A Three-Dimensional Representation of Soil Profile Depth and Crop Yield over an Eroded Landscape

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Abstract: Soil erosion has been a problem in agriculture since ancient times, with the major impact of erosion being the loss of soil productivity because of degradation of soil biological, chemical and physical properties. Soil erosion not only reduces crop production, but it also affects the environment. A study was started 17 years ago (1985) to investigate the effects of soil erosion on soil productivity and corn production in southwest Wisconsin, USA. Three levels of erosion (slight, moderate and severe) were identified based on the depth of topsoil above a red clay residuum (2Bt horizon) on a Dubuque silt-loam soil. In 2000 a three-dimensional (3-D) soil erosion map was developed with the aid of a profile cone penetrometer (PCP). Corn grain yield data were collected with a grain combine equipped with a yield monitor and a global positioning system. Yield was related to topsoil depth with a trend of decreasing yield with increasing erosion level. Combination of modern technologies such as 3-D soil and yield maps can help farmers better manage their land than traditional methods of erosion impact assessment.

1 Introduction

Although it is a natural process, soil erosion can create serious environmental and economical problems worldwide. Erosion and deposition of eroded soil materials have a detrimental effect on crop productivity and surface water quality. Not only crop grain yields are generally reduced in eroded soils (Frye *et al*., 1982; Chengere and Lal, 1995; Shaffer *et al*., 1995), but soil erosion also reduces total biomass, delays crop emergence, reduces plant height, and creates uneven plant populations (Lindstrom *et al*., 1986; Schumacher *et al*., 1994). However, greater and similar yields have been observed in eroded areas when compared to uneroded soils. This mainly reflects rainfall and other weather differences between years (Arriaga and Lowery, 2002; Swan *et al*., 1987). At a study site located at the University of Wisconsin Agricultural Research Station at Lancaster, Wis. (USA), it was shown that the main impact of erosion on corn (Zea mays L.) yield is caused by a reduction in the water holding capacity of this soil (Andraski and Lowery, 1992). For this reason, we feel that there is a need to develop maps of eroded landscape to better understand yield variability and better manage eroded areas.

Civil engineers have studied the use of penetrometers to explore subsoil conditions such as relative density, shear strength, bearing capacity, and settlement (deRuiter, 1988; Swedish Geotechnical Society, 1974; Sanglerat's, 1972). Use of penetrometers in agriculture has mainly been limited to investigate compaction, generally omitting soil profile depths below the root zone. However, recent publications have included a description of the use of a PCP to map soil horizons (Rooney and Lowery, 2000) and develop 3-D soil maps (Grunwald *et al*., 2001a,b; Grunwald *et al*., 2000). However, this method has not been used to create maps of eroded landscapes. Therefore, the objective of this study was to develop a new method that would help understand better crop yield variability for eroded soils on a landscape basis, and assess its potential for developing new management tools for eroded soils.

2 Materials and Methods

The research area was located in the driftless region of southwestern Wisconsin, at the Lancaster Agricultural Research Station, Univ. of Wisconsin-Madison (42° 52' N, 90° 42' W). Soil at the research

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[1] There is no Fig. 2 in this paper.

site is a Dubuque silt loam (fine-silty, mixed, mesic, Typic Hapludalfs), which formed in loess underlain by a red clay residuum. The study site is 90 by 45 m and is located on a southwest-facing slope (10% to 14%). Previous research was done to establish three levels of erosion at the site based on the thickness of soil layers above the clayey residuum (Table 1) (Andraski and Lowery, 1992).

Soil profile penetration data were collected with a PCP in May 2000. The PCP consisted of a 30E cone with a 2.0 cm base diameter, threaded to a 1.25 cm in diameter by 1.5 m long stainless steel rod (ASAE, 1999). Penetration force was measured with a 1,360 kg load cell, while depth was measured using a string potentiometer (Rooney and Lowery, 2000). The PCP was pushed in the soil profile at a rate of 5 cm • sec^{-1} with a hydraulic soil probe mounted to a truck. An electronic data logger was used to collect load cell and string potentiometer data every 0.05 sec. A digital elevation model (DEM) was created from data collected with a differentially corrected GPS unit attached to an all-terrain vehicle. Profile cone penetrometer sampling points were also geo-referenced with a GPS unit.

Penetration force data were transformed into cone index (*CI*) using $CI = F_p/A_c$, where F_p is the penetration force, and A_c is the basal area of the cone. At each recorded depth, there was an associated *CI* value, thus creating a continuous curve for the entire profile at each sampling point. These data were then analyzed using the Cluster Observation procedure in Minitab (Minitab, 2000), with the standardize variables option selected, and using the Squared Pearson and Ward method for distance measure and linkage method, respectively. The cluster procedure creates clusters, or groups, of observations that are similar.

Corn grain yield data were collected in 2001 with a combine equipped with a yield monitor and a GPS. In years previous to 2001,corn grain yield were measured by hand in areas identified as been slightly, moderately, and severely eroded.

3 Results and discussion

Depth to the red clay residuum at this site is 0.95 m, 0.74 m, and 0.45 m for the slight, moderate, and severe erosion levels, respectively (Table 1). These differences in depth simply reflect the amount of erosional removal of the upper horizons (i.e., Ap and Bt1 horizons). As the top soil erodes, lower lying soil layers become closer to the soil surface. Often times these lower lying layers have less desirable properties, mainly root restricting layers such as clayey or high density soil and/or bedrock. Depth to the red clay residuum layer at this site was used to map the different erosion phases with the PCP. Profile cone penetrometer readings were obtained at 72 locations at the test site. These 72 PCP readings were grouped in three distinct clusters; cluster 1, 2, and 3, corresponding to the slight, moderate, and severe erosion levels, respectively. Penetrometer observations between erosion levels are mainly differentiated by a reduction in the thickness of the Ap horizon, an increase in *CI*, and the appearance of spikes in *CI* with increasing erosion level. Thickness of the Bt1 soil horizon also varied with erosion level, with a trend of decreasing horizon thickness with increasing erosion level (Fig. 1). It is estimated that of the total research area 44%, 31%, and 25% is covered by slight, moderate, and severe erosion levels, respectively. Corn grain yield distribution for 2001 generally follows a similar pattern as the soil erosion distribution (Fig. 2). However, there are differences in corn yield within the same erosion levels, but at different locations on the landscape. From yield records of previous years its has been determined that rainfall amount and distribution have a significant impact on grain yields at this site (Arriaga and Lowery, 2002). Some years no differences in yield have been recorded between erosion levels, while other years yield in the severely eroded areas has been 20% less than in the slightly eroded areas.

4 Conclusions

The PCP method for mapping soils is faster and easier to conduct than mappings soils with the traditional method of taking soil cores. We feel that the PCP technique gives reasonable results compared to the traditional methods, and opens the possibility of mapping larger areas with a greater sampling density. Further, data are obtained in electronic format, making analysis and comparison to other soil and crop data easy, including yield data collected in electronic format. Maps created with this technique are of great use for management of eroded landscapes, such as the one studied here. For example, restorative efforts such as applying manures to increase soil organic matter and improve crop productivity, can be better targeted with the aid of soil erosion and yield maps created with this technique.

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Table 1 Depths and particle size information of the different soil horizons for three erosion levels at the Lancaster site (adapted from Andraski and Lowery, 1992)

Erosion level	Soil horizon	Depth	Textural class	Sand content	Clay content
		(m)		(%)	(%)
Slight	Ap	0—0.36	silt loam	5	13
	Bt1	0.36—0.95	silty clay loam	2	32
	2Bt2	0.95—> 1.13	silty clay	5	54
Moderate	Ap	0—0.20	silt loam	6	16
	Bt1	0.20—0.74	silty clay loam	2	29
	2Bt2	0.74—> 0.99	silty clay	3	45
Severe	Ap	0—0.17	silt loam	5	17
	Bt1	0.17—0.45	silty clay loam	3	33
	2Bt2	0.45—0.79	silty clay	4	40

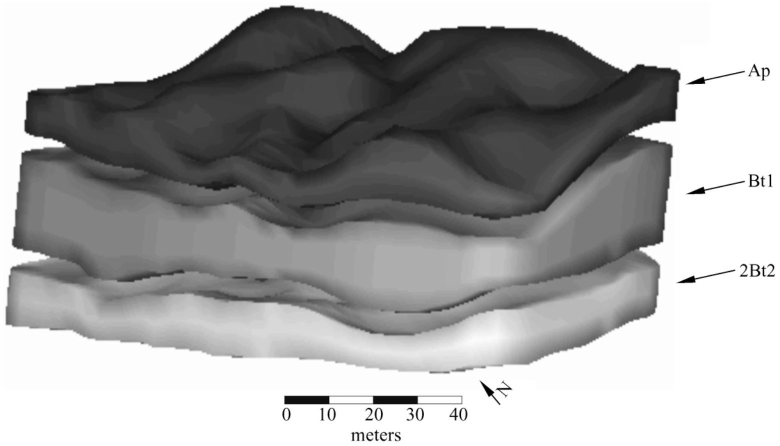

Fig. 1 Three-dimensional representation of the Ap, Bt1, and 2Bt2 soil horizons at the Lancaster site. Thickness of the 2Bt2 soil horizon is greater than shown, and the vertical axis is exaggerated ten times