# COMPARATIVE SOIL MICROBIAL STRUCTURAL-FUNCTIONAL RELATIONSHIPS OF INTRODUCED CRESTED WHEATGRASS AND NATIVE PRAIRIE COMMUNITIES[1]

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Abstract.--Paired crested wheatgrass (AGCR) and native rangeland communities located at Cheyenne, Wyoming were examined for comparative aboveground- belowground relationships during 1984 and 1985. Major differences in belowground microbial characteristics were evident. The AGCR system underwent N immobilization in the spring, a phenomenon not observed later in the year for this plant community or for the native rangeland. Structural and functional differences in nutrient cycling and microbial communities in the two plant communities may contribute to the continued maintenance of the introduced AGCR in this environment.

## INTRODUCTION

Large areas of abandoned croplands in the western U.S.A. were seeded with crested wheatgrass (Agropyron cristatum) from the U.S.S.R. during the 1930's (Rogler and Lorenz 1983). In Montana alone, more than a million hectares were seeded with this species (Woolfolk 1951). Although it cannot be stated with certainty that these communities are stable, some of these crested wheatgrass communities have remained as virtual monocultures for more than 50 years with little or no apparent successional trend (Vallentine 1971). We anticipate that there are some basic structural and functional differences among ecosystem components between the introduced stands and adjacent shortgrass steppe that make them distinctly different.

Information is available concerning the differences in the standing biomass and net primary production of these two plant communities in different geographical areas. However, in attempting to integrate and explain the different mechanisms utilized within these two strikingly different plant communities, major emphasis has been placed on temperature and water utilization responses. Essentially no information is currently available where differences in plant responses have been analyzed in terms of nitrogen dynamics and belowground processes.

Studies by Brown and Trlica (1977), Detling (1979), Kemp and Williams (1980), Caldwell et al. (1981), and Monson et al. (1983) concerning photosynthesis and carbon allocation, and of Sala (1982) directed towards evaluation of plant-water relationships, have shown major differences in carbon and nutrient allocation and for water utilization for crested wheatgrass and two major components of the shortgrass steppe, blue grama (Bouteloua gracilis) and western wheatgrass (Agropyron smithii). A substantial amount of carbon (70 to 80%) is allocated to the roots by dominant native species, while crested wheatgrass allocates more carbon to the aboveground photosynthetic tissue (Power 1980). Native species have been shown to have a high capacity to use water, but water use efficiency over the entire growing season (measured in terms of aboveground production) has been shown to be higher in crested wheatgrass.

The importance of the microflora in controlling soil fertility, soil organic matter dynamics, and nutrient availability has recently

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been stressed by O'Neill and Reichle (1980), and McGill and Cole (1981). Data presented by Woodmansee et al. (1978) and Clark and Rosswall (1981) emphasize the important role of the soil microflora in mineralization-immobilization processes upon which plants are dependent.

In relation to these concerns, the present study was carried out to provide the following information: (1) to determine the biomass, carbon, and nitrogen distribution of the primary producers (above- and belowground) and soil microflora throughout the growing season in both ecosystems; (2) to evaluate contributions of the microflora to carbon mineralization, and to nitrogen mineralization and immobilization processes.

This information was considered to be essential for better understanding the unique characteristics of AGCR communities which allow their maintenance over extended periods in the semi-arid steppe.

## MATERIALS AND METHODS

### Site Description

The field studies were conducted at the High Plains Grassland Research Station (HPGRS-USDA/ARS), located 7 km west of Cheyenne, Wyoming.

The topography of the area is nearly level to undulating and elevation at the HPGRS headquarters is about 1900 m. The growing season averages 120 days, with the average dates for the first and last freeze being May 21 and September 21, respectively. The average annual temperature is 9° C with extremes ranging from 42° C to -36° C. Precipitation averages 365 mm with recorded extremes of 159 and 544 mm. Approximately 78% of the precipitation falls between April 1 and September 30.

The soil of the experimental areas is an Ascalon fine, loamy, mixed mesic Aridic Arguistol (Young and Singleton 1977). These soils are on nearly level to gently sloping fans and terraces of granitic origin. The soil holds about 13 cm of water available to plants in the surface 120 cm.

The native vegetation of the area is characteristic of the shortgrass plains. Blue grama is the dominant warm season species. Western wheatgrass, needle-and-thread (Stipa comata), junegrass (Koleria cristata) and Sandberg bluegrass (Poa secunda) are the principal cool season grasses. Sedges (Carex spp.), annual grasses and annual and perennial forbes make up a minor part of the native vegetation.

The shortgrass prairie research site has never been plowed or tilled. The crested wheatgrass site was plowed and used for research plots for many years, then was seeded to crested wheatgrass in the late 1940's, and has not been tilled since then. Both sites were grazed at a moderate level in the past, but have been fenced to exclude domestic livestock.

### Field Studies

The total size of each research area is about 0.3 ha, which was fenced to exclude livestock grazing. Rectangular (1.5x32 m) plots (with walkways among plots) served as the basic experimental unit for the field experiments. This configuration was used to minimize trampling effects during sampling and allowed use of a tractor-mounted soil probe. Four blocks (replications) of these plots were established in both the native shortgrass and nearby crested wheatgrass ecosystems during the late fall of 1984.

Soils were sampled to at least 1 m by depth increments to provide a more precise evaluation of belowground responses. Standard analyses performed on soil samples included pH, organic matter, and total N.

### Plant Community Measurements

The method described by Sala et al. (1981) was used to estimate NPP. Three harvests were made during 1985 beginning on April 15 and ending on October 15.

Soil cores (5.7 cm) in each quadrat harvested for net aboveground production were obtained with a hydraulic, tractor-mounted corer. One core was taken within each 0.5 x 1 m quadrat on two sampling dates; one at the beginning of the growing season and the second during peak production. Each core was divided into four sections: 0-5, 5-10, 10-30, and 30-60 cm during each sampling time. Additional cores from the same quadrats were taken for microfloral analyses.

Each core section was sieved to remove soil from roots for further analyses described later. Root samples were washed to prevent dessication and decomposition (Bartos and Sims 1974). A hydropneumatic elutriation system was used to separate roots from remaining soil materials.

Roots were hand-sorted to separate live and dead root material, based on root color and friability. The living and dead roots were oven-dried at 60° C, weighed and washed.

Root growth in both the crested wheatgrass and in the native shortgrass ecosystems were monitored with the improved root periscope developed by Richards (1983). The glass observational tubes were used in both control and perturbed plots in both ecosystems to monitor root growth and depth of penetration. Sampling was conducted monthly throughout the growing season. Calculation of total root length was based on a modification of Newman's (1966) formula, which was used to convert root length to mass.

Plants parts were fractioned into leaves, stems, crowns, litter, and roots (living and dead). TNC, N, and lignin concentrations in these plant fractions were determined.

### Belowground Microbial Measurements

Microflora structural and functional evaluations included the following: fungal hyphal lengths (Ingham and Klein)1982, microscopic estimates of soil bacteria (Paul and Johnson 1977), and activity (Macdonald 1980), mycorrhizal infection (Phillips and Hayman 1970), aerobic heterotrophs and physiological diversity (Klein et al. 1986, Metzger et al. 1986), nitrification potential (Belser and Mays 1980), radioactive glucose mineralization (Harrison et al. 1971, Nakas and Klein 1980), nitrogen mineralization-immobilization processes (Keeney and Nelson 1982), and nitrogen fixation potential (Klein et al. 1985).

## RESULTS

The comparison of the plant communities at the two sites indicated that there were major differences in the two sytems, as noted in Table 1.

Aboveground net primary production (ANPP) was significantly greater in the crested wheatgrass system compared to the native shortgrass system (Table 1). Belowground net primary production (BNPP) and total net primary production (TNPP), however, were not different (Table 1). Although BNPP was not different between the two systems, the native shortgrass ecosystem had significant greater live root dry matter early in the growing season (Table 1).

The crested wheatgrass ecosystem had a high accumulation of aboveground dead material in May, which was followed by a significant decline in June and an increase in July. This is compared with lower accumulations of aboveground dead material in the native shortgrass ecosystem and minimal seasonal variation. The lignin to nitrogen (N) ratio of the aboveground litter and total N immobilized in dead material also were

Table 1.--Plant community characteristics for crested wheatgrass and native shortgrass communities, 1985 - Cheyenne, Wyoming[1].

| Variable | Crested | | Native | |
|---|---|---|---|---|
| Primary producers | | | | |
| ANPP (kg/ha) | 1075 | a | 712 | b |
| BNPP (kg/ha) | 8542 | a | 6777 | a |
| TNPP (kg/ha) | 9617 | a | 7689 | a |
| Aboveground LDM[2] (kg/ha) | 832 | a | 575 | b |
| Aboveground DDM[3] (kg/ha) | | | | |
| May | 1585 | a | 809 | b |
| June | 940 | a | 1012 | a |
| July | 1221 | a | 899 | b |
| Belowground LDM (kg/ha) | | | | |
| May | 4283 | a | 7898 | b |
| June | 4826 | a | 6654 | a |
| July | 8682 | a | 9231 | a |
| Belowground DDM (kg/ha) | | | | |
| May | 3428 | a | 1734 | a |
| June | 4577 | a | 3623 | a |
| July | 2326 | a | 1560 | a |
| Litter (kg/ha) | 985 | a | 378 | b |
| Standing dead (kg/ha) | 263 | a | 529 | a |
| Total N immobilized in dead material in the fall (g N/m2) | 5.1 | a | 2.4 | a |
| Lignin/N ratio for aboveground litter | 10.6 | a | 7.0 | b |

[1]Different letters in the columns indicate a statistical difference at P = <0.05.
[2]LDM = Live dry matter
[3]DDM = Dead dry matter

significantly higher in the crested wheatgrass system, as compared with the native shortgrass ecosystem (Table 1).

The microbial populations for the samplings completed in the 1985 season for the two different plant communities are shown in Table 2.

Similar levels of culturable bacteria were found in both systems, but higher microscopic fungal hyphal lengths and higher percentages of active bacteria were evident in the crested wheatgrass system. Mycorrhizal infection showed significant seasonal dynamics, with the crested

Table 2.--Microbial populations for crested wheatgrass and native shortgrass communites, 1985 - Cheyenne, Wyoming[1].

| Variable | Crested | Native |
|---|---|---|
| Rhizosphere hyphae (m $g^{-1}$) | 28.3 a | 22.5 b |
| Non-rhizosphere hyphae (m $g^{-1}$) | 8.5 a | 6.1 b |
| % mycorrhizal infection[2] | | |
| June | 14.8 a | 9 b |
| July | 8.8 a | 16.3 b |
| Bacteria (log bact.)[3] | 9.2 a | 9.3 a |
| Bacteria % active | 14.4 a | 12.7 a |
| Bacteria (log bact.)[4] | 8.1 a | 8.1 a |
| Physiological diversity (E(S) 90 isolates S = 0.80) | | |
| Rhizosphere | 19 a | 12 b |
| Free soil | 15 a | 14 a |

[1]Different letters in the columns indicate a statistical difference at $P = <0.05$.
[2]Intersect method
[3]Microscopic procedure, rhizosphere
[4]Microscopic procedure, non-rhizosphere

Table 3.--Nutrient pools and nutrient cycling for crested wheatgrass and native shortgrass communities, 1985 - Cheyenne, Wyoming[1].

| Variables | Crested | Native |
|---|---|---|
| Organic matter % | 0.59 | 0.85 |
| Acetylene reduction (nmol $C_2H_4$ $g^{-1}$ $hr^{-1}$) | 8.2 a | 14.9 b |
| Denitrification ($\mu g$ $N_2O$-N $g^{-1}$ $hr^{-1}$) | 126 a | 115 b |
| Nitrification | | |
| $NH_4$ oxidation ($\mu g$ N g soil $hr^{-1}$) | 0.12 a | 0.14 a |
| $NO_2$ oxidation ($\mu g$ N g soil $hr^{-1}$) | | |
| June | -0.01 a | 0.11 b |
| July | 0.07 a | 0.09 a |
| Glucose mineralization $^{14}C$ (turnover time, hr) | 6.1 a | 3.1 b |
| Phosphatase activity ($\mu g$ PNP $g^{-1}h^{-1}$) | 223 a | 1013 b |

[1]Different letters in the columns indicate a statistical difference at $P = <0.05$.

wheatgrass system having higher values than the native shortgrass system in June, while the reverse was true in July. Analyses of bacterial physiological diversity completed during the spring and fall in both the free soil and the rhizosphere soil provided additional information on differences between the two plant communities. While microbial diversity in the free soil was similar in both systems, microbial diversity in the rhizosphere was significantly different, when the crested wheatgrass system was compared with the native steppe community.

Initial data on microflora-related nutrient pools and activities indicated that the native shortgrass community had a higher potential for nutrient cycling than the crested wheatgrass system (Table 3). Significant differences were observed in soil organic matter, radioactive glucose mineralization, N fixation potential, potential nitrification, and phosphatase activities, with the native shortgrass system having higher values in all cases. Another very important result was the tendency toward N immobilization in the orested wheatgrass system early in the growing season, based on nitrification measurements, which was not evident in the native system.

## DISCUSSION

Our hypothesis is that the crested wheatgrass system will be nitrogen-limited because of accretion of more nitrogen in the aboveground plant components, whereas the belowground component will play a greater role in nitrogen dynamics in the native shortgrass system.

The measurements of plant community structual components between the two ecosystems indicated differences in nutrient dynamics which might influence the microbial communities. The crested wheatgrass system had higher amounts of N in standing dead materials in the fall, and in addition, these materials also had a higher lignin/N ratio. This plant community appears to retain N in more recalcitrant plant materials instead of in the soil organic matter component of the ecosystem.

The microbial population estimates indicate that only in terms of fungal hyphal lengths was there a major difference in the saprophytic microbial populations. The mycorrhizal responses showed a seasonal effect, which could be related to water and/or phosphorous availability.

The measurements of belowground nutrient pools and cycling processes indicated an all-over increased potential for nutrient cycling in the

native shortgrass system, in comparison with the introduced crested wheatgrass. This was especially evident in terms of acetylene reduction, glucose mineralization (based on use of a radioactive tracer technique), and on nitrification potential. Phosphatase, which is a less specific enzyme, also showed markedly higher values in the native system.

The longer-term maintenance of crested wheatgrass plant communities in the high plains region of the USA is of importance in terms of improving our understanding of functional characteristics of grasslands, and for better predicting the effects of plant community selection and development on management of the rangeland resource. Based on our results and the prior literature, it would appear that differences in the functional characteristics of these markedly different ecosystems will only be adequately understood in terms of an integrated analysis of nitrogen-carbon-water dynamics as influenced by the belowground microbial community. This is especially true in the context of intermittent pulses of inputs into the ecosystem that vary in importance, as limiting factors change over the course of a growing season. Developing an overall understanding of the functional differences between these two important ecosystems, including microbial communities and processes, will be of value for better understanding the longer-term implications of use of introduced AGRC in reclamation management and plant community establishment.

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