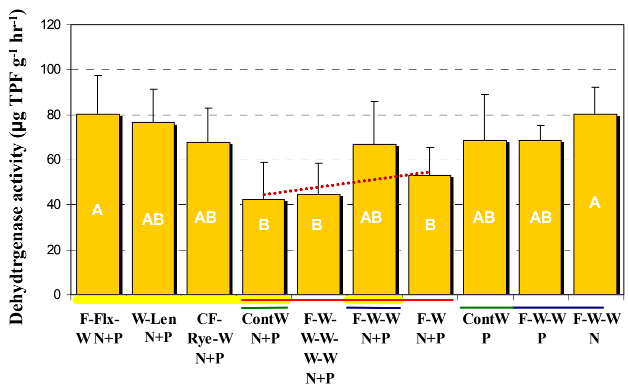

Fig.2. Dehydrogenase is an intracellular enzyme (Alexandre,1977). It activity reflects the sum of all energy-yielding biological reactions in soil. *n=3*, error bars are standard deviations. Bars with the same letter are not different, according to least significant intervals. Red underline facilitate the comparison of fallow frequency; blue and green underline facilitate the comparison of the N and P fertilization treatments; and the yellow underline, that of crop diversification.

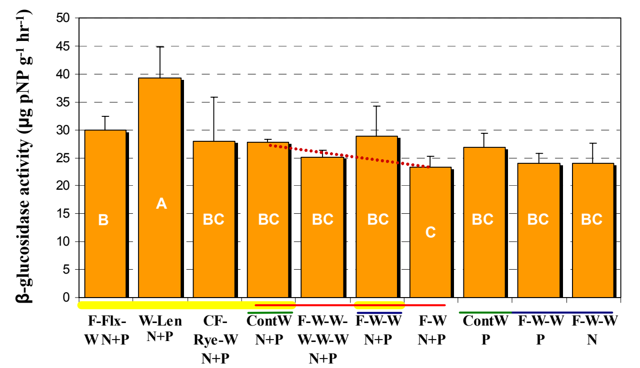

Fig. 3. ß-glucosidase is an extracellular enzyme produced inductively by cellulolytic populations (Alexandre, 1977). *n=3*, error bars are standard deviations. Bars with the same letter are not different, according to least significant intervals. Red underline facilitate the comparison of fallow frequency; blue and green underline facilitate the comparison of the N and P fertilization treatments; and the yellow underline, that of crop diversification.

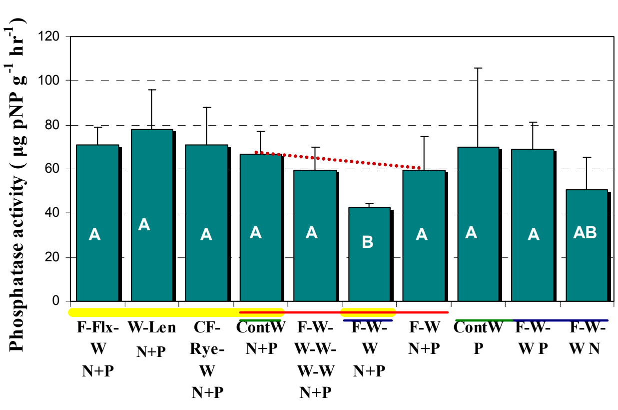

Fig. 4. Phosphatase is an extracellular enzyme that cleaves phosphate from orthophosphoric monoesters (Paul and Clark,1996). *n=3*, error bars are standard deviations. Bars with the same letter are not different, according to least significant intervals. Red underline facilitate the comparison of fallow frequency; blue and green underline facilitate the comparison of the N and P fertilization treatments; and the yellow underline, that of crop diversification.

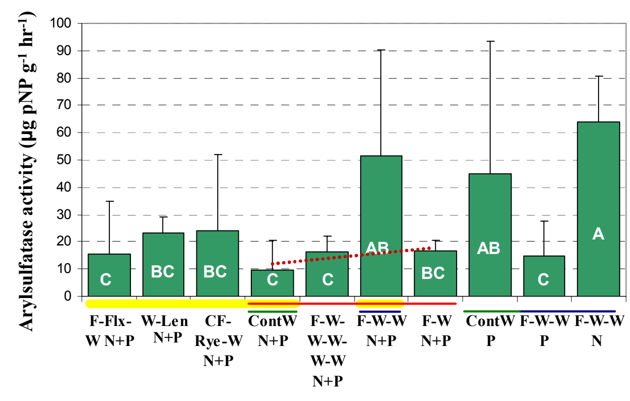

Fig. 5. Arylsulphatase is an inducible enzyme that is at least partly extracellular and cleaves sulfate from phenol sulphate (Paul and Clark, 1996). *n=3*, error bars are standard deviations. Bars with the same letter are not different, according to least significant intervals. Red underline facilitate the comparison of fallow frequency; blue and green underline facilitate the comparison of the N and P fertilization treatments; and the yellow underline, that of crop diversification.

Fallow frequency's effects : Low fallow frequency was associated with high soil mineralizable C (Fig.1). This effect was expected as plants are the main primary producers in soil.

Fallow frequency did not influence potential soil dehydrogenase activity (Fig.2), but C was more available in plots with lower fallow frequency, suggesting a build up of organic matter in the latter soils.

Fallow frequency did not influence soil potential ß-glucosidase activity (Fig.3). It seems that cellulose decomposition proceeded at a rate such that after one growing season, glucose oligomers from previous year residues had not all been used, resulting in the presence of substantial amounts of glucose oligomers in plots under contW and in those which were under fallow the previous year (F-W / N+P). The absence of fallow frequency effect on ß-glucosidase potential activity also reflects the relative abundance of glucose in all soils. ß-glucosidase is not produced in excess of cellulolytic population needs (Alexander 1977) and is repressed by the product of the reaction (Paul and Clark 1996). Straw had a turnover of 300 days, in an experiment conducted in Saskatchewan (Paul and Clark 1996). In any case, it appears that the supply of glucose oligomers to cellulolitic populations was not a factor limiting their activity under wheat after fallow at least in September, 2003.

Fallow frequency seemed to have an erratic effect on potential soil enzyme activities, as the F-W-W / N+P treated plots did not follow the general relationship found between fallow frequency and the different biochemical activities (see the dashed line on Fig. 1-5). Mineralizable C, dehydrogenase, ß-glucosidase and arylsulfatase activities in F-W-W / N+P treated soils exceeded the levels expected from linear relationships between fallow frequency and potential activities, while potential phosphatase activity was lower than expected. These unexpected results may be attributable to a confunding effect of soil moisture, as all plots sampled where planted with wheat the previous year, except those under the F-W rotation, which were under fallow, accumulating water for the 2003 cropping season. The impact of soil moisture on enzyme activity was significant for phosphatase and β-glucosidase activity (Fig. 6a and 7). This suggests that the data collected from F-W plots must be regarded with caution.

If we exclude the F-W data, it can be seen that low fallow frequency in well fertilized wheat monocultures is associated with high phosphatase activity and low arylsulfatase activity. High phosphatase activity indicates a high P demand / P availability in systems with no or infrequent fallow, and suggests that P could limit growth in these systems. A low arylsulfatase activity under cropping systems with no or infrequent fallow suggests a low S demand / S availability in these systems. In general, most of the S used by plants is from organic sources (Paul and Clark 1996). Thus, high arylsulfatase activity in systems with frequent fallow may be related to lower amounts of S-containing labile organic matter in these systems. This is consistent with the measurement of lower amounts of soil mineralizable C under F-W-W (Fig. 1). It is worth noting, however, that the availability of a C source did not seem to limit soil biological activity at the time of sampling, as only potential ß-glucosidase activity, the activity of an enzyme involved in cellulose decomposition, was correlated with potentially mineralizable C (Fig. 6).

***N- or P-fertilization effects**:* Absence of N- or P-fertilization in F-W-W plots did not influence soil mineralizable C, dehydrogenase, ß-glucosidase or phosphatase activities (Fig.1-4), suggesting that N and P availability was not limiting any of the F-W-W cropping systems, at least at the time of sampling, and this, in spite that soil available orthophosphate levels varied widely with fertilizer treatments (Hamel et al. 2004). This observation shed doubts on the adequacy of sampling the soil after the crop is harvested, and prevent us to reach any conclusion on the factors potentially limiting wheat growth in the systems under study. Absence of N-fertilization reduced soil mineralizable C under contW, but not under F-W-W (Fig. 1) suggesting that N fertilization becomes more important as cropping intensity increases.

Unexpectedly, potential arylsulfatase activity was reduced in absence of N-fertilization under F-W-W, but enhanced in absence of N-fertilization under contW (Fig. 5).

Crop diversification effects: Inclusion of a preceding crop of lentil, rye or flax in wheat-based rotations did not influence soil mineralizable C, potential phosphatase or arylsulfatase activity when diversified cropping systems are compared to the wheat-monoculture system with the same fallow frequency (Fig. 1-3). However, lentil largely enhanced overall potential biological activity (dehydrogenase) (Fig. 2) suggesting that at the same soil mineralizable C level, the soil community under W-Len has a superior metabolic performance (more potential activity per unit of soil mineralizable C) than that under contW. Lentil in rotation also increased potential soil ß-glucosidase activity (Fig. 3) indicating a rapid use of glucose, the product ß-glucosidase, in W-Len plot soils. This relatively rapid utilization of glucose under wheat following lentil, a N_2-fixing plant, may indicate that N availability limits microbial activity in rotations without legume. The causes and consequences of these effects of lentil on soil biological activity should be investigated further.

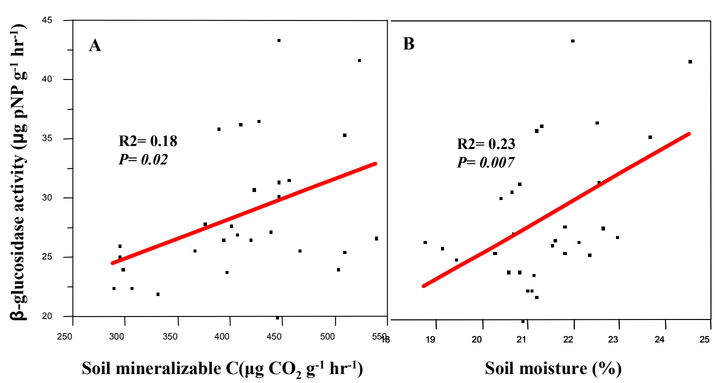

Fig. 6. ß-glucosidase activity was positively related with soil mineralizable C and soil moisture

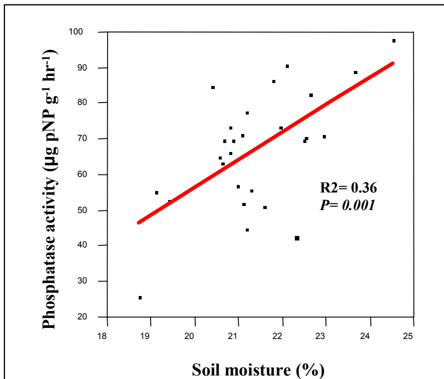

Fig. 7. Phosphatase activity was related to soil moisture but not to soil mineralizable C.

Concluding Remarks

Enzyme activity was proposed as a sensitive early indicator of the impact of cropping systems on soil quality. We have shown that soil enzyme measurement reflects the status of soils as created under different cropping systems. Enzyme assays revealed that low fallow frequency increases the P demand relative to soil P supply, presumably by reducing the amount of P from labile inorganic sources, and that it reduces S demand in relation to S supply, in our system. S is presumably mobilised through an increase in the size of the soil organic S pool. Low fallow frequency and inclusion of lentils in rotation with wheat enhanced soil biological properties, but little impact of N- and P-fertilization on soil biological activity was found, except under continuous cropping where N-fertilization limits biological quality. Impacts of fertilization might have been better detected if soil sampling had been performed during the growing season, when nutrient needs are maximized by plant nutrient uptake.

We have also found that enzyme activity measurements are influenced by fluctuating environmental variables such as soil moisture level, a property that limits the use of soil enzyme activity as indicator of long-term impact of cropping systems on soils. We believe, however, that the measurement of soil enzymes is a useful tool to study the mechanisms of soil function, when used in combination with modern microbiology techniques and chemical soil analysis.

Table 1. Treatments applied for 36 years in plots of the Old rotation experiment of AAFC, in Swift Current. The phase of the rotation sampled is indicated by an underline. The levels of soil organic C and N, as measured in 1999, are also presented.

Soil organic C (0-15 cm) in 1999	Soil organic N (0-15 cm) in 1999	Abbreviation	Treatment description
36.6	3.6	F-Flx-W / N+P	Fallow-flax-wheat, fertilized with N and P[*]
41.7	4.2	W-Len / N+P	Wheat-lentil, fertilized with N and P
42.0	4.1	CF-Rye-W / N+P	Chemical fallow-fall rye-wheat, fertilized with N and P
42.2	4.2	ContW / N+P	Continuous wheat, fertilized with N and P
39.7	3.9	F-W-W-W-W-W / N+P	Fallow and 5 years in wheat, fertilized with N and P
-	-	F-W -W / N+P	Fallow-wheat-wheat, fertilized with N and P
36.5	3.7	F-W / N+P	Fallow-wheat, fertilized with N and P
37.9	3.7	ContW / P	Continuous wheat, fertilized only with P
37.1	3.7	F-W-W / P	Fallow-wheat-wheat, fertilized only with P
35.3	3.5	F-W-W / N	Fallow-wheat-wheat, fertilized only with N

[*] N and P fertilizers rates applied, where appropriate, were those recommended according to soil tests.

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