COMPARISON OF SOIL SPATIAL VARIABILITY IN CROP AND RANGELAND[1]

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ABSTRACT

Many recent studies have investigated soil spatial variability in cultivated lands. Less research has been conducted to quantify native range variability. This study examines the spatial variability of pH, electrical conductivity (EC), soil organic carbon (SOC) at three depths (0-5cm, 5-15cm, and 15-25cm), and soil water content at 0-15cm in 200 x 350m plots on adjacent cropland and rangeland. Surface cropland pH (mean = 7.59, standard deviation (SD) = 0.44) and EC (mean = 156.09 μS/cm, SD = 81.70 μS/cm) were more variable than rangeland (mean = 6.77 and 120.08 μS/cm, SD = 0.33 and 46.48 μS/cm, respectively), and had strong and moderate spatial dependence. Rangeland did not have any spatial dependence at this depth. Surface cropland SOC (mean = 0.49%, SD = 0.188%) was less variable than rangeland (mean = 1.16%, SD = 0.462%), but both had moderate spatial dependence. The difference between these two systems was less distinct at other depths. Soil water content was more variable and exhibited strong spatial dependence on cropland, but moderate spatial dependence on rangeland. Cropland pH likely is controlled by depth to free carbonates or soil forming processes, while EC and SOC may be affected by tillage and farming practices. All measured parameters on rangeland are affected by the unpredictable nature of cattle grazing.

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INTRODUCTION

Soil variability can exist in both undisturbed and intensively managed ecosystems (Robertson et al., 1997) because of complex interactions between time, parent material, topography, climate, and organisms (Jenny, 1941), and different human management practices. Information on soil variability has been very limited in the past because of the limitation of technology. During the past decade, advances in computer technology, geographical information systems (GIS), global positioning systems (GPS), remote sensing, yield monitors, variable-rate application equipment, and geostatistics, etc. have greatly increased our ability to identify, record, analyze, and manage soil spatial variability. Precision agriculture (PA) or site-specific farming has been gaining popularity in mainstream agriculture and offers the promise of being both economically and environmentally sound.

Soil spatial variability research has focused on cultivated fields in the past and information on rangeland soil spatial variability has been relatively limited. Herrick and Whitford (1995) identified three characteristics distinguishing rangeland soils from cropped soils: (1) higher spatial variability in rangelands; (2) high temporal variability in rangeland due to dependence of many biological and physical processes on limited and frequently unpredictable supply of soil water (this is true for dryland crop fields as well); and (3) many uses of the land in addition to food production. A better understanding of the differences of soil spatial variability between these two systems is necessary to apply site-specific management strategies to range management.

The objectives of this study were to identify and compare the soil spatial variability of a dryland crop field and an adjacent rangeland with known long-term management history, and to quantify the spatial dependence of the soil variability.

MATERIALS AND METHODS

Study Sites

This study was conducted on the West Texas A&M University (WTAMU) Nance Ranch, which is located 10 km southeast of Canyon, Texas. The soil is classified as Pullman clay loam, a fine, mixed, superactive, thermic, Torrertic Paleustolls. Plots, 200 X 350m on cropland and adjacent rangeland were selected for the study.

Field History

Prior to this study, the cropland had been cultivated for about 75-100 years, mainly in a winter wheat - grain sorghum – fallow rotation. Most of the years, wheat was grown both for grazing and grain. Weeds were controlled by tillage. Small amounts of fertilizer have been applied only in recent years. No irrigation has ever been applied. Tillage systems currently use sweep or chisel plows, and disk plows have been used in the past. The rangeland is adjacent to the cropland and it has been used for cattle grazing and never been plowed (Thomason, personal communication).

Sampling Design

In August 1998, the field was surveyed and the sample locations were determined at the same time. The study sites were sampled on a 50 x 50 m grid, 40 nodes per system (see Figure 1). Samples were collected from three depths: 0-5 cm, 5-15 cm, and 15-25 cm. Each sample was a composite of five 7-cm diameter augered samples taken within a radius of 50 cm from the node. More intensive samples were taken from each depth at nine nodes in each plot to evaluate the within cell variability. These samples were obtained 1m, 2m, 4m, 8m, 16m and 32m from the node in a straight line on a random bearing. They were not composited. Another three samples were also taken randomly within 1meter radius around the chosen nodes. Soil water content was measured in the field on a transect in each system at different times (Oct. 6 and Oct. 29, 1998, which was one day after rain) to evaluate both the spatial and temporal variability. The 0-15 cm average volumetric soil water content was measured using Time Domain Reflectrometry (TDR). A portable TDR system was used employing a cable tester (model 1502C, Tektronix, Inc, Redmond, OR) operated via a laptop computer running the TACQ program (Evett, 1998). The TDR probe was a trifilar hand-held probe with exposed rods of 15-cm length spaced at 3 cm center-to-center (Evett, personal communication).

Measurements

Soil samples were collected over a two-week period in late August and early September 1998. The sampling was a two-stage process with grid point samples collected first and then the intensive samples. The soil samples were put in paper bags and transported to the laboratory to be air-dried. Electrical conductivity (EC, μS/cm) and pH were determined on 10 g soil in 20 ml distilled water (1:2 soil: water ratio). The solution was stirred several times and allowed to equilibrate for 30 min. The EC measurements were adjusted to 25 ^{0}C. The pH was measured using Accument® pH Meter (Model 815MP) and Polymer-Bodied Combination Electrode with Calomel Reference at 22 ^{0}C. Three replications of fifty randomly selected soil samples were analyzed for quality control. Organic carbon samples were ground to pass a 4mm sieve. Gravel and plant residues were removed. Duplicate samples (0.5g subsamples) were analyzed for organic carbon using a dry combustion method (575 ^{0}C, Chichester and Chaison, 1992) with LECO CN-2000 analyzer which measures C using an IR cell. The means of duplicates were used for further statistical analysis. During analysis, extreme values were analyzed one or two more times to ensure data quality and integrity.

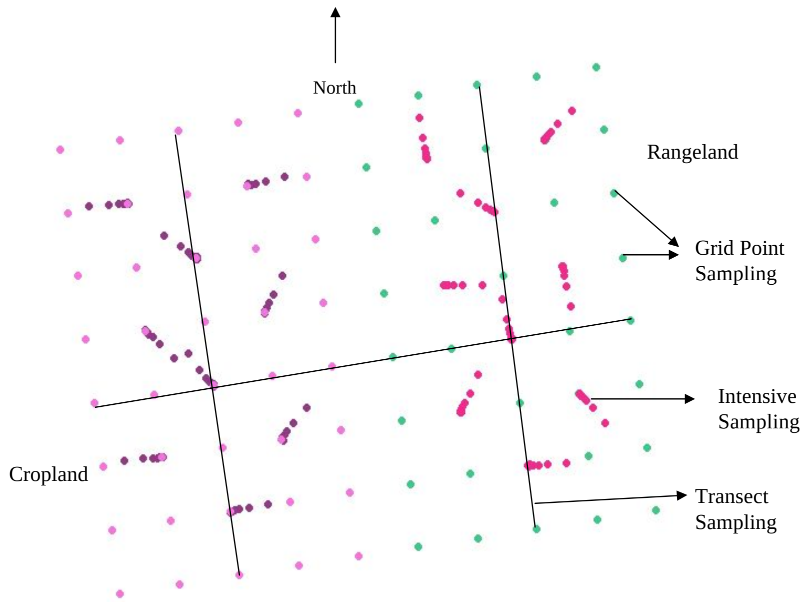

Fig. 1. Sampling locations of cropland and rangeland: including grid point sampling, intensive sampling and transect sampling.

Statistical Analysis

Sample mean, median, standard deviation (SD), minimum, maximum, range, and coefficient of variation (CV) were determined for all data. Correlation analysis was performed for relative elevation, pH, EC and OC to determine the relationship between these soil properties.

Semi-variogram analysis was performed using Geostatistical Environmental Assessment Software (GEO-EAS, Englund and Sparks, 1988). The semi-variogram models were fitted visually and only isotropic models were considered in the study. The Mean Correlation Distance (MCD)(Han et al., 1996, 1994) was calculated using the following formula:

$$MCD = \frac{3}{8} * \left(\frac{C}{C_0 + C}\right) * A$$

where C_0 is nugget, $C+C_0$ is the sill, and A is the range of spatial dependence.

The spatial structural parameters of semi-variogram models were used for kriging and producing contour maps using SURFER ® for Windows Version 6 (Golden Software, 1997) for pH, EC, and SOC.

RESULTS AND DISCUSSION

Descriptive statistics for the measured soil properties are presented in Table 1. The EC exhibited the greatest variability, followed by organic C, volumetric water content, and pH. Relative elevation was the least variable soil parameter, with CV less than 1%.

Cropland exhibited higher variability of pH and EC than rangeland (0 – 5 cm), but rangeland had higher SOC variability than cropland at all three depths. The variability of pH and EC between these systems was more distinct in 0 to 5cm depth than in 5 – 25 cm depths. Volumetric water content variability was higher in cropland both times than in rangeland.

Semi-variogram analysis results are presented in Table 2 and examples of the contour maps of SOC at first depth are given in Figure 2

Table 1. Descriptive statistics of the measured soil properties.

Soil Property	Syst.†	N	Mean	Median	SD	Min.	Max.	Range	CV
									-%-
Relative Elevation (m)									
	C	40	0.89	0.80	0.28	0.48	1.53	1.05	0.28
	R	40	0.43	0.46	0.21	0.00	0.76	0.76	0.21
pH									
0-5cm	C	121	7.59	7.69	0.44	6.71	8.31	1.60	5.83
	R	121	6.77	6.74	0.33	6.00	7.49	1.49	4.81
5-15cm	C	121	7.57	7.60	0.34	6.85	8.14	1.29	4.49
	R	121	7.07	7.05	0.31	6.37	7.95	1.58	4.43
15-25cm	C	121	7.49	7.53	0.29	6.80	8.10	1.30	3.80
	R	121	7.21	7.21	0.30	6.42	8.08	1.66	4.12
EC (μS/cm)									
0-5cm	C	121	156.09	136	81.70	71	476	405	52.34
	R	121	120.08	103.5	46.48	60	332	272	38.71
5-15cm	C	121	128.99	117	68.30	63	534	471	52.95
	R	121	91.98	77.3	52.20	42.6	394	351	56.75
15-25cm	C	121	125.39	111	53.71	61.8	355	293	42.84
	R	121	90.37	81	36.93	54	358	304	40.87
SOC(%)									
0-5cm	C	121	0.49	0.46	0.19	0.18	1.09	0.91	38.43
	R	121	1.16	1.09	0.46	0.38	2.50	2.13	39.72
5-15cm	C	121	0.46	0.43	0.15	0.18	1.05	0.87	33.14
	R	121	0.66	0.60	0.26	0.23	1.39	1.16	39.91
15-25cm	C	121	0.61	0.59	0.17	0.23	1.33	1.10	27.30
	R	121	0.77	0.73	0.27	0.31	2.07	1.76	34.85
Water Content (%)									
Oct. 6, 1998	C	16	12.23	12.30	2.28	8.95	18.11	9.16	18.70
	R	18	17.05	17.30	1.64	12.79	18.85	6.06	9.59
Oct. 29, 1998	C	16	20.75	19.80	3.39	15.30	27.00	11.70	16.35
	R	16	14.81	14.98	2.10	11.35	19.05	7.70	14.19

† C and R stand for cropland and rangeland.

and 3. Many soil properties have non-zero nugget effect, which is caused by measurement error or micro-variability that can't be detected at the scale of sampling (Trangmar et al., 1985). To compare the relative size of the nugget effects among different properties and different models, the nugget effect can be expressed as a percentage of the sill (Yost et al., 1982). This ratio can also be used to define distinct classes of spatial dependence (Karlen et al., 1996). A ratio of 0% indicates that the measurement error and short-range variability is negligible (Trangmar et al., 1985). A ratio $\leq$ 25% means the spatial dependence of the variable is strong; between 25 and 75% has moderate spatial dependence, and $\geq$ 75% has weak spatial dependence (Cambardella et al., 1994). Ratios of 100% exhibit pure nugget effect, indicating no spatial dependence at the scale of sampling (Trangmar et al., 1985). Mean correlation distance (MCD) values represent the size of the spatial dependence of the soil property (Han et al., 1996).

Table 2. Semi-variogram parameters and MCD† values of measured soil properties.

Soil Property	System	Model	C_0	C	$C_0/(C_0 + C)$	A	MCD
					%	- m-	
Relative Elevation (m)							
	C	Gaussian	0	0.125	0.0	250	93.75
	R	Gaussian	0	0.08	0.0	290	108.75
pH							
0-5cm	C	Gaussian	0.06	0.2	23.1	200	57.69
	R	-----------	------	-----	-------	-----	-------
5-15cm	C	Gaussian	0.036	0.165	17.9	270	83.12
	R	Gaussian	0.08	0.018	81.6	100	6.89
15-25cm	C	Spherical	0.04	0.055	42.1	220	47.76
	R	Linear	0.072	0.016	81.8	130	8.86
EC (μS/cm)							
0-5cm	C	Linear	4200	2419.5	63.4	165	22.62
	R	-------	------	--------	-------	-----	-----
5-15cm	C	Linear	3000	1626.2	64.8	165	21.75
	R	Spherical	900	1802	33.3	95	23.76
15-25cm	C	Spherical	2600	350	88.1	100	4.45
	R	Linear	700	652.7	51.7	120	21.71
SOC (%)							
0-5cm	C	Linear	0.024	0.011	68.6	120	14.14
	R	Spherical	0.16	0.052	75.5	75	6.90
5-15cm	C	Spherical	0.013	0.01	56.5	60	9.78
	R	Gaussian	0.04	0.029	58.0	65	0.24
15-25cm	C	Linear	0.017	0.011	60.7	125	18.42
	R	Spherical	0.05	0.022	69.4	85	9.74
Water Content (%)							
Oct. 6, 1998	C	Spherical	0.3	4.20	6.7	60	21.00
	R	Spherical	0.8	1.73	31.7	65	16.65
Oct. 29, 1998	C	Spherical	0.0	14.30	0.0	140	52.50
	R	Spherical	1.2	2.54	32.1	130	33.11

† C_0 is nugget, C is sill – nugget, and A is range. MCD is mean correlation distance.

Cropland soil pH was strongly spatially dependent at in 0-5 and 5-15 cm depths, but moderate in 15-25 cm depth. Spatial dependence of EC and OC was moderate at all depths, except EC at third depth. On rangeland, soil pH and EC did not have any spatial dependence at 0-15 cm. At other depths, the spatial dependence was either moderate or weak. Soil OC had either moderate or weak spatial dependence at all the three depths examined. Soil water content exhibited strong spatial dependence during both sampling times on cropland, but moderate spatial dependence on rangeland. Most of the time, the range of spatial dependence and MCD values for soil properties on rangeland was shorter than on cropland. The difference of spatial variability between these two systems was more distinct at first depth.

It seems that cattle grazing had a strong influence on the spatial dependence of soil properties measured on rangeland. Grazing cattle exert several effects on rangeland soils. Their trampling damages plant tissue, increases soil bulk density, and slows water infiltration. Excretion is not distributed uniformly, but concentrates urine and dung in small areas, and affects plant palatability and nutrient cycling (Hart and Hoveland, 1989). Cattle grazing might also affect soil microbial activity and its role in nutrient transformation (Banerjee et al., 2000). Many factors may influence cattle grazing distribution, including slope, distance to water, forage quantity and quality, proximity to fence, abundance of weeds, etc. (Brock and Owensby, 2000). The unpredictable nature of cattle grazing may be the direct reason for the weaker spatial dependence of the soil properties on rangeland, esp. at 0-5cm depth.

It has been hypothesized that soil variables exhibiting strong spatial dependence may be controlled by intrinsic variability, while soil variables exhibiting less strong spatial dependence may be controlled by extrinsic variability, i.e., management practices (Rao and Wagenet, 1985; Cambardella et al., 1994). Cropland pH may be controlled by intrinsic variation in soil forming processes or depth to free carbonates, while EC and OC may be controlled by extrinsic variability of tillage, and other farming practices.

SUMMARY AND CONCLUSIONS

This study examined the small-scale spatial variability of selected soil properties for a typical dryland crop field and adjacent rangeland. Cropland displayed higher variability of pH and EC at 0-5cm, and higher variability of water content at both times of sampling. Rangeland displayed higher variability of SOC at all three depths than cropland. Generally, most soil properties on cropland had stronger spatial dependence than on rangeland, thus making it easier to use kriging or other interpolation methods to predict soil properties at unsampled locations. This also makes it practical to apply site-specific management strategies on cropland. Because most soil properties on rangeland exhibited moderate, weak or no spatial dependence, it would be more difficult to design an optimal soil sampling plan to capture the soil variability. It may also be difficult to use soil spatial variability information to aid in applying site-specific management strategies on rangeland.

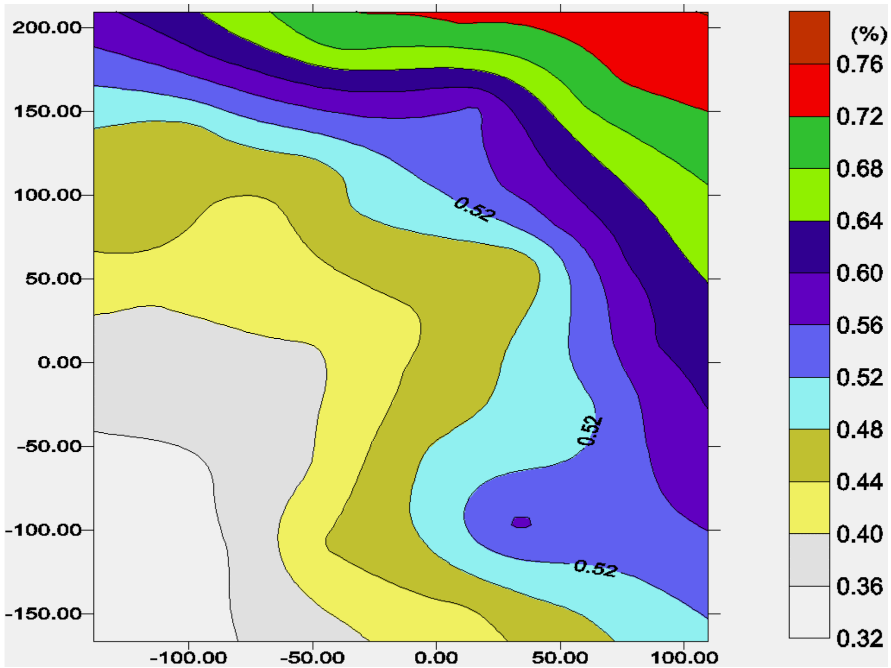

Fig. 2. Contour map of cropland SOC at first depth (0-5cm).

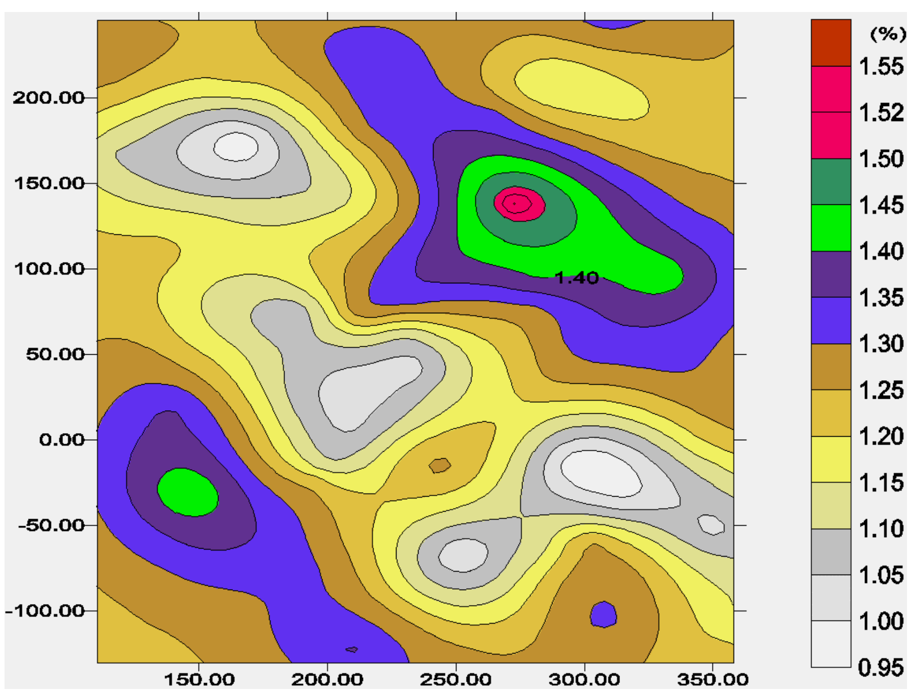

Fig. 3. Contour map of rangeland SOC at first depth (0-5cm).

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