GRASSLANDS AS A COMPARATIVE FOR FARMING PRACTICES' INFLUENCE ON CARBON/NITROGEN DYNAMICS

S.A. Clancy[1], M.E. Biondini[2] and J.C. Gardner[1]

Carrington Research Extension Center, North Dakota State University, P.O. Box 219, Carrington, ND[1], Department of Animal and Range Science, North Dakota State University, Box 5727, Hultz Hall, Fargo, ND 58105[2]

ABSTRACT

A remnant prairie was used for comparison of the soil as a natural resource among alternative and conventional farming systems. Beginning and ending biotic and abiotic characteristics were quantified directly. Carbon and N flow was calculated using CENTURY model. Carbon decay was not tied to the size of the soil organic matter pool (SOM), but to crop choice. Nitrogen decay was linked to the size of the SOM pool. Nitrogen fertilizer depressed the amount of N mineralized by soil biota. The alternative farming systems in North Dakota (no-till and green-manure fallow) more nearly mimic the ecosystem processes of the prairie by increasing biotic storage (perennial roots and soil biota), increasing abiotic storage (residues), and slowing the flow of active soil C which helped slow and stabilize SOM-C.

KEYWORDS

Carbon and nitrogen cycling, sustainable agriculture, residue effects, green manure effects

INTRODUCTION

Little data exists to compare the impact of emerging alternative farming practices to conventional agriculture. Two farm organizations, Manitoba-North Dakota Zero Till Association (ManNDZT) and Northern Plains Sustainable Agriculture Association (NPSAS), joined the NDSU experiment station to define the researchable questions and to develop a list of farmer participants. The characteristic most affected by agronomic management, they agreed, was the soil. Since most farms in North Dakota had been in cultivation for 100 years or more, remnant prairie ecosystems are used for comparison. Twelve sites were visited bi-weekly in 1990 and 1991 to measure the environmental impact as follows: physically on soil, chemically on soil nutrient use-efficiency, and biologically on above- and belowground flora and fauna. Carbon and nitrogen (C and N) flow charts were developed using the quantified beginning and ending biotic and abiotic data with the flow to the various pools calculated on the basis of Parton et al. (1987) CENTURY submodel and Hunt et al. (1987) calculations of C and N flow of detritus in the short grass prairie. A pictorial was developed to represent the status of each system patterned after the early work of Webster et al. (1975) on nutrient cycling and the stability of ecosystems.

METHODS

Carbon (C) in soil organic matter was assayed by direct measurements while the C content in all of the biological samples was estimated using a combination of direct methods and published estimates from various sources (Clancy, 1995). Above- and belowground plant material was first fractionated into labile C and resistant C. Labile C was divided into the components metabolic C and active C. The lignin component and decomposition rate were published estimates. These constants were used to calculate the portion of plant C that contributed to the active soil C and the resistant soil C. The active and resistant flow into the stable soil organic C (SOM-C) pool were calculated as well as the C flow from SOM-C pool (Parton et al., 1987)]. Plant biomass C was estimated by dividing biomass dry weight by 2.5 [atomic weights: CH_2O/C (Sauer 1976)]. Aboveground biomass was experimentally measured while root biomass was estimated using root to shoot ratios from literature. The labile C fraction of aboveground net primary production and belowground net primary production was estimated using Hunt's (1977) formula. Total soil organic C was calculated using high ignition heating and weight differentiation with regional adjustments (Schulte 1988, Danke, 1990a) to make the values comparable to SOM estimations using the Wakley Black method. The values were expressed in g C m^{-2} to a depth of 0.15 m. The annual flow of labile carbon to the active carbon and resistant carbon pools was estimated by using the metabolic, active, and resistant components of the labile fraction of dead above- and belowground plant biomass in conjunction with the respiration constants from the CENTURY model (Parton et al., 1987). The annual flow to resistant and active carbon pools attributed to the resistant component of dead plant biomass was calculated using constants from the CENTURY model (Parton et al, 1987). The bacteria bioassay estimated the population in terms of timed ammonium production. Values were transformed to mean values of g N m^{-2} per year (y^{-1}); Collembola and mites were direct counts and were adjusted for bulk density and converted to C using a C/N ratio suggested by Hunt et al. (1987). Nitrogen (N) in the soil was assayed by KCl extracted soil N as determined by colorimity while the N content of the biological samples was estimated using a combination of direct methods and published estimates. Carbon to nitrogen ratios were determined from measurement and published estimates. Two-way ANOVA was applied to determine significance of farm type and farm type versus location. A two-way repeated observation ANOVA was also used when measurements of time and depth were involved. The Tukey test was used to separate means when overall analysis was significant (Snedecor and Cochran, 1967). Principal component analysis (PCA) was used to determine the most significant component among treatments. A cluster of treatments was identified by PCA (Ludwig and Reynolds, 1988).

RESULTS AND DISCUSSION

A prairie system has high organic soil carbon which is the result of annual net production of residues resistant to decay. These residues have a higher C/N mineralization ratio. An agroecosystem farmed in a manner which would lead to long-term sustainability of the soil as a natural resource would mimic the prairie. The C/N mineralization ratios calculated from the flow charts derived from direct and calculations show variation from year to year depending on the crop and decomposer activity (Table 1). One particular no-till system (CN) showed consistently stable residues mimicking the ideal prairie. The dramatic change in tillage practices from four field operations to two was observed for the central conventional system attributing to the increased C quantified in this system. Prairie systems in this study show more mineralization than the ideal prairie because of the influence of animals. Nitrogen decay was linked to the size of the SOM pool. The mean active C/active N ratio for the high SOM-C pool was 4.5. The low SOM-C pool was 3.0, reflection the N produced from soil biota activities. Low C/N ratio of the SOM pool would imply less stable products which could potentially supply annual N requirements. The central and east prairie, central and east no-till, and east organic were characterized as having high SOM (Figure 1). Conventional and west organic were characterized as having a low SOM pool (Figure 2). Nitrogen fertilizer depressed the amount of N mineralized by soil biota. The mean mineralization for the 1990 growing season for the prairie was 8.92 gm^{-2} and for the agroecosystems which added fertilizer amendments was 5.03 gm^{-2}. Of the soil biota quantified, bacteria were the major contributors of N mineralization. Higher numbers were observed on the prairie sites and a high turnover rate was calculated, both of which contributed to the high mineralization rate. A summary of the alternative characteristic of nutrient cycles for the three prairie sites and nine farms can be described in terms of abiotic nutrient reserves, stores in living plants and fauna, and activity of the cycling pools (Figure 2). Prairie systems observed in this study have the most SOM-C (abiotic storage), the highest proportion of intact biotic storage in roots and microbial and soil fauna, and the slowest cycling. The extremes in temperature and moisture in the western semi-arid region appear to cause rapid cycling and a flush of N when rain occurs. The east and central green manure systems had higher intact biotic storage in overwintering legumes than the comparable agroecosystems, but these systems had lower abiotic storage and more rapid cycling because of the tillage. The east and central no-till sites had abundant abiotic storage in residues because of reduced tillage and slow cycling due to lignin content of substrates. The biotic components of these systems were suppressed by fertilizer amendments. The east and central conventional and the west green-fallow had low abiotic storage (SOM-C) and rapid cycling due to tillage crop choice and fertilizer amendments. The west conventional has high abiotic storage in manure amendments. The mathematical relationships derived from the CENTURY submodel (Parton et al,. 1987) and Hunt et al.'s (1987) work which seemed helpful in describing C and N flow for the prairie and agroecosystem comparisons were as follows: a) the comparisons of microbial and soil fauna inputs, resistant carbon inputs and active soil carbon inputs to the SOM-C pool; b) N flow from the SOM-C pool and the active pool / SOM-C ratio were evidence of accelerated decay due to management treatments; and c) the C/N ratio of annual net primary production, residues, active soil pool, and respiration/mineralization.

REFERENCES

Clancy, S.A. 1995. Farming practices' influence on soil biology and carbon/nitrogen dynamics. Thesis, Animal and Range Science Dept., NDSU, Fargo, ND.

Danke, W.C. 1990. Conversion weight loss on ignition and O.M. by the Walkley-Black procedure for North Dakota Soils. North Dakota State University, Soils Dept., Fargo.

Hunt, H.W. 1977. A simulation model for decomposition in grasslands. Ecology **58**: 469-484.

Hunt, H.W., D.C. Coleman, E.R. Ingham, R.E. Ingham, E.T. Elliot, J.C. Moore, S.L. Rose, C.P.P. Reid, and **C.R. Morley.** 1987. The detrital food web in a shortgrass prairie. Biol. Fertil. Soils **3**: 57-62.

Ludwig, J.A. and **J.F. Reynolds.** 1988. Principal components analysis. *In* Statistical ecology: a primer on methods and computing. John Wiley & Sons, New York p 223-241.

Parton, W.J., D.S. Schimel, C.V. Cole, and **D.S. Ojima.** 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci. Soc. Am. J. **51**: 1173-1179.

Sauer, R.H. 1976. Producer phenology submodels. *In* ELM: version 2.0. Range Sci. Dep. Ser. # 20. (ed.) G.W. Cole. Colorado State University, Fort Collins p 62 - 136.

Schulte, E.E. 1988. Recommended soil organic matter tests. *In* Recommended chemical soil test procedures. North Central Regional Publ. 221. North Dakota Agric. Exp. Sta. Bull. No. 499. Fargo.

Snedecor, G.W. and **W.G. Cochran.** 1967. *In* Statistical Methods, 6th edition. Iowa State U. Press, Ames.

Webster, J.R., J.B. Waide, and **B.C. Patten.** 1975. Nutrient recycling and the stability of ecosystems. *In* Mineral cycling in southeastern ecosystems. Eds. F.G. Howell, J.B. Gentry, and M.H. Smith. ERDA Symposium Series CONF-740513. National Technical Information Service, Springfield, VA p 1-27.

Table 1
Ranking of C/N Ratios for C Respiration to Net N Mineralization for 1990 and 1991 with the Corresponding Crop Rotation

Mineralization			Mineralization		
Site 1990*	C/N	Crop rotation	Site 1991*	C/N	Crop rotation
EP	13.4	Tallgrass prairie	WO	26.9	2nd year oats
CN	12.9	Wheat	CO	18.8	Soybeans
WC	11.4	Manure-fallow	CN	15.8	Sunflowers
CC	10.1	Wheat	CC	15.4	Sunflowers
CP	9.9	Mixed grass prairie	WN	14.7	Brown-fallow
EC	9.4	Navy beans	CP	13.9	Mixed grass prairie
EN	9.0	Corn	EN	12.0	Soybeans
WN	9.0	Wheat	WP	11.5	Mixed grass prairie
EO	8.3	Alfalfa	EC	10.8	Barley
WO	7.9	Oats on green-fallow	EP	10.8	Tallgrass prairie
WP	6.6	Mixed grass prairie	WC	10.6	Wheat
CO	3.8	Green-fallow	EO	8.2	Green-fallow

These data identify ANPP residue quality and mineralization effects indicative of decomposer activity.

*Sites as follows: WP = west prairie, WC = west conventional, WN = west no-till, WO = west organic, CP = central prairie, CC = central conventional, CN = central no-till, CO = central organic, EP = east prairie, EC = east conventional, EN = east no-till, EO = east organic.

Figure 2
The alternative characteristics of nutrient cycling for nine farms and three prairie sites (after Webster et al,.1975).

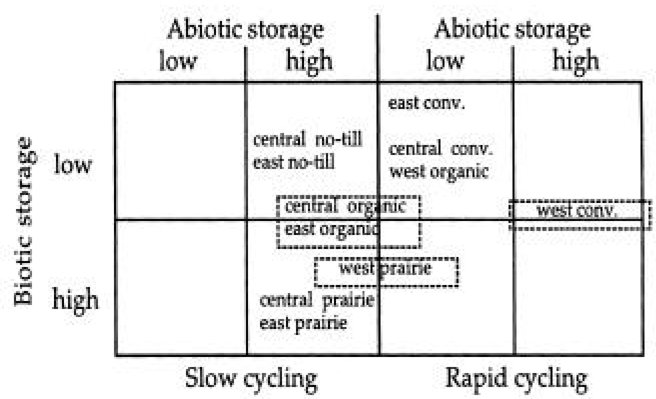

Figure 1
Annual soil organic matter carbon pool (SOM-C) showing statistical comparisons (P<0.01) across observed sites. (This was a multivariate case with each observation characterized by two data points, 1990 and 1991 values).
WP = west prairie, WC = west conventional, WN = west no-till, WO = west organic, CP = central prairie, CC = central conventional, CN = central no-till, CO = central organic, EP = east prairie, EC = east conventional, EN = east no-till, EO = east organic.