Assessment of Cropping System Effects on Soil Quality in the Great Plains: Introduction

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Abstract

Soils serve a multitude of functions and play an important role in environmental quality through interactions with the hydrosphere and the atmosphere. Long-term studies are usually required to compare management effects on the soil resource to make soil quality assessments. This requirement exists because of the effect annual variations in weather has on the system and also because we are often trying to detect changes in the value of large pools exhibiting spatial variability. In protocols established by the Great Plains Cropping System Network in 1998, sampling and testing procedures were selected to identify components or fractions of larger pools that are responsive to management that may serve as indicators of changes in the larger pool, which would be useful in assessing the effect management practices have on the soil resource. Several existing long-term studies are available in the region and these locations and the selected conventional and alternative treatments selected for soil quality assessments are described in the paper. Precipitation, temperature, and yield data for each location are also presented.

Introduction

Soils serve a multitude of functions and play an important role in environmental quality through interactions with the hydrosphere and the atmosphere. Management of the soil resource affects how efficiently the soil performs its various functions and ultimately impacts environmental quality. There is currently a great deal of interest in improving our understanding of how soils interact with the hydrosphere and atmosphere; in developing management practices that improve the capacity of the soil to perform its various functions; and in identifying physical, chemical, and biological soil attributes that can be used to quantify the present state of the soil and detect changes in the state of the soil resulting from management.

A number of physical, chemical, and biological soil attributes have been proposed for use in assessing soil quality. Several lists of attributes have been suggested for comprising a minimum data set and combinations of attributes have been incorporated into indices having potential for assessing soil function and management impacts. A large number of studies have been conducted comparing various soil quality attributes under different management systems (e.g. comparing crop fallow to annual cropping, conventional tillage to conservation tillage, or conventional farming to organic farming). These studies are of value in quantifying the magnitude of the differences in the various soil attributes under different management systems, creating a data set that can be used to determine the range and expected value of the various soil attributes, and improve our understanding of the effect management practices have on the soil resource.

Long-term studies are usually required to compare management effects on the soil resource. This requirement exists because of the effect annual variations in weather has on the system and also because we are often trying to detect changes in the value of large pools exhibiting spatial variability. In protocols established by the Great Plains Cropping System Network in 1998, sampling and testing procedures were selected to identify components or fractions of larger pools that are responsive to management, may serve as indicators of changes in the larger pool and would be useful in assessing the effect management practices have on the soil resource. Fortunately, several existing long-term studies were available in the region on which these evaluations could be made. These locations and the selected treatments are described below.

Materials and Methods

Soil quality assessments were done at eight different locations. These locations cover both temperature and moisture gradients in the Great Plains from North to South and East to West. The locations used in these assessments are Mead, NE; Brookings, SD; Fargo, ND; Swift Current, SK, Canada; Mandan, ND; Akron, CO; and Bushland, TX. The commonality across these locations was that all had long-term experiments comparing various management systems including those representative of the current predominant practices as well as those considered to be representative of possible alternative practices for that area. The information presented below describes each location and the specific treatments or systems within that experiment that were selected to represent so-called current and alternative practices.

Akron: The Alternative Crop Rotation study is located on the USDA Central Great Plains Research Station. There are 23 rotations included in this study. The two treatments selected were winter wheat-summer fallow and winter wheat–corn-proso millet. The experiment is a 3 rep randomized complete block, established on a Weld Silt Loam (fine, smectitic, mesic, Aridic Argiustolls). The conventional system is conventional till WF where wheat is planted in the fall (Sept-Oct) and harvested the subsequent summer in July. The land is then fallowed for 14 months and weeds are controlled with V-blade sweeps. The alternative system is no-till WCM where herbicides are used for weed control. Corn, millet, and wheat are seeded no-till directly into the previous crops undisturbed stubble. Millet and wheat grain yield are reported at 13.5% moisture. Corn is reported at 15.5 % moisture Additional details of the plot area, tillage systems, and experimental design are given in Anderson et al. (1999).

Brookings: Experimental plots were located at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD on Barnes clay loam (fine-loamy, mixed Udic Haploborolls) soils with nearly level topography. Soil tests conducted in the fall of 1989 indicated 16.5 g kg^{-1} organic matter, extractable ion concentrations of 14.8 mg kg^{-1} NO_3-N, 9.2 mg kg^{-1} Olsen-P, and 192 mg kg^{-1} K in the top 26 cm (Ap1 horizon) of the soil profile.

Cropping systems used in this experiment were established in the 1990-growing season under dry-land conditions. Three crop rotations (one monoculture, one 2-yr rotation, and one 4-yr rotation) and 3 input level treatments were included in the overall study. All crops in the rotation treatments were present each year. The three separate input level sub-plot treatments were superimposed upon the main plot rotation treatments. Sub-plots were 30.5 m long by 30.5 m wide with 3 replications. Corn plots were tilled using a fall moldboard plow/spring tandem disk/spring field cultivator system from 1990-1995. Beginning in 1996, primary tillage was with a chisel plow in the fall of the year and a tandem disk/field cultivator in the spring. Other implements used for fall primary tillage were a chisel plow proceeding soybean and a tandem disk proceeding wheat. A tandem disk/field cultivator operation was used to prepare the seedbed prior to corn, soybean, and wheat/alfalfa planting operations. The specific treatments selected from this experiment for soil quality assessments were the continuous corn and the corn–soybean–spring wheat under-seeded with alfalfa–alfalfa 4-yr rotation. Additional details on crop and soil management practices can be found in Pikul et al. (2001) and Riedell et al. (1998).

Bushland: The experimental plots are located on graded-terraced watersheds at the USDA-ARS Conservation and Production Research Laboratory on Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll). These plots mainly consist of wheat-sorghum-fallow and continuous wheat cropping systems managed under no tillage or stubble-mulch tillage since 1983. The terraces have an organic carbon content of 10 g kg^{-1} (0-15 cm) and medium and very high levels of P and K, respectively. The specific treatments selected from this experiment for soil quality assessments were continuous winter wheat and a single-phase of the wheat-sorghum-fallow rotation, both under no-tillage management. The plots received no fertilizers throughout the duration of the study. Jones and Popham (1997) provide further details of weed control, experimental layout, and cultural practices for these long-term plots.

Fargo: This dryland experiment covering 2 hectares is located 8 kilometers NW of Fargo, ND on the NW22 research land of the North Dakota Agricultural Experiment Station. The soil is mapped as a Fargo silty clay (fine, smectitic, frigid, Typic Epiaquert) with average soil tests in the 0-15 cm depth of 41 g kg^{-1} organic matter, a 1:1 pH of 7.7, phosphorus at 47 kg ha^{-1} and potassium at 629 kg ha^{-1}. A tillage system study was initiated at this site in the fall of 1977 with four primary tillage systems after the small grain crop including fall plow, fall sweep, fall intertill (strip till) and no-till. Each tillage block was 14 m wide by 32 m long and replicated four times. A rotation of sugarbeet, spring wheat, sunflower and barley was maintained the first eight years. Sugar beet was replaced by soybean in the rotation during the next two years and the sweep system was changed to fall chisel. In 1987, the rotation was switched to a small grain and grain legume rotation that included spring wheat, durum, soybean, drybean, and field pea. In the spring of 1997 a N fertilizer variable was added to the study with 0, 45, 90 and 135 kg N ha^{-1} randomly split across each replication. The specific treatments selected for this study were the plow and no-till tillage systems for the small grain (durum wheat even years) and grain legume (field pea odd years) rotation without nitrogen fertilizer. Specific details are available in Deibert (1989, 1995).

Mandan: The experiment was located about 6 km southwest of Mandan, ND on a Wilton silt loam (fine-silty, mixed, superactive frigid Pachic Haplustoll). The site had a soil pH of 6.4 and an organic C concentration of 21.4 g kg^{-1} in the surface 76 mm. Sodium-bicarbonate extractable P in the surface 152 mm ranged from 20 to 26 mg kg^{-1} in the spring of 1984. The experiment was initiated in 1984 and was rainfed.

Two crop sequences, three residue managements, three N fertilizer rates, and two crop cultivars were included in the research. Three replicates of crop sequences (137.2 by 73.1 m), residue management (45.7 by 73.1 m), N fertilizer rates (45.7 by 24.4 m), and crop cultivars (22.8 by 24.4 m) were arranged in a randomized complete block design. Specific treatments selected for the soil quality assessments were the spring wheat-fallow with conventional residue management (< 30% soil surface covered by residue), and 22 kg N ha^{-1} as the conventional system and the spring wheat–winter wheat–sunflower with no-tillage residue management (> 60% soil surface covered by residue), and 67 kg N ha^{-1} as the alternative system. Detailed soil characterization and management information have been described by Black and Tanaka (1997).

Mead: The experiment is located on the Agronomy Farm at the University of Nebraska Agricultural Research and Development Center near Mead, Nebraska on a well-drained Sharpsburg silty clay loam (fine, smectitic, mesic Typic Argiudoll). This site has an average organic matter content of 31 g kg^{-1} and soil test P and K levels in the very high categories in the surface 75 mm. The experiment was initiated in 1982 and is rainfed.

Seven cropping systems (three monoculture, two two-year, and two four-year rotations) with three rates of N fertilizer are included in the study. Each phase of every rotation occurs every year for a total of 15 rotation treatments. Treatments were assigned to experimental units (9 by 32 m) in factorial combinations of rotation and crop within rotation in five randomized complete blocks in 1982. Three subplots separated by 1 m alleys were randomly assigned a 0, low, or high N rate within each whole plot treatment in 1983. Nitrogen rates are 0, 90, or 180 kg N ha^{-1} for corn and sorghum and 0, 34, or 68 kg N ha^{-1} for soybean and oat+clover. Nitrogen applications are made in late-May or early- to mid-June for all three crops. Cultural practices are similar to those used by local farmers. All plots are tilled once or twice with a tandem disk just prior to planting each year for all crops. The specific treatments selected from this experiment for soil quality assessments are the continuous corn and 4-year soybean-sorghum-oat+clover-corn cropping systems. Additional background and management information are presented in Peterson and Varvel (1989a,b,c).

Swift Current: The experiment is located at the Semiarid Prairie Agricultural Research Centre of Agriculture and Agri-Food Canada near Swift Current, SK on a Swinton silt loam (fine-loamy, mixed, calcareous, frigid Typic Haplustoll). Two rotations within a larger rotation experiment were involved in this study: i) spring wheat-fallow (initiated 1967), and ii) spring wheat-lentil (initiated 1979). There are three replicates and the plot size is 10.5 x 40 m. Although each phase of the rotations was present every year, only the wheat on lentil and fallow on wheat phase was measured in 2000 with the succeeding phase (lentil on wheat and wheat on fallow, respectively) measured in 2001. General seedbed preparation, fertilization, herbicide application, planting, harvesting and tillage practices for this experiment have been reported previously (Campbell et al. 1983). Commercial farm equipment was used to perform cultural and tillage operations.

Results

Monthly and yearly precipitation and temperature data for the four years of the study and long-term averages are presented in Tables 1 and 2 for each of the locations participating in the soil quality assessment project. Stover and grain yields for the selected treatments (conventional and alternative management systems) at each location are shown in Table 3.

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Table 1. Monthly and yearly precipitation and long-term averages at each location.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
	Month												
	Precipitation (cm)												
Akron, CO													
1999	0.2	0.4	0.7	5.7	5.5	8.7	6.9	16.4	4.0	1.1	1.2	1.4	52.3
2000	0.6	0.8	5.7	3.0	1.9	1.9	6.8	4.9	4.5	4.4	1.2	0.6	36.3
2001	2.2	1.1	2.6	3.4	10.1	3.4	6.8	5.7	3.9	1.6	2.0	0.0	42.6
2002	0.2	0.2	0.2	1.3	1.4	4.3	0.3	8.7	3.8	2.6	1.0	0.1	24.1
Ave.†	0.8	0.9	2.1	4.2	7.5	6.2	6.8	5.4	3.2	2.3	1.4	1.0	41.8
Brookings, SD													
1999	1.8	0.2	3.4	10.6	8.7	6.5	6.9	4.7	7.2	1.9	0.1	0.4	52.4
2000	0.7	2.1	2.8	3.7	17.1	7.6	4.5	4.1	2.3	3.0	8.0	7.6	63.5
2001	1.7	1.7	2.0	15.0	4.8	9.3	6.6	1.8	5.7	2.5	6.1	0.1	57.3
2002	0.4	0.1	5.4	3.3	7.8	6.2	7.1	18.3	3.5	6.5	0	4.3	62.9
Ave.†	0.9	1.0	3.3	5.2	7.5	10.7	7.9	7.5	6.3	4.5	2.5	0.7	58.0
Bushland, TX													
1999	3.7	0.0	4.3	6.2	11.3	8.1	12.5	3.9	5.1	0.6	0.0	1.5	57.1
2000	0.2	0.0	7.7	1.4	1.5	9.9	2.5	0.0	0.0	5.9	3.5	2.7	35.3
2001	3.5	2.6	9.3	0.8	8.2	3.7	0.5	3.3	2.0	0.3	3.1	1.1	38.4
2002	3.4	0.5	1.5	3.0	0.2	2.6	5.8	11.9	4.4	6.8	0.2	2.9	43.3
Ave.†	1.4	1.3	2.2	2.7	6.6	7.3	6.6	6.9	4.7	4.0	1.8	1.6	47.3
Fargo, ND													
1999	2.9	0.5	4.6	2.6	8.9	7.2	5.9	11.2	16.5	2.6	0.0	1.1	64.3
2000	0.8	2.5	4.5	3.4	6.8	29.8	6.2	7.8	9.2	5.0	10.5	1.8	88.3
2001	0.5	1.9	0.7	6.8	7.3	6.9	8.0	5.6	3.7	7.0	2.5	0.6	51.4
2002	0.5	0.3	2.7	3.2	9.8	12.1	14.4	9.5	4.4	3.6	0.4	2.1	63.0
Ave.†	1.9	1.5	3.0	3.5	6.6	8.9	7.3	6.4	5.5	5.0	2.7	1.4	53.8
Mandan, ND													
1999	0.9	2.4	0.3	2.4	16.8	8.7	4.7	17.0	2.6	0.9	0.1	0.5	57.2
2000	1.2	4.1	3.0	3.5	6.6	10.3	6.6	3.6	3.2	4.0	3.4	1.0	50.6
2001	0.9	1.9	0.5	5.1	3.9	10.4	21.3	0.0	3.0	2.4	0.1	0.2	49.5
2002	0.5	0.3	1.1	2.5	1.3	3.2	6.6	4.9	0.9	1.8	0.4	0.7	24.2
Ave.†	0.8	1.0	1.4	3.8	5.7	7.1	7.8	5.2	4.3	3.2	1.5	0.9	42.7
Mead, NE													
1999	3.0	3.4	3.9	14.1	14.9	12.8	5.6	8.0	7.0	0.0	1.7	1.0	75.4
2000	0.6	4.0	1.7	5.1	7.0	15.2	8.8	4.3	1.5	6.5	4.4	1.6	60.6
2001	3.5	4.6	2.6	4.6	23.0	4.0	2.5	7.9	6.7	5.3	5.3	1.5	71.5
2002	2.5	1.4	1.7	6.9	7.5	2.0	3.1	16.7	3.6	9.3	0.3	0.0	55.1
Ave.†	1.4	1.9	5.6	7.2	10.8	10.8	8.6	9.4	9.2	6.0	3.3	2.3	76.6
Swift Current, SK													
1999	--	--	--	--	--	--	--	--	--	--	--	--	--
2000	1.1	1.6	1.3	4.2	6.5	5.4	12.7	1.3	4.9	1.6	0.8	1.9	43.3
2001	0.4	0.9	1.1	1.0	2.3	3.3	6.3	0.3	0.6	2.0	0.4	0.5	18.9
2002	--	--	--	--	--	--	--	--	--	--	--	--	--
Ave.†	1.6	1.4	1.8	2.2	4.4	7.3	5.3	4.3	3.1	1.9	1.4	1.5	36.1

† Akron (93-yr), Brookings (30-yr), Bushland (64-yr), Fargo (30-yr), Mandan (30-yr), Mead (30-yr), and Swift Current (117-yr) averages, respectively.

Table 2. Monthly and yearly average temperatures and long-term averages at each location.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Yearly Mean
	Month												
	Mean Temperature (°C)												
Akron, CO													
1999	0.8	3.6	5.3	6.8	15.0	18.5	23.8	26.1	14.9	10.2	6.9	0.4	11.0
2000	-0.7	2.6	4.5	8.7	13.5	19.1	23.9	27.2	16.9	10.0	-2.2	-3.4	10.0
2001	-2.0	-3.0	2.7	9.4	13.6	20.0	24.5	26.4	17.9	10.5	5.0	-0.6	10.4
2002	-1.4	-0.1	0.1	9.5	13.1	22.3	24.5	22.0	17.0	7.1	2.1	2.1	9.8
Ave.†	-3.7	-0.9	2.4	8.1	13.5	19.2	23.0	22.0	16.9	10.2	2.6	-2.4	9.2
Brookings, SD													
1999	-12.3	-3.6	-0.2	6.6	14.3	18.9	22.8	20.2	14.3	7.2	4.2	-4.9	7.3
2000	-9.4	-3.0	3.4	5.9	14.3	18.2	21.2	20.7	14.5	9.6	-4.0	-14.6	6.4
2001	-9.1	-13.9	-5.4	6.5	14.4	19.1	22.8	21.6	15.3	7.3	5.7	-5.4	6.6
2002	-7.1	-2.9	-7.9	6.1	10.9	20.8	24.0	20.2	16.3	3.8	-7.2	-5.1	6.0
Ave.†	-12.3	-9.2	-1.7	6.5	13.1	18.6	21.4	19.9	14.4	7.8	-0.8	-9.2	5.7
Bushland, TX													
1999	3.9	6.7	7.2	11.7	15.6	21.7	25.0	25.0	18.9	13.9	11.1	1.7	13.5
2000	3.3	7.2	8.3	13.9	20.6	22.2	25.6	26.7	22.2	14.4	3.3	-0.6	13.9
2001	-0.3	2.9	6.1	14.8	17.6	24.3	28.0	24.6	20.5	14.7	9.2	3.1	13.8
2002	2.7	2.9	6.7	14.6	18.8	25.0	25.0	24.8	19.9	11.1	6.0	1.2	13.2
Ave.†	1.7	4.0	7.7	12.9	17.8	22.9	24.9	24.0	20.1	14.2	7.3	2.8	13.4
Fargo, ND													
1999	-14.2	-5.3	-0.4	7.3	14.4	19.1	21.9	20.0	13.0	6.8	2.8	5.0	6.7
2000	-12.3	-5.8	1.8	5.8	14.0	17.0	21.4	20.9	14.4	9.0	-3.3	-17.6	5.4
2001	-9.8	-15.6	-5.0	6.9	14.7	18.8	22.5	21.4	15.2	6.9	4.3	-6.6	6.2
2002	-8.6	-4.4	-6.7	4.5	10.7	20.6	22.8	19.6	16.5	2.9	-2.3	-6.7	5.7
Ave.†	-14.0	-9.9	-2.7	6.4	14.1	18.9	21.4	20.6	14.4	7.4	-2.8	-10.8	5.3
Mandan, ND													
1999	-12.5	-3.8	1.2	5.9	12.4	17.3	21.0	19.7	11.9	6.8	3.4	-3.3	6.7
2000	-9.0	-4.8	1.4	5.9	13.4	16.2	20.8	20.4	14.5	8.5	-5.2	-14.8	5.6
2001	-6.5	-13.4	-1.6	6.7	13.8	17.1	21.4	21.9	15.2	5.8	2.7	-6.4	6.4
2002	-6.8	-3.8	-8.1	4.0	10.1	19.1	22.9	19.6	15.3	1.7	-0.3	-4.8	5.7
Ave.†	-12.2	-8.3	-1.7	6.1	13.3	18.3	21.1	20.6	13.9	7.2	-2.2	-9.4	5.6
Mead, NE													
1999	-5.2	1.3	3.5	10.6	16.2	20.9	26.4	22.3	17.1	11.2	7.7	-1.0	10.9
2000	-3.1	1.6	6.6	10.6	18.8	21.4	23.8	23.8	19.5	13.4	-0.2	-9.8	10.6
2001	-3.5	-6.5	1.7	12.5	17.3	21.8	25.9	24.0	18.1	11.5	8.9	-0.7	10.9
2002	-1.6	-1.2	0.1	11.1	15.3	24.9	26.8	23.6	19.4	8.0	2.4	-0.5	10.7
Ave.†	-5.6	-2.6	3.7	10.9	16.9	22.4	25.2	23.6	18.4	12.1	4.1	-3.4	10.5
Swift Current, SK													
1999	--	--	--	--	--	--	--	--	--	--	--	--	--
2000	-11.5	-7.4	0.1	4.9	10.9	13.9	19.1	18.5	12.4	6.4	-5.0	-13.8	4.0
2001	-5.0	-14.1	-0.7	5.4	12.2	15.0	19.7	20.7	15.0	4.2	1.7	-8.7	5.5
2002	--	--	--	--	--	--	--	--	--	--	--	--	--
Ave.†	-13.3	-10.8	-4.7	4.6	10.9	15.4	18.6	17.6	11.8	5.6	-3.5	-9.6	3.6

† Akron (93-yr), Brookings (30-yr), Bushland (64-yr), Fargo (30-yr), Mandan (30-yr), Mead (30-yr), and Swift Current (117-yr) averages, respectively.

Table 3. Grain and stover dry matter yields each year and long-term averages for selected conventional and alternative management systems at each location participating in the regional soil quality assessment project.

Location	Yield											
	Grain				Mean		Stover				Mean	
	1999	2000	2001	2002	4-Yr	LT†	1999	2000	2001	2002	4-Yr	LT
	Mg ha^{-1}											
Akron, CO (10-yr)												
WW-F (CT)‡	2.4	0	3.5	0	1.5	1.1	4.1	--	5.3	--	2.4	2.4
WW-C-M (NT)‡	1.1	2.4	2.2	0.8	1.4	1.5	2.7	4.8	4.4	1.4	3.3	3.4
Brookings, SD (7-yr)												
Cont. C‡	5.4	5.5	5.3	4.5	5.2	6.4	5.9	4.7	5.1	4.4	5.0	--
C-SB-SW/Alf-Alf‡	7.8	2.4	2.6	0	3.2	--	7.5	5.6	--	8.4	--	--
Bushland, TX												
Cont. WW (NT)	1.9	1.5	1.9	0.2	1.4	--	7.2	4.2	3.8	0.3	3.9	--
WW-SG-F (NT)	3.1	2.4	--	0.8	--	--	10.9	3.3	--	3.3	4.4	--
Fargo, ND (15-yr)												
FP-D (Plow)‡	2.6	2.5	2.5	2.1	2.4	2.1	2.5	5.9	1.8	4.6	3.7	3.5
FP-D (NT)‡	2.8	2.4	2.4	1.6	2.3	2.0	2.7	5.6	2.3	3.9	3.6	3.5
Mandan, ND (12-yr)												
SW-F (CT)	1.6	--	--	--	1.6	1.1	4.2	--	--	--	4.2	1.8
SW-WW-SF (NT)‡	1.7	3.2	--	--	2.4	1.7	4.5	--	--	--	4.5	3.4
Mead, NE (20-yr)												
Cont. C	8.8	6.5	6.6	6.0	7.0	7.1	6.9	5.0	6.2	4.3	5.6	6.2
C-SB-SG-OCL‡	8.9	2.7	4.2	0.7	4.1	4.6	8.8	5.9	7.7	2.2	6.2	5.6
Swift Current, SK												
SW-F	--	0	2.3	--	1.5	1.3	--	0	3.2	--	2.5	2.2
SW-Lentil	--	2.4	0.4	--	1.7	1.6	--	4.9	1.5	--	3.3	3.1

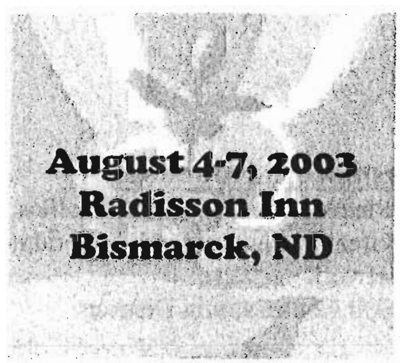
† Long-term averages for each management system (# of years in parentheses by location)

‡ Abbreviations; WW=winter wheat, F=fallow, CT=conventional till, M=millet, C=corn, NT=notill, Cont.=continuous, SB=soybean, SW=spring wheat, Alf=alfalfa, FP=field pea, D=durum, SG=sorghum, OCL=oat+clover, SF=sunflower

A CROPPING SYSTEMS SYMPOSIUM

DYNAMIC CROPPING SYSTEMS

Principles, Processes, and Challenges



J.D. Hanson and J.M. Krupinsky (Editors)

PROCEEDINGS