ANALYSIS OF HISTORICAL CHANGES IN SOIL FERTILITY AND ORGANIC MATTER LEVELS OF THE NORTH AMERICAN GREAT PLAINS*

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INTRODUCTION

Major changes in soil organic matter and nutrient supplying capacity have occurred as a result of conversion of Great Plains grasslands to croplands (Haas et al. 1957, Tiessen et al. 1982). Similar changes have been recorded for Australian grasslands (Russell and Williams 1982). Initial levels of grassland productivity and soil organic matter levels varied widely across the region reflecting a 20°C difference in mean annual temperature from north to south and a range of 300 mm of annual precipitation from east to west. Soil texture also had large effects on productivity and organic matter accumulation.

There have been major changes in cropping practices over the approximately 80 years of cultivation with improved varieties and soil management practices so that the semiarid Great Plains is now more productive in terms of yields of grain and other adapted crops than it was when sod was first broken. We conducted an analysis of these historical changes as a basis for prediction of future changes with existing or newly developed management practices and as a consequence of possible climatic changes in the region.

EARLY DRYLAND RESEARCH

Haas et al. (1957) summarized N and C changes at seventeen research stations as influenced by cropping over a period of approximately 40 years. The losses of soil N under small grains were considerably less than under row crops. However, losses of N under small grains were greater for alternate cropping and fallow than under continuous cropping. The mean loss of C in the surface 20 cm of soil at 11 of the stations with the best documentation was 33% under wheat fallow compared to 29%

under continuous wheat (Table 1). During much of this period crops were harvested with a binder and much of the crop biomass was removed leaving little crop residue on the land. Later in this period combine harvest was used which left straw and chaff in the field and reduced losses of N. The significant influence of tillage and wheat residue management was documented by Black and Siddoway (1979). The introduction of stubble mulch practices in the late 40's and early 50's reduced soil disturbance and maintained crop residues resulting in significant reductions in losses of C and N as documented by Bauer and Black (1981). These investigators also documented significant effects of soil texture on patterns of loss of organic matter. In more recent studies, Lamb et al. (1985) have shown reduced losses of soil N under wheat fallow with no tillage compared to stubble mulch or bare fallow. Interpreting historical changes in soil fertility and productivity of the region and projecting the impact of new management practices require a systematic evaluation of the effects of climate and soil properties on changes in levels of organic matter.

REGIONAL ORGANIC MATTER LEVELS - A DATA BASE ANALYSIS

A soils data base was developed and analyzed to quantify relationships among temperature, precipitation, soil texture and organic matter in rangeland and cultivated soils of the region. These relationships then were used to develop predictions of C and N losses as a consequence of cultivation. Data were obtained from SCS National Soil Survey Laboratory pedon data base, SCS soil series investigation reports, and our own field studies. We selected 383 pedons to represent cultivated soils and 562 pedons to represent rangeland soils of the region (Burke et al. in press). Organic C and N concentrations, as well as, sand, silt, and clay were calculated from the raw data. Carbon and N weights to 20 cm were calculated by horizon and summed to a 20-cm depth. Climatic data corresponding to pedon location were linked with each pedon.

The best predictors of organic C as established by best-possible- subset regression analysis were mean annual temperature (MAT) and its square, annual precipitation (APPT) and its square, APPT times silt, and APPT times clay (Table 2). Neither silt nor clay by itself was a significant predictor. These regressions accounted for 51% of the variation in rangeland soils and 54% of the variation in cultivated soils. Nitrogen contents were highly correlated with C contents in both data sets. The equations predict a slight narrowing of C/N ratios from 10 in rangelands to 9 in cultivated soils.

SIMULATION MODELING OF ORGANIC MATTER CHANGES

A mechanistic model (CENTURY) based on rates of organic matter formation and decomposition was developed for analysis of factors controlling soil organic matter levels in Great Plains grasslands (Parton et al. 1987, 1988a, 1988b). The model was also applied to a study of land-use effects on soil organic matter dynamics (Cole et al. in press)

Predicted values of soil organic C using the regression equations in Table 2 were used to validate the performance of CENTURY in simulating regional patterns of soil C for soil of different texture in the Great Plains. The model gave a good representation of soil C levels at 56 sites over a range of APPT from 30 to 120 cm and MAT from 4 to 23°C with fine, medium, and coarse soil textures (R^2=0.76).

Application of CENTURY to analysis of cropping effects was validated by simulation of C and N losses at 11 experiment stations and comparing those values with historical data for the first 40 years of cropping (Cole et al. in press). Mean values of losses under wheat fallow and continuous wheat for data and model output are in good agreement (Table 1). Regional analysis of soil C levels in virgin sod and croplands was conducted by initially simulating virgin sod at 55 sites in seven east-west transects of the Great Plains. Initial soil C ranged from 2.3 to 7.8 kg/m^2 in the fine-textured soils and 1.3 to 4.2 kg/m^2 in the sandy soils. Soil C was greatest in the northeast and declined toward the warm and dryer region in the southwest. Soil N had a similar pattern, with C/N ratios close to 11.

Simulated C loss during the first 40-year period (Fig. 1) was greatest in the mesic part of the region reflecting greater initial amounts of soil organic matter in this area and the influence of climatic controls on decomposition rates. The mean loss of C was 2.1 and 1.3 kg C/m^2 for fine- and coarse-textured soils, respectively. Soil C losses under continuous wheat were slightly less than under wheat fallow (82% and 89% of wheat fallow losses for fine and coarse textured soils, respectively) but the geographic pattern was similar.

During the next 40 years, management practices simulated were modified to include higher yielding varieties in common use, application of N and P fertilizers, no straw removal, and stubble mulching. Soil C and N loss was arrested and soil C levels recovered. Greater soil C recovery occurred in the sandy soils (an average of 0.37 kg C/m^2) compared to the fine-textured soils (0.25 kg C/m^2).

The combined use of statistical and mechanistic models was an effective means of quantifying major controls on productivity of the region.

The results indicate that with adoption of management practices incorporating high yielding varieties, minimum soil disturbance, replacement of nutrients removed in harvest and residue conservation, the region can sustain higher levels of productivity over the long-term.

Table 1. The effects of 40 years of cropping in wheat fallow or continuous wheat on percentage weight loss of organic C and total N at 11 experiment stations* in the U.S. Great Plains region; comparison of historical data with model results.** Data recalculated from Haas et al. 1957 on basis of weight of element, g/m^2, in the surface 20 cm.

		Organic C		Total N	
		Data (%)	Model (%)	Data (%)	Model (%)
Wheat fallow	$\bar{x}$	33	33	30	27
	sd	(11.7)	(5.0)	(7.5)	(4.8)
Continuous wheat	$\bar{x}$	29	26	21	21
	sd	(11.7)	(5.7)	(6.7)	(5.1)

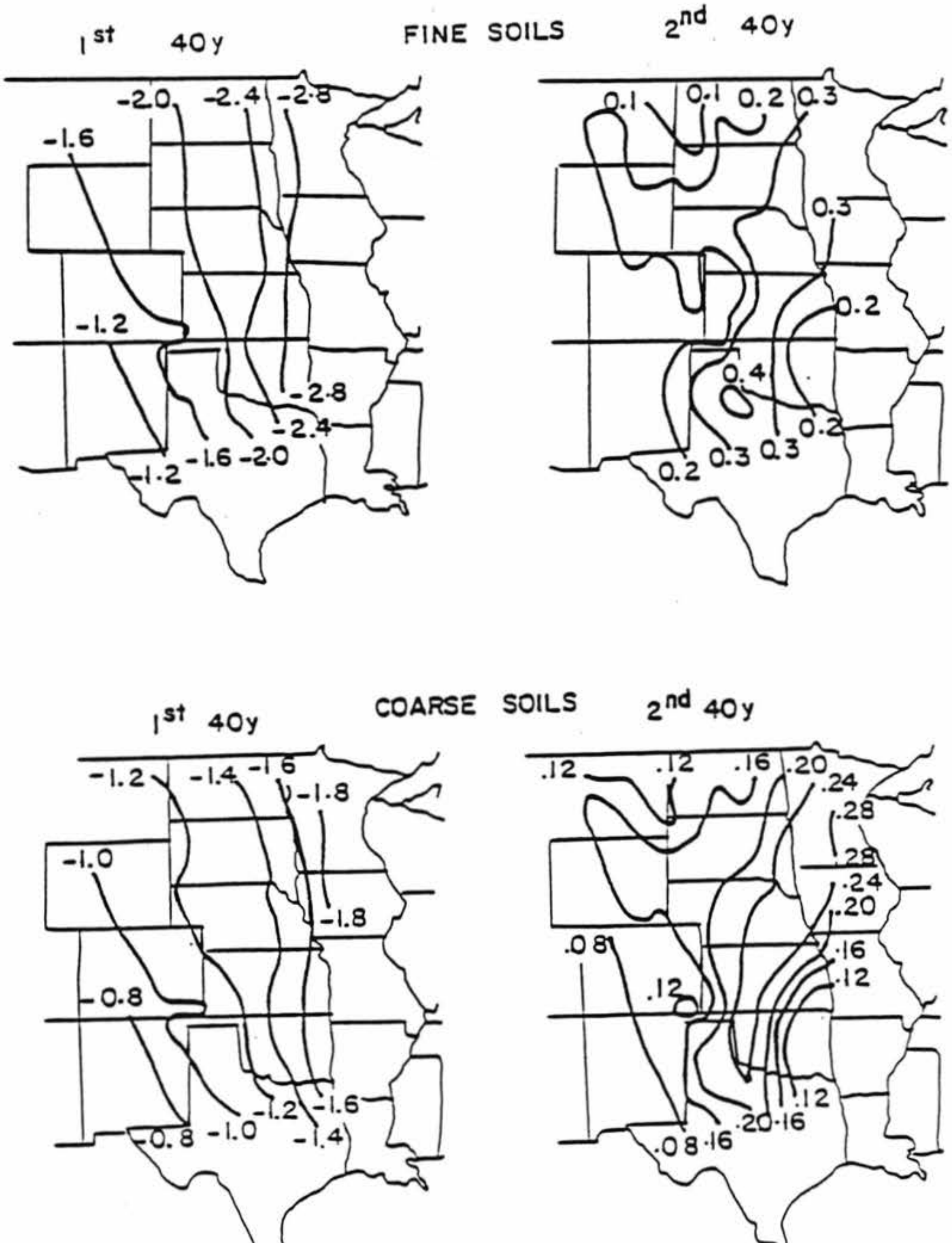
* Locations: Havre, MT; Mocassin, MT; Dickinson, ND; Mandan, ND; Sheridan, WY; Archer, WY; Akron, CO; Colby, KS; Hays, KS; Garden City, KS; and Dalhart, TX.
** Straw removal assumed at 50%.

Table 2. Best-fit regression of soil organic carbon (kg m^{-2} to 20 cm) for rangeland and cultivated soils of the U.S. Great Plains (Burke et al. in press).

Independent variables	Range soils: Coefficient	Range soils: Standardized coefficient	Range soils: Significance	Cultivated soils: Coefficient	Cultivated soils: Standardized coefficient	Cultivated soils: Significance
MAT	-8.27×10^{-1}	-1.64	0.00001	-7.50×10^{-1}	-2.32	0.00001
MAT^2	2.24×10^{-2}	1.17	0.00001	2.10×10^{-2}	1.69	0.00001
APPT	1.27×10^{-1}	1.08	0.00001	5.81×10^{-2}	0.64	0.0045
$APPT^2$	-9.38×10^{-4}	-1.02	0.00001	-4.58×10^{-4}	-0.68	0.0009
APPT x silt	8.99×10^{-4}	0.44	0.00001	4.94×10^{-4}	0.41	0.00001
APPT x clay	6.00×10^{-4}	0.21	0.0001	5.82×10^{-4}	0.32	0.00001
Constant	4.09			5.15		
	$r^2 = 0.51$ $P < 0.0001$ $N = 562$			$r^2 = 0.54$ $P < 0.0001$ $N = 383$		

Fig. 1. Simulated changes in soil organic carbon (kg C/m^2) of fine- and coarse-textured soils of the Great Plains under wheat fallow cropping during consecutive forty year periods: initial decreases 40 years after breaking sod and increases in the subsequent 40 years under typical management practices of the period. Historical lower yielding varieties, bare fallow and 50% straw removal were assumed for the first 40 years.

SOIL C CHANGE WITH CULTIVATION



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