Crop Rotation Effects on Soil Microbial Populations, Biomass and Diversity under Wheat in a Brown Loam

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Introduction

The inclusion of grain and green manure (GM) or forage legumes in cereal production systems on the Prairies does improve the fertility and quality of soils (Wright 1990; Campbell et al. 1992; Green and Biederbeck 1995; Biederbeck et al. 1998). Legume-based cropping systems can also reduce nitrogen losses and greatly increase the proportion of crop residue-carbon that is sequestered in stable soil organic matter (Drinkwater et al. 1998). As growing environmental and economic concerns are shifting agricultural systems away from high-input to more ecologically sustainable systems (Tilman 1998), there will be increasing reliance on biological soil processes and on high microbial diversity, since soil microorganisms mediate most of the processes that are essential to agricultural productivity (Paul and Clark 1996).

Recent research on Gray Luvisols in northern Alberta shows that reduced tillage and inclusion of legumes in crop rotations do increase soil microbial biomass and diversity, thus confirming them as more sustainable management systems than conventional tillage and fallowing (Lupwayi et al. 1998 and 1999). It is not known whether tillage reductions and inclusion of grain or GM legumes in wheat-dominated rotations elicit similarly beneficial responses from the microflora in the Brown Chemozems of the southern, semiarid Prairie region.

The existence of two long-term rotation experiments at SPARC in Swift Current, that differ in management and in age, has made it possible for us

> **‘to assess the impact of fallowing, monoculture wheat and inclusion of annual legumes (pulse or GM) on major components of soil biological quality’**

by measuring selected microbial and biochemical attributes in root-free and in rhizosphere soil of the wheat phase.

Materials and Methods

Both rotation experiments are on the same Swinton silt loam (Orthic Brown Chemozem), on level land and located within less than 1 km of each other, at the South Farm of SPARC. From the ‘Old Rotations’ Study, that was initiated in 1967 and had been managed as stubble mulch tillage, we selected these four rotations for sampling:

(i) Conventional Fallow-Spring Wheat (F-W);
(ii) Conv. Fallow-Fall Rye-Wheat (F-Rye-W);
(iii) Continuous Wheat (Cont. W); and
(iv) Grain Lentil-Wheat (Len-W), which was started in 1979 by conversion from an extra Cont. W rotation.

From the ‘New Rotations’ Study, that was initiated in 1987 and had been managed as minimum tillage, we selected these four rotations for sampling:

(i) Chem. Fallow-Wheat-Wheat (F-W-W);
(ii) Green Manure Lentil, cv. Indianhead,-Wheat-Wheat (GM-W-W);
(iii) Continuous Wheat (Cont. W); and
(iv) Crested Wheatgrass, grown for Hay (CWGHay).

Three replicate plots from each of these eight rotations were sampled on July 3rd 1997, when the wheat growing in seven of the rotations, i.e., all except CWGHay, was at the flag-leaf stage. In each plot, five non-rhizosphere samples were dug to 15 cm depth between crop rows and bulked into one composite sample. Five rhizosphere samples were collected by digging the wheat plants along 0.5 m lengths of five rows, shaking off excess soil and then bulking these root samples with adhering soil into large plastic bags. At the laboratory, the rhizosphere soil was taken off the roots by gentle brushing within 24 h of field sampling. All soil samples were sieved (< 2 mm) and stored field-moist at 0°C.

Microbial populations were enumerated by soil dilution plating technique, using soil extract agar for bacteria and actinomycetes, rose bengal streptomycin agar for filamentous fungi and yeasts, and carboxymethylcellulose-congo red agar for cellulose degraders. Microbial diversity and community structure was assessed using the BIOLOG system for detection of specific patterns of substrate utilization by bacteria. Microbial biomass carbon was determined by a substrate-induced respiration method and unamended, i.e., endogenous, soil microbial respiration was measured during 30 days of incubation in Biometer flasks. Water soluble organic carbon (WSOC) and dehydrogenase enzyme activity were determined by standard methods.

Results and Discussion

As continuous wheat is the only rotation common to both long-term experiments, we have used this well-managed (N and P fertilized) monoculture as the basis for evaluating specific rotation effects within each experiment. Therefore, the only measured values (and units of measurement) of soil microbial and biochemical attributes, presented in this paper, are those listed in Table 1 for continuous wheat in the 30 yr old and in the 10 yr old rotation studies.

A comparison of the measured variables for monoculture wheat between the ‘Old” and ‘New’ rotations shows that most values and also the root effects are quite similar (Table 1). However, there are definite indications of beneficial effects due to the reduction in tillage from the old to the new rotations, but they are only evident for the respective bulk or non-rhizosphere soil such as the marked increase in bacteria (64 to 116), in Shannon’s diversity index (2.35 to

3.34), in substrate richness (30 to 54), in microbial biomass (401 to 508) and dehydrogenase activity (24 to 47). The extent of stimulation of procaryotes by the wheat roots in the old rotations, viz. doubling of the bacterial plus tripling of the actinomycete populations (Table i), was certainly greater than the 11% increase Grayston and Germida (1990) have reported for heterotrophic procaryotes in the wheat rhizosphere of four Saskatchewan soils including a Brown loam of the Haverhill soil association.

Table 1. Effect of soil management of monoculture wheat on selected microbial and biochemical attributes of bulk and rhizosphere soil in two long-term rotation studies on a Brown loam at Swift Current, SK.

	Continuous Wheat (N + P fertilized)			
	Old Rotations		New Rotations	
Variable measured+	Non-Rhizosphere	Rhizo-sphere	Non-Rhizosphere	Rhizo-sphere
Microbial counts (organisms/g soil):				
Bacteria (x 10^6)	**64**	131	116	120
Actinomycetes (x 10^6)	**1.6**	4.6	2.3	4.3
Cellulolytic orgs. (% of Bacteria + Actinos)	**6.0**	1.6	3.5	1.2
Filamentous fungi (x 10^3)	410	**440**	**280**	**350**
Yeasts (x 10^3)	10	**25**	**13**	**24**
Microbial diversity (as indicated by H, S and E):				
H - Shannon's index	**2.35**	**3.98**	**3.34**	**3.86**
S - Substrate richness	**30**	**79**	**54**	**68**
E - Substrate evenness	**0.71**	**0.91**	**0.84**	**0.91**
Microbial biomass (μg C/g soil)	401	**383**	**508**	**379**
Microbial respiration (30 day cumul. μg CO,-C/g soil)	169	173	180	182
Water soluble organic carbon (μg C/g soil)	14	17	15	21
Dehydrogenase activity (μg TPF/h/g soil)	**24**	**32**	**47**	41

+ Values are means of composite samples taken from 0- 15 cm on July 3, 1997 from each of 3 replicates at flag-leaf stage of growth.

Rotation Effects

The rotation effects were definitely more pronounced in the 30 yr old (Figure 1) than in the new, i.e., 10 yr old (data not shown), rotation experiment. In the new field study there were generally no significant rotation effects detectable for more than three quarters of all measurements. In both experiments, the rotation effects on filamentous fungi and yeasts in bulk and rhizosphere soil were generally not significant (data not shown).

All indices of soil microbial diversity were higher in wheat following grain lentil than in any other rotation, but the differences were not quite statistically significant at $p = .05$ (data not shown). In the new rotations, continuous wheat and wheat after GM lentil had significantly greater substrate richness than in other crop sequences (data not shown).

When there were significant rotation effects, as shown in Figure 1 A) and B) from the old field study, they were generally more prominent in the non-rhizosphere soil and impacts were almost invariably greatest in wheat following lentil. Thus the pulse-cereal rotation had by far the largest microbial biomass and the highest dehydrogenase activity but also the lowest proportion ofprocaryotic cellulose degraders and a lower level of soil microbial respiration. The reduced soil respiration and cellulolytic activity may reflect a general narrowing of residue C/N ratios and a more effective bioconversion of the mixed lentil/wheat residues into stable soil humus. The 3 yr fallow-fall rye-wheat rotation also showed some positive rotation effects, relative to continuous wheat, particularly for bacterial population and dehydrogenase activity (Figure 1).

Root Effects

Root-associated soil biological effects can be meaningfully assessed by comparing the ‘rhizosphere/non-rhizosphere ratio’ (R/NR) of the measured variables. R/NR ratios well above 1.0 indicate root-induced stimulation in the presence of carbon-rich exudates, while ratios markedly below 1 .O signify repression or inhibition of a population or a microbially mediated process.

In both experiments, cellulose degraders were drastically decreased within the wheat rhizosphere (Figure 2A), suggesting that very few of the root-associated bacteria can attack and degrade the cellulose-containing mucigels on root surfaces. Actinomycete and total bacteria populations in the rhizosphere were boosted 1.5 to 4.5-fold in all rotations except continuous wheat in the new field study where the R/NR ratio was only 1 for the bacteria (Figure 2A). Root-induced increases in bacterial populations were generally greater in the old than in the new rotations with the exception of wheat after GM lentil and also in the crested wheatgrass. Yeast populations were boosted more by wheat roots in the old than in the new field study, particularly following fall rye and in continuous wheat (Figure 2A), while the reverse trend was observed for filamentous fungi.

Root-induced increases in soil microbial respiration were only found to be significant after fallow in the old and after GM lentil and also in crested wheatgrass of the new rotations (Figure 2B). Similarly, microbial biomass carbon was generally not increased by vicinity to

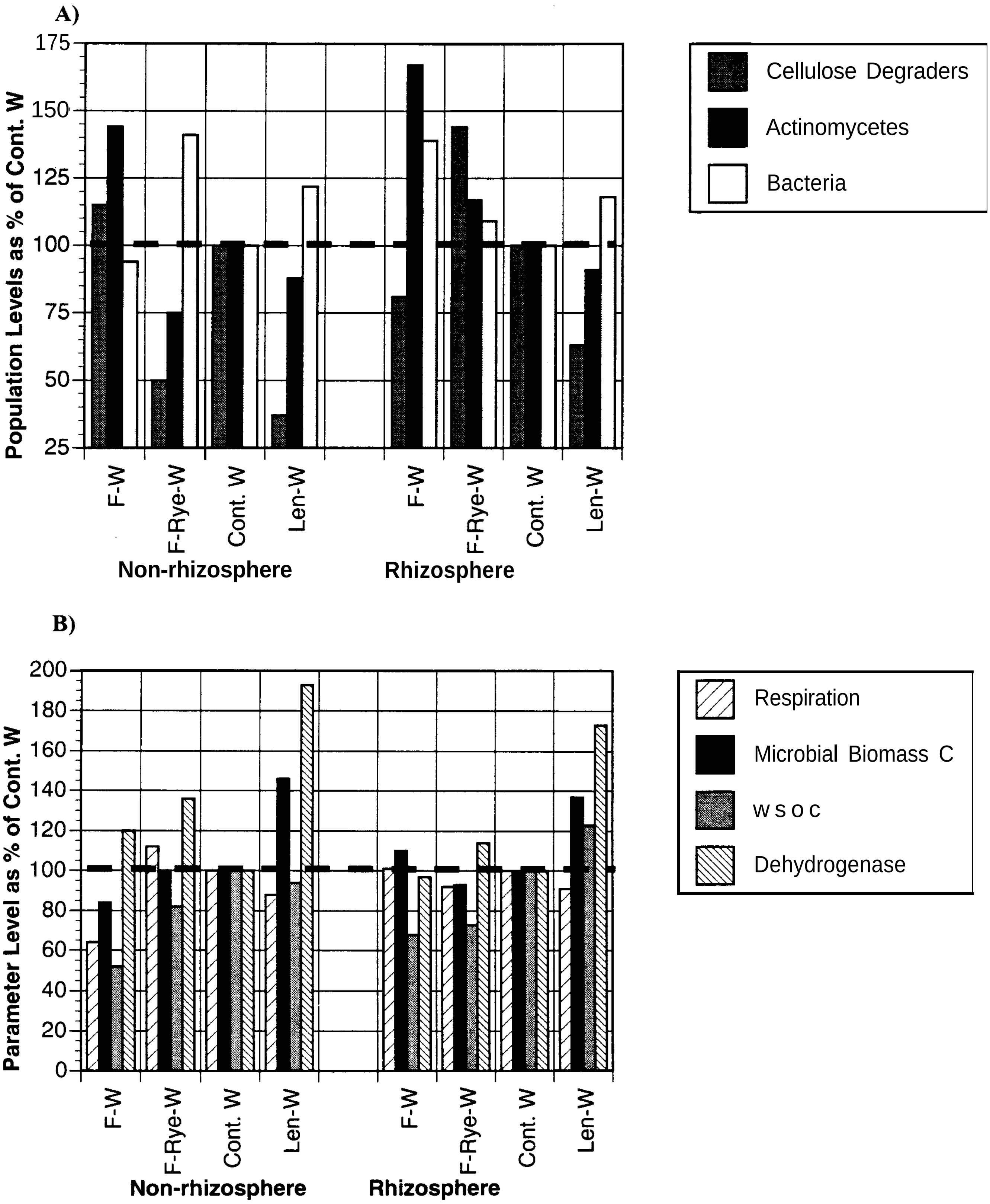
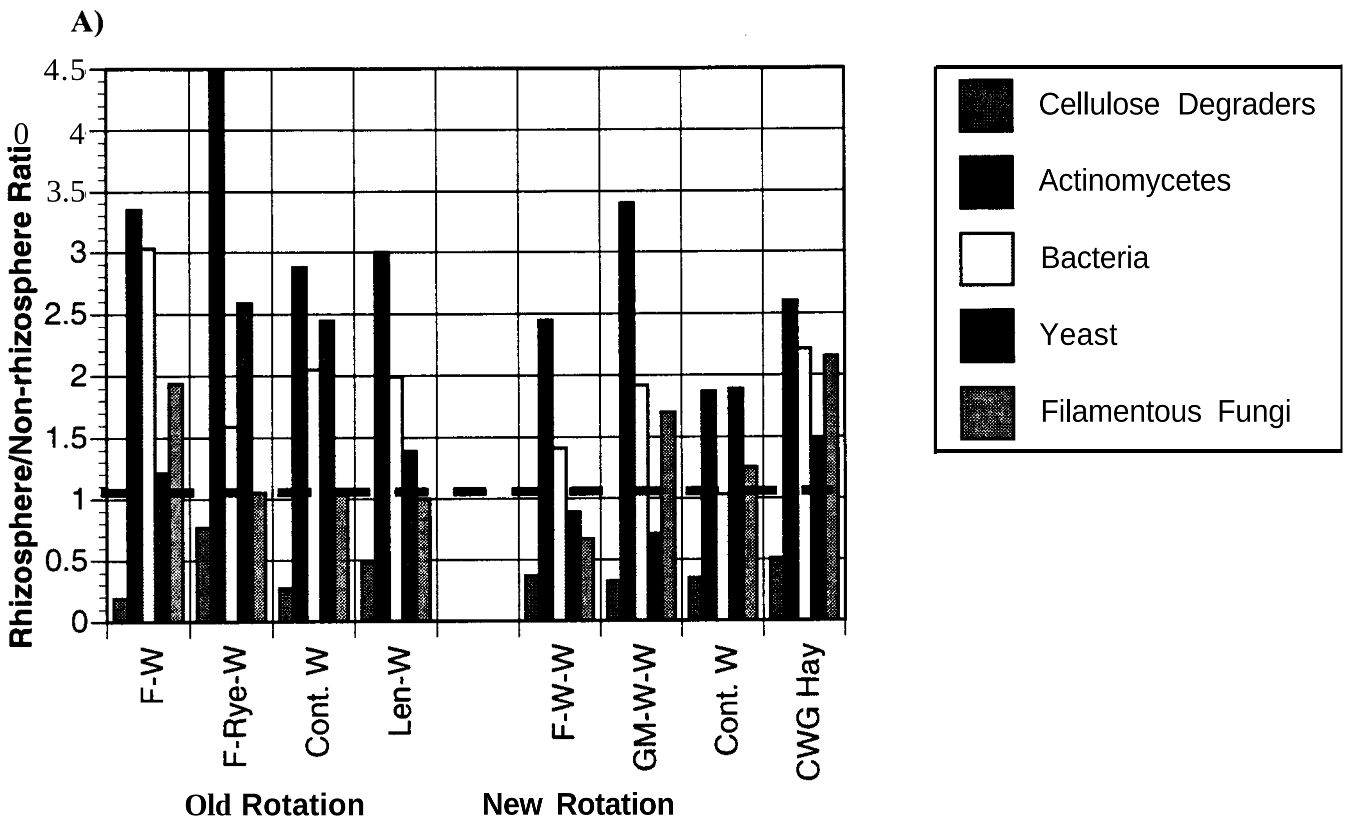


Figure 1. Rotation effect on A) populations of cellulose degraders (% of total procaryotic population), actinomycetes and bacteria, and B) microbial respiration, microbial biomass-C, water soluble organic carbon and dehydrogenase enzyme activity in Old Rotations relative to continuous wheat in 1997 at Swift Current, SK.



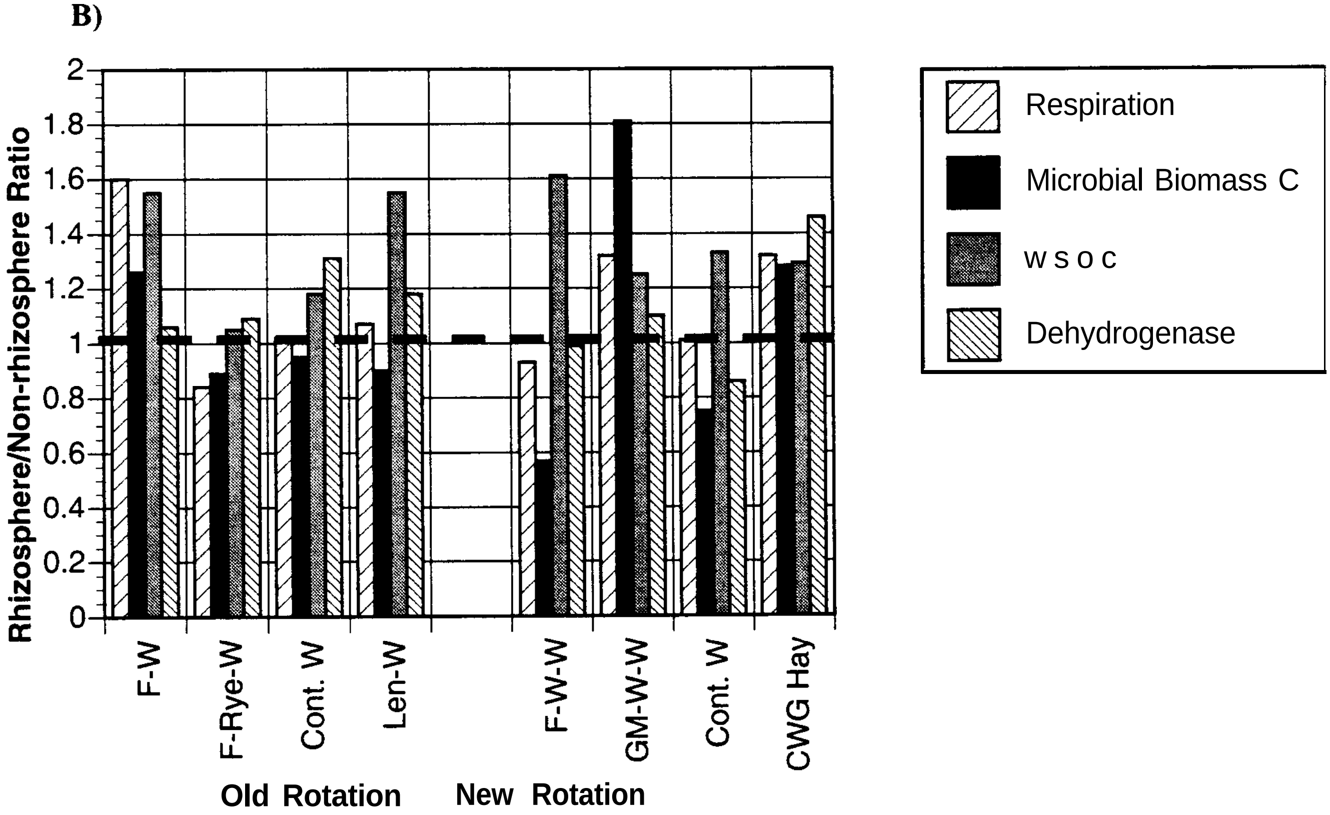


Figure 2. Root effect on A) populations of cellulose degraders (% of total procaryotic population), actinomycetes, bacteria, yeast and filamentous fungi, and B) microbial respiration, microbial biomass-C, water soluble organic carbon and dehydrogenase enzyme activity in 1997 at Swift Current, SK.

roots in the old rotations, but it was significantly boosted after GM lentil and in the crested wheatgrass of the new experiment.

As expected, levels of water-soluble organic carbon (WSOC) were generally increased within the wheat rhizosphere. These increases were greatest after grain lentil in the old and after chemical fallow in the new rotations (Figure 2B). Dehydrogenase enzyme activity was only boosted significantly in wheat rhizosphere after grain lentil and in the rhizosphere of the crested wheatgrass being grown for hay.

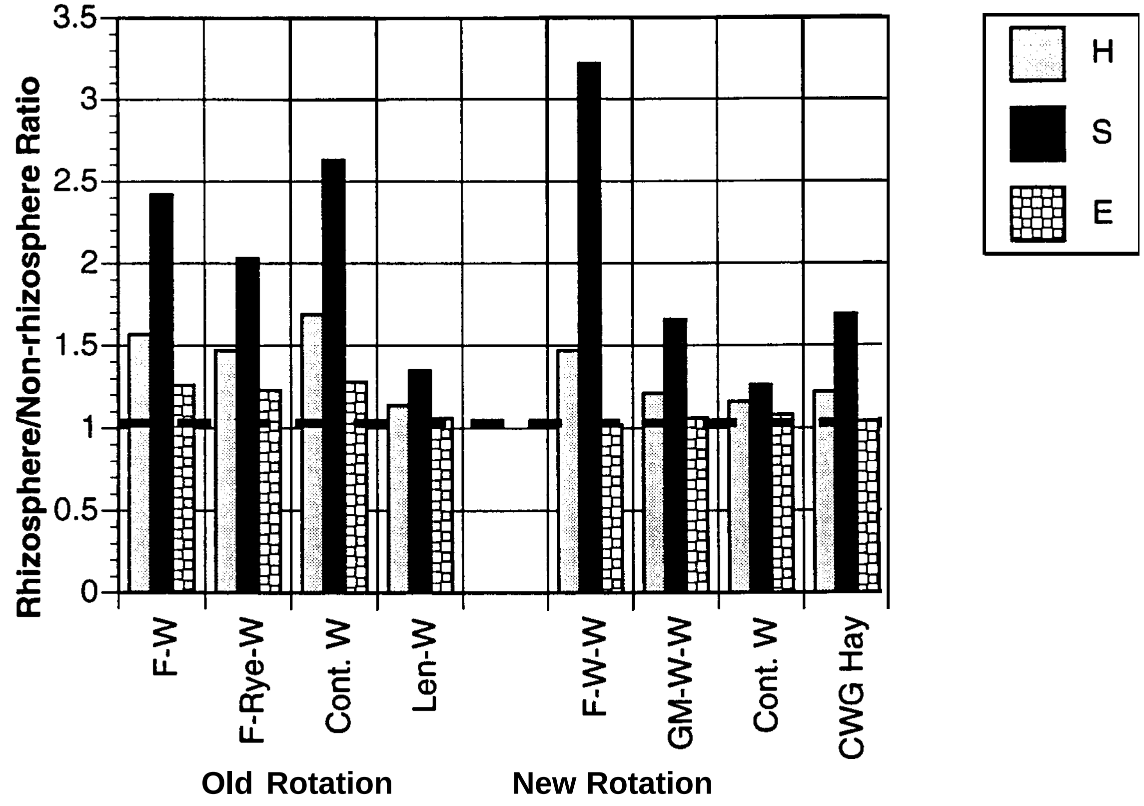


Figure 3. Root effect on microbial diversity as indicated by Shannon's diversity index (H), substrate richness (S) and substrate evenness (E) in 1997 at Swift Current, SK.

Beneficial rhizosphere effects on all three indices of soil microbial diversity were generally significant and more prominent in the old than in the new rotations (Figure 3). The grain lentil-wheat rotation is a notable exception, with its R/NR ratios being close to 1, because the high legume frequency in this 18 yr-old rotation has obviously already increased the microbial diversity of the bulk soil so much that the vicinity to live wheat roots could effect very little further ecological enrichment. The only significant root-induced change in biodiversity of the new rotations occurred for Shannon's index and for substrate richness in continuous wheat.

Conclusions

From the results of the initial sampling (i.e. 1997) in this collaborative, two-year monitoring and ecological assessment effort (1997 and 1998), we can draw the following preliminary conclusions:

1) Crop rotation effects on soil microbial and biochemical attributes were consistently stronger in the 'old' (30 yr) than in the 'new' (10 yr) rotation experiment, despite the reduced tillage in the new rotations.

2) In the old experiment, rotation effects were generally more prominent in the bulk soil than in the wheat rhizosphere.

3) Rotation effects in bulk and in rhizosphere soil on microbial populations, diversity and biomass were always most beneficial with wheat following grain lentil in the 18 yr-old lentil-wheat rotation.

4) Our findings confirm that legume-based rotations improve biological soil quality and sustainability of grain production systems - even in semiairid Brown soils.

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