Increasing Rhizosphere Fungi and Improving Soil Quality with Biologically Effective Grazing Management

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Abstract

This report compares the effects of grazing management strategies on livestock performance, herbage biomass, and rhizosphere fungal populations on Northern Plains native rangeland. Compared to traditional grazing management strategies, the biologically effective twice-over rotation grazing management strategy improves cow and calf weight performance, yields greater herbage biomass production, stimulates rhizosphere organism activity, and enhances activity levels of ectomycorrhizal fungi with the ability to aggregate and stabilize soil particles and improve soil quality.

Introduction

Biologically effective defoliation management places priorities on meeting grass plant biological requirements and enhancing beneficial ecological processes performed by soil microorganisms in grassland ecosystems. Grass plants, grazing mammals, and grassland ecosystem processes have evolved together. During the long period of coevolution, grass plants developed both internal and external biological processes as defoliation resistance mechanisms. A complex system of symbiotic organisms that has numerous trophic levels and is critical for ecosystem functions and for energy and nutrient flow through the ecosystem developed in conjunction with the evolution of plants. The relationships among the grass plants, the soil organisms in the rhizosphere, and the grazing mammals are not completely understood. The objective of this study was to help clarify these complex relationships by evaluating defoliation treatments for differences in 1) livestock performance, 2) herbage biomass production, and 3) rhizosphere microbial populations, including ectomycorrhizal fungi involved in aggregating and stabilizing soil.

Procedure

The study site is on the Dickinson Research Extension Center ranch, operated by North Dakota State University and located 20 miles north of Dickinson in southwestern North Dakota, U.S.A. (47°14'N.lat., 102°50'W.long.). Mean annual temperature is 42.2°F (5.7°C). Long-term annual precipitation is 16.57 inches (420.90 mm). The growing-season precipitation (April to October) is 14.04 inches (356.73 mm), 85.0% of the annual precipitation (Manske 2003a). The vegetation is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988) of the mixed grass prairie.

Commercial crossbred cattle were weighedon and off each treatment and on each rotation date. Live-weight performance of weight gain per day and weight gain per acre for cows and calves was used to evaluate each treatment. Aboveground herbage biomass was collected by the standard clipping method (Cook and Stubbendieck 1986) on both grazed and ungrazed quadrats from April to November. Differences between means of livestock weights and differences between means of herbage weight were analyzed by a standard paired-plot t-test (Mosteller and Rourke 1973). Field samples of soil with plants and roots were collected on the grazing management treatments. The enzyme-linked immunosorbent assay (ELISA) technique (Caesar-TonThat et al. 2001a) was used on the water-stable rhizosphere soil to detect specific basidiomycete fungi. Results were statistically analyzed using ANOVA models.

Grazing Management Treatments

The grazing treatments and a nongrazed control were organized as a paired-plot design. The nongrazed control, 4.5-month twice-over rotation treatment, and 6.0-month seasonlong treatment had two replications. The 4.5-month seasonlong treatment had three replications. The long-term nongrazed treatments had not been grazed, mowed, or burned for more than 30 years prior to the start of data collection. The 4.5-month twice-over rotation (4.5 TOR) management treatment began in early June. The livestock followed a rotation sequence through three native rangeland pastures for 135 days, until mid October. Each pasture was grazed for two periods, one period of 15 days between 1 June and 15 July (from the third-leaf stage to anthesis phenophase), followed by a second period of 30 days after 15 July and prior to mid October. The first pasture grazed in the sequence was the last pasture grazed the previous year. The 4.5-month seasonlong (4.5 SL) management treatment began in early June, with livestock grazing one native rangeland pasture.

The livestock remained on this pasture for 135 days, until mid October. The 6.0-month seasonlong (6.0 SL) management treatment began in mid May, with grazing on one native rangeland pasture. The livestock remained on this pasture for 183 days, until mid November.

Results

Livestock weight performance was greatest on the twice-over rotation treatment (Manske et al. 1988, Manske 1996a, 2001, 2003b). Cow and calf weight gain per acre was significantly greater on the twice-over rotation treatment than on the seasonlong treatments. Cow weight gain per day on the twice-over rotation treatment was 82% greater than that on the 4.5-month seasonlong and 417% greater than that on the 6.0-month seasonlong treatments. Cow weight gain per acre on the twice-over rotation treatment was 157% greater than that on the 4.5-month seasonlong and 937% greater than that on the 6.0-month seasonlong treatments. Calf weight gain per day on the twice-over rotation treatment was 6% greater than that on the 4.5-month seasonlong and 23% greater than that on the 6.0-month seasonlong treatments. Calf weight gain per acre on the twice-over rotation treatment was 49% greater than that on the 4.5-month seasonlong and 115% greater than that on the 6.0-month seasonlong treatments.

Herbage biomass production was greatest on the twice-over rotation treatment (Manske 1994, 2003c). An average of 15% more herbage remained standing after each grazing period on the twice-over rotation treatment than the amount that grew on the long-term nongrazed treatment. The amount of herbage remaining standing after grazing during July, August, and September was significantly greater on the twice-over rotation treatment than on the seasonlong treatment. The seasonlong treatment averaged 8% less herbage standing after grazing than the nongrazed treatment and 29% less than the rotation treatment. The amount of herbage remaining standing at the end of the grazing season was significantly greater on the twice-over rotation treatment than the amount of herbage remaining on the nongrazed and seasonlong treatments. The measurements of the amount of herbage standing after each grazing period do not include the amount of vegetation removed by livestock during the grazing period.

Grassland ecosystem productivity is variable and depends on the degree of success of the mutually beneficial relationships among large herbivores, grass plants, and rhizosphere organisms. The rhizosphere is the narrow zone of soil surrounding living roots of perennial grassland plants where the symbiotic soil organisms--bacteria, protozoa, nematodes, mites, small insects, and fungi (primarily vesicular-arbuscular mycorrhizae)--interact as a complex trophic web that is critical for energy and nutrient flow in grassland ecosystems. Rhizosphere microorganism activity is affected by levels of root exudation. As the amount of root exudate increases, so do the biomass and the activity of beneficial rhizosphere organisms. Increases in carbon allocation from the crown and aboveground portions of the plant to roots of grasses under some grazing treatments result in an increase of carbon exuded from the grass plant roots compared to the amount exuded from the roots of ungrazed grasses (Holland et al. 1996). The amount of root exudate is higher on the twice-over rotation treatment, and this greater influx of carbon influences the quantity of fungi in the rhizosphere. As a result of the increased activity of rhizosphere fungi, grass plant rhizospheres are more robust and soil aggregates adhere more securely to root surfaces of grasses on the twice-over rotation treatment than on traditional grazing management treatments in the Northern Plains.

An immunological assay (ELISA) was developed for the detection and quantification of specific basidiomycete fungi that have the ability to aggregate and stabilize soil particles by forming water-stable aggregates in soil (Caesar-TonThat et al. 2000, 2001a). Water-stable rhizosphere soil samples collected during the field seasons of 1999 and 2000 were analyzed by the ELISA techniques. Absorbance readings (Caesar-TonThat et al. 2001b) for the detection of antigens in the rhizosphere soil of grasses from 3 soil layers of twice-over rotation and 6.0-month seasonlong grazing treatments indicated that in sandy soil and in silty soil layer 2, the amount of these fungi in the rhizosphere of grasses was significantly greater on the twice-over rotation treatment than on the seasonlong treatment, but a significant difference was not detected in layers 1 and 3 of the silty soil samples. The rhizosphere fungi detected during this study are ectomycorrhizal basidiomycete fungi from the Homobasidiomycete class and the Russuloid clade; they stabilize soil by forming water-stable soil aggregates near the rhizosphere of grasses (CaesarTonThat et al. 2001b).

Discussion

The twice-over rotation grazing management strategy on native rangeland was developed for the Northern Plains and designed to improve vegetation and livestock performances compared to those of traditional grazing management treatments (Manske et al. 1988, Manske 1999, 2001, 2003b). The biologically effective twice-over rotation treatment coordinates defoliation periods with grass phenological growth stages in order to manipulate the defoliation resistance mechanisms developed by grass plants during the long period of coevolution with herbivores. Two mechanisms that can be manipulated by defoliation of grasses between the third-leaf stage and flowering phenophase stimulate both vegetative tillering from axillary buds and activity of symbiotic soil organisms in the rhizosphere (Manske 1999, 2000).

The increased livestock weight performance on the twice-over rotation system over that on the traditional grazing management treatments results from the greater herbage production on the biologically effective grazing management system (Manske et al. 1988, Manske 1996a, 2001, 2003b).

The higher plant biomass measured on the twice-over rotation treatment compared to that on seasonlong grazing treatments and the ungrazed control (Manske 1994, 2003c) may be attributed to the beneficial results of applying a defoliation treatment to grass plants that are between the third-leaf stage and the flowering stage. The timed grazing of the twice-over system allows plants to retain sufficient leaf surface to recover from defoliation. Grass plants subjected to continuous, severe defoliation on seasonlong treatments do not completely recover and cannot produce at their potential levels (Manske 1999, 2000). Long-term seasonlong grazing causes superficial root system development and reduced root biomass (Chaieb et al. 1996, McNaughton et al. 1983, Mawdsley and Bardgett 1997), resulting in reduced production of aboveground herbage biomass. Grazing plants that are between the third-leaf and the flowering stages not only improves grass plant health but also leads to herbage biomass increases through beneficial changes in grass plant growth. The photosynthetic rate of the regrowth leaves is higher than that of the same-age foliage on undefoliated plants (Briske and Richards 1995), and expanding leaves tend to grow longer on defoliated plants (Langer 1972). The timed defoliation of the twice-over rotation treatment also stimulates vegetative tillering from axillary buds.

The twice-over rotation treatment further enhances the growth of secondary tillers and of remaining foliage on defoliated tillers by increasing rhizosphere organism activity beneficial to grass plants. The stimulated organisms include rhizosphere fungi, which are primarily vesicular-arbuscular mycorrhizae (taxonomically in the class Phycomycetes and the family Endogonaceae) that form endomycorrhiza in which the vesicles, arbuscules, and hyphae of the fungus enter the cells and tissue of the host plant (Harley and Smith 1983). The symbiotic function of endomycorrhizal fungi in grassland plant rhizospheres is the nitrification of ammonia and the enhancement of plants' absorption of phosphorus, other mineral nutrients, and water (Moorman and Reeves 1979, Harley and Smith 1983, Allen and Allen 1990, Box and Hammond 1990, Marschner 1992, Manske 1996b).

The twice-over rotation system also strengthens grass plant growth and grassland ecosystem health by increasing activity of ectomycorrhizal fungi in the Homobasidiomycetes class and the Russuloid clade (Caesar-TonThat et al. 2001b). Rhizosphere fungi of this type form ectomycorrhizae; the hyphae do not enter tissue of the host plant but develop a sheath around the root (Harley and Smith 1983). Russuloid homobasidiomycete ectomycorrhizal fungi form water-stable aggregates in soil and stabilize soil particles around the rhizosphere by excreting large amounts of insoluble extracellular polysaccharides that have adhesive qualities. These substances can act as binding agents of soil particles, causing aggregation of soil around fungal structures (Caesar-TonThat 2002). Increases in soil aggregation and stabilization are an indication of soil quality improvement that causes increases in soil oxygenation, increases in water infiltration, and decreases in erodibility (Caesar-TonThat et al. 2001a).

The detection of these fungi is an important scientific discovery. Finding ectomycorrhizal basidiomycete fungi in the rhizosphere of grass plants in the mixed grass prairie is unusual. Ectomycorrhizal fungi are slow growing and are limited almost exclusively to associations with woody plants. Very few herbaceous species are known to form ectomycorrhiza on their roots (Harley and Smith 1983). The factors and conditions that enhance the development of these ectomycorrhizal fungi in the rhizosphere of grass plants managed with the twice-over rotation grazing system are not completely understood. The capacity of this grazing management practice to enhance the activity levels of rhizosphere fungi with the ability to aggregate and stabilize soil particles and thereby improve the quality of soil in grassland ecosystems is of considerable significance for the development of biologically effective grazing management treatments.

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Literature Cited

Allen, E.B., and M.F. Allen. 1990. The mediation of competition by mycorrhizae in successional and patchy environments. p. 307-389. *in* J.B. Grace and D. Tilman (eds.). Perspectives on plant competition. Academic Press Inc., San Diego, CA.

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Box, J.E., and L.C. Hammond. 1990. Rhizosphere dynamics. Westview Press, Boulder, CO.

Briske, D.D., and J.H. Richards. 1995. Plant response to defoliation: a physiological, morphological and demographic evaluation. p. 635-710. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Caesar-TonThat, T.C., and V. Cochran. 2000. Soil aggregate stabilization by a saprophytic lignin-decomposing basidiomycete fungus. I. Microbiological aspects. Biology and Fertility of Soils 32:374-380.

Caesar-TonThat, T.C., W. Shelver, R.G. Thorn, and V.L. Cochran. 2001a. Generation of antibodies for soil-aggregating basidiomycete detection to determine soil quality. Applied Soil Ecology 18:99-116.

Caesar-TonThat, T.C., D.H. Branson, J.D. Reeder, and L.L. Manske. 2001b. Soil-aggregating basidiomycetes in the rhizosphere of grasses under two grazing management systems. Poster. American Society of Agronomy Annual Meeting. Charlotte, NC.

Caesar-TonThat, T.C. 2002. Soil binding properties of mucilage produced by a basidiomycete fungus in a model system. Mycological Research 106:930-937.

Chaieb, M., B. Henchi, and M. Boukhris. 1996. Impact of clipping of root systems of three grasses species in Tunisia. Journal of Range Management 49:336-339.

Cook, C.W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Society for Range Management, Denver, CO. 317p.

Harley, J.L., and S.E. Smith. 1983. Mycorrhizal symbiosis. Academic Press, New York, NY.

Holland, J.N., W. Cheng, and D.A. Crossley, Jr. 1996. Herbivore-induced changes in plant carbon allocation: assessment of below-ground C fluxes using carbon-14. Oecologia 107:87-94.

Langer, R.H.M. 1972. How grasses grow. Edward Arnold Ltd., London, U.K.

Manske, L.L. 1994. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds.). Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program, Regina, Saskatchewan, Canada.

Manske, L.L. 1996a. Economic returns as affected by grazing strategies. p. 43-55. *in Z.* Abouguendia (ed.). Total ranch management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan, Canada.

Manske, L.L. 1996b. Adaptive tolerance mechanisms in grass plants. p. 97-99. *in Z.* Abouguendia (ed.). Total ranch management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan, Canada.

Manske, L.L. 1999. Can native prairie be sustained under livestock grazing? p. 99-108. *in* J. Thorpe, T.A. Steeves, and M. Gollop (eds.). Proceedings of the Fifth Prairie Conservation and Endangered Species Conference. Provincial Museum of Alberta. Natural History Occasional Paper No. 24. Edmonton, Alberta.

Manske, L.L. 2000. Management of prairie in the Northern Great Plains based on biological requirements of the plants. NDSU Dickinson Research Extension Center. Range Science Report DREC 00-1028. Dickinson, ND. 12p.

Manske, L.L. 2001. Biological effectiveness of grazing strategies. 2001 NDSU Beef Cattle Report. North Dakota State University. Fargo, ND. p. 37-42.

Manske, L.L. 2003a. Ombrothermic interpretation of range plant water deficiency from temperature and precipitation data collected at the Ranch Headquarters of the Dickinson Research Extension Center in western North Dakota, 1982-2002. NDSU Dickinson Research Extension Center. Range Research Report DREC 03-1019f. Dickinson, ND. 17p.

Manske, L.L. 2003b. Cow and calf performance as affected by grazing management. NDSU Dickinson Research Extension Center. Range Research Report DREC 03-1052. Dickinson, ND. 28p.

Manske, L.L. 2003c. Effects of grazing management treatments on rangeland vegetation. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 03-3027. Dickinson, ND. 6p.

Manske, L.L., M.E. Biondini, D.R. Kirby, J.L. Nelson, D.G. Landblom, and P.J. Sjursen. 1988. Cow and calf performance on seasonlong and twice-over rotation grazing treatments in western North Dakota. Proceedings of the North Dakota Cow-Calf Conference. Bismarck, ND. p. 39-43.

Marschner, H. 1992. Nutrient dynamics at the soil-root interface (Rhizosphere). p. 3-12. *in* D.J. Read, D.H. Lewis, A.H. Fitter, and I.J. Alexander (eds.). Mycorrhizas in ecosystems. C.A.B. International, Wallingford, U.K.

Mawdsley, J.L., and R.D. Bardgett. 1997. Continuous defoliation of perennial ryegrass (Lolium perenne) and white clover (Trifolium repens) and associated changes in the microbial population of an upland grassland soil. Biology and Fertility of Soils 24:52-58.

McNaughton, S.J., L.L. Wallace, and M.B. Coughenour. 1983. Plant adaptation in an ecosystem context: effects of defoliation, nitrogen, and water on growth of an African C4 sedge. Ecology 64:307-318.

Moorman, T., and F.B. Reeves. 1979. The role of endomycorrhizae in revegetation practices in the semi-arid west. II. A bioassay to determine the effect of land disturbance on endomycorrhizal populations. American Journal of Botany 66:14-18.

Mosteller, F., and R.E.K. Rourke. 1973. Sturdy Statistics. Addison-Wesley Publishing Co., MA. 395p.