

## Relating Crop Yields to Physiographic Attributes in Ohio Through Principal Component Analysis

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### ABSTRACT

On-site impacts of erosion on crop yield are difficult to evaluate because of the confounding effect of landscape position. In a six-year study of crop productivity on soils of three erosion phases and one depositional phase occupying 0 to 6% slopes in west-central Ohio, few significant differences were found when crop yields from replications of these four phases were averaged and compared. Therefore, principal components analysis was used as an alternative approach. The slope, aspect, and plan and profile curvatures of each replicate were calculated from elevation survey data. Erosion phase was significantly but weakly correlated with slope, aspect and plan and profile curvature. Quartile yield rank was significantly but weakly correlated with concave profile curvature and with the depositional phase. Quartile yield rank was also correlated with the second principal component, showing that higher yields were associated with concave profile curvature and low slopes. The data have direct relevance to identifying strategies for erosion management on the basis of its on-site effects.

### INTRODUCTION

Crop growth and yields vary with landscape position on gently sloping terrain (Olson et al., 1994; Lal, 1998). One cause of this variability is the influence of topography on water movement over the landscape (Weyman, 1973; Burt and Butcher, 1985). As a result, each landscape position exhibits some differences in the quality and depth of soil formed (Hall, 1983), and in the soil's susceptibility to erosion (Kirkby, 1978). Furthermore, the amount of plant available water is influenced by slope, aspect, and plan and profile curvature at any point on a landscape (Hanna et al., 1982).

In a six-year study of crop productivity on soils of three erosion phases and one depositional phase occupying 0 to 6% slopes in west-central Ohio, few significant differences were found when crop yields from replications of these four phases were averaged and compared (Salchow and Lal, 1999). This lack of significant difference may be due to the fact that each of the replicates differed sufficiently in physiographic attributes to influence crop productivity in some manner.

The objective of the experiment was to relate crop yield to physiographic attributes on a landscape with variable soil erosion using principal components analysis. The specific

goal was to relate crop yields over a six-year period to the measured physiographic attributes, slope, aspect, and plan and profile curvature. It was hypothesized that eroded phases have significantly low yields and that losses in crop yields on eroded sites can be compensated by increase in yields on depositional sites.

### METHODS AND MATERIALS

This field study was conducted on a privately owned farm in Clark County, Ohio, USA. The specific farm, located in west-central Ohio (39° 58' 19"N, 83° 32' 30"W) has been described in another report by Salchow and Lal (1999). Three replications of three erosional phases: (i) slightly (SL), (ii) moderately (MOD), and (iii) severely (SEV) eroded, and (iv) one depositional (DEP) phase were identified (Fahnestock et al., 1995a). The criteria used to classify the phases were depth to carbonates and percentage of topsoil remaining (Soil Survey Staff, 1993). Agronomic yields of corn (*Zea mays*) and soybeans (*Glycine max*) were measured on all phases by harvesting crops on twelve known areas each year from 1992 through 1997. Corn was grown in 1992, 1994 and 1996, and soybeans in 1993, 1995, and 1997. All phases were managed with uniform soil and crop management practices recommended for this county. Corn is sown at the seeding rate of 68,000 kernels per hectare, and receives fertilizer at the rate of 150-170 Kg N/ha (as ammonium nitrate), 20-40 Kg P/ha and 80-100 Kg K/ha as compound fertilizer. Weed control was achieved by applying glyphosate (1.7 l/ha), atrazine (2.2 l/ha) and other herbicides (metolachlor, cyanazine etc.). The seeding rate of soybean was 280,000 to 470,000 plants/ha. Depending on soil type and cropping history, soybeans received fertilizers at the rate of 13-46 Kg/ha of P and 40-120 Kg/ha of K. Glyphosate is commonly used to control weeds.

In 1997, the field was surveyed every 15.2 m with a dumpy level. The x and y coordinates were rotated to true north using the Clark County Tiger file (U.S. Census Bureau, 1997). Field notes from each year were used to locate the harvested areas on the surface plot generated from these data. The harvested location varied slightly every year because of the uncertainty involved in using internally referenced written instructions rather than an externally referenced global positioning system. In addition to surface and contour plots, slope, aspect, and plan and profile curvatures were calculated with the terrain analysis functions of Surfer (Golden Software, Inc., 1996). Slopes were reported in percent, and aspect in degrees from north, or azimuth. Plan curvature and profile curvature refer to the

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**Table 1. Crop yield data for farm B over a 6-year period.**

Phase	1992	1993	1994	1995	1996	1997
	C	S	C	S	C	S
	-----Mg/ha-----					
Slight	15.0a (11.4)	3.4b (1.3)	11.2ab (16.5)	2.2b (57.0)	8.9a (9.8)	2.0a (25.1)
Moderate	14.4A (10.8)	3.3b (13.2)	11.0b (29.5)	2.4b (17.5)	9.0a (16.3)	2.2a (23.7)
Severe	14.7a (23.9)	3.6b (26.9)	12.1ab (12.9)	3.4ab (14.3)	7.7a (26.9)	1.6a (50.0)
Depositional	15.8a (6.7)	5.7a (11.1)	14.9a (6.1)	4.1a (6.9)	7.3a (7.1)	2.4a (17.1)
LSD (.05)	4.1	1.2	3.9	1.4	2.1	1.1

C = corn; S = soybean. Figures in parenthesis are the CV.

shape of the terrain, parallel and perpendicular to the contour, respectively. Positive values indicate concave curvature, which tends to cause water flowing over the surface to converge on the landscape. Conversely, negative values indicate convex, or water-diverging, curvature.

Crop yield data for 6 years in relation to erosional phases on farm B are shown in Table 1. There were three crops of corn and three of soybeans. Corn grain yield was significantly affected by erosional phases in one out of three years. Corn grain yield in 1994 was significantly more for the depositional site compared with other erosional phases. In comparison, soybeans grain yield was significantly more for the depositional sites than erosional phases in two out of three years (Table 1). Crop yield of each of the 12 sampled areas were ranked by quartile each year, with Quartile 4 representing the highest value for that year, and Quartile 2 the median. SAS statistical software (SAS Institute, 1994) was used for descriptive statistics, including correlation coefficients between yield and all physiographic attributes, and for principal components analysis (PCA).

Principal components analysis is an ordination method, used to simplify data by reducing the number of variables. The PCA procedure generates indices called principal components, which are linear combinations of the original variables. The most efficient data description and reduction are obtained when the variables are highly correlated. Plotting the indices provides information on the extent to which objects differ. Variables are first standardized to keep any one variable from having undue influence on the results (Manly, 1994).

## RESULTS AND DISCUSSION

The sampled areas are shown on the contour plot generated from the elevation survey (Figure 1). The same points were sampled in 1992 and 1993, but harvest location varied slightly in each of the next four years. Aspect varied least for the DEP areas (Figure 2). Slopes were highest for SEV and lowest for DEP areas, while the SL and MOD phases exhibited a range of values. DEP areas were predominantly concave in both plan and profile curvature,

while SL, MOD, and SEV phases were predominantly convex.

The coefficients resulting from the PCA characterize the variation in slope, aspect and plan and profile curvatures of the 60 harvested areas. The sign and magnitude of the coefficient ascribed to each attribute determine how the data are displayed when the principal components resulting from the multiplication of the coefficients by the standardized attribute variables are plotted on perpendicular axes. The first principal component (Prin 1) accounts for 50% of the variability between the 60 harvested areas. Coefficients for Prin 1 are -0.56 for aspect, 0.59 for plan, 0.48 for slope and 0.32 for profile curvature. The second principal component (Prin 2) primarily separates the replicates on the basis of profile curvature and slope and accounts for another 25% of the variability between the 60 harvested areas. Coefficients for Prin 2 are 0.83 for profile curvature, -0.46 for slope, 0.25 for aspect and 0.17 for plan.

Aspect varies generally from high to low along the Prin 1 axis, but in the lower right quadrant, a point with aspect of 18 degrees is close to two points with aspect of 151 degrees (Fig. 3). The third principal component (Prin 3) separates the points using all four attributes, and accounts for another 12% of the variability between the 60 harvested areas. Coefficients for Prin 3 are 0.74 for slope, 0.46 for aspect, -0.35 for plan, and 0.34 for profile curvature.

One benefit of PCA is that it allows visualization, in 2 or 3 dimensions, of differences between objects with many characteristics by effectively reducing the number of variables (Manly, 1994). However, the four attributes were not sufficiently correlated (Table 2) to achieve efficient data reduction. With low correlation and unclear separation of attributes, two-dimensional plots (Fig. 4) showing the quartile yield ranking and erosion phase of each replicate plot for the years 1992 through 1997 offer little insight into the range of attributes associated with highest yields (Quantile 4) or lowest yields (Quantile 1). The letters S, M, V and D represent SL, MOD, SEV and DEP phases, respectively, and the numbers represent quartile yield rank.

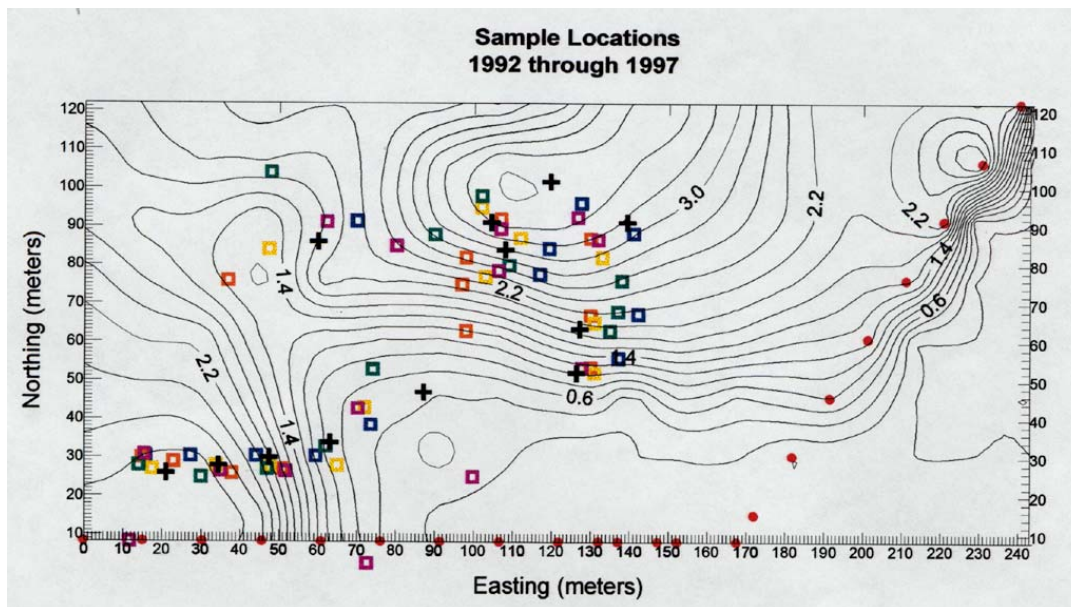


Figure 1. Topography and location of 60 points used as sampling locations for corn and soybean yield from 1992 through 1997. Red dots = fence line; Black crosses = 1992 and 1993 plots; green = 1994 sample locations; blue = 1995; red = 1996; yellow = 1997.

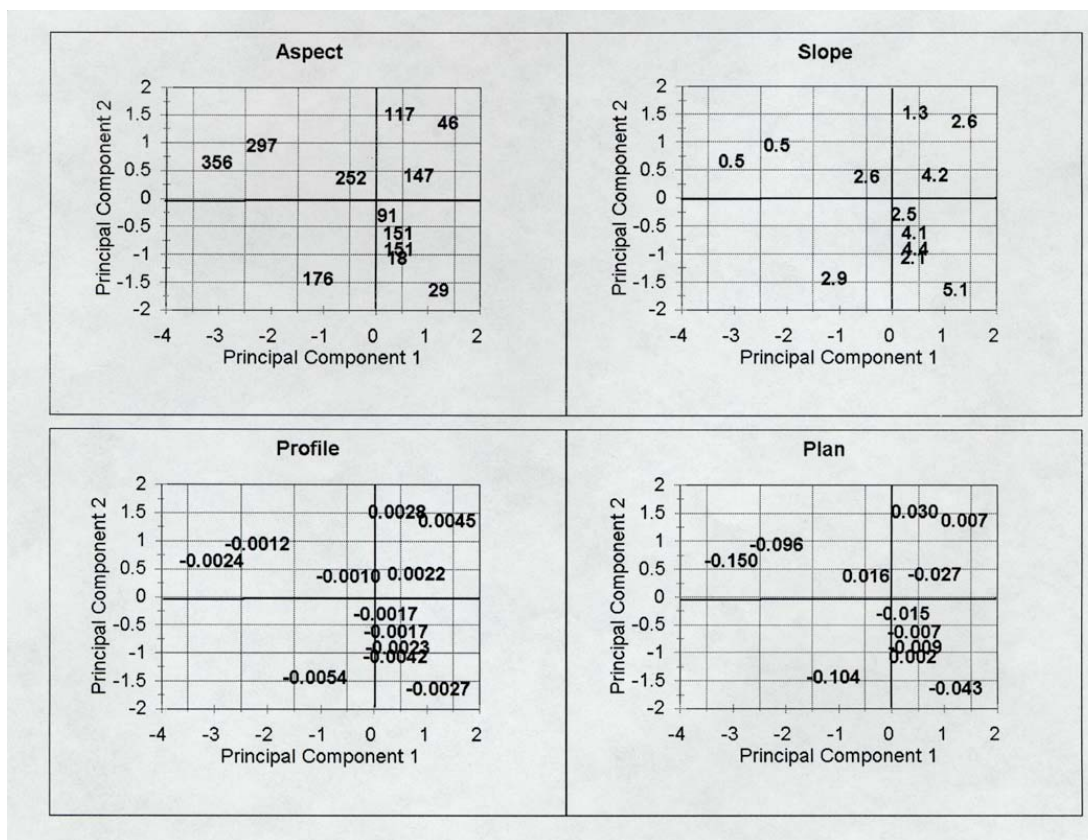
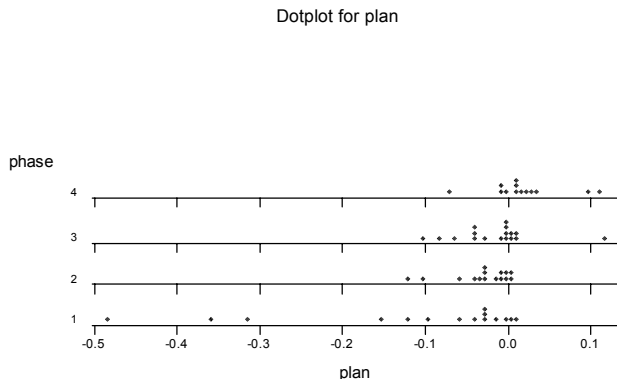
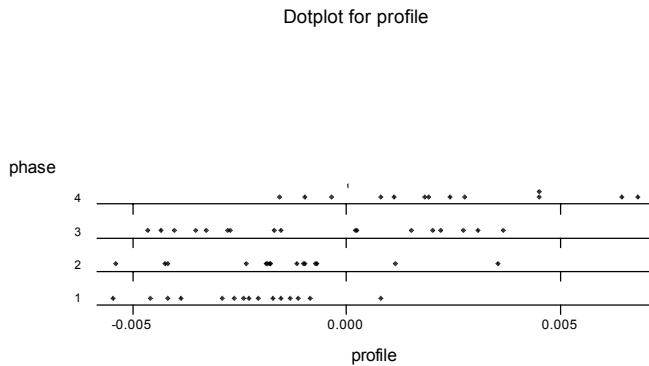


Figure 2. Range of the physiographic attributes of slope, aspect, plan curvature and profile curvature, for 4 erosion phases. 1 = slightly eroded; 2 = moderately eroded; 3 = severely eroded; 4 = depositional. Slope is in percent; aspect is expressed as degrees from North; plan and profile curvature are in units of m/m.



**Figure 3.** The actual attributes of aspect, slope, profile curvature and plan curvature are used to label the points on a graph of the first two principal components based on these four attributes. The twelve points are those harvested in 1992 and 1993.



**Figure 4.** The first two principal components for each year are plotted, using symbols for each erosion phase. Numbers represent the quartile yield ranking for each location that year. S = slightly eroded; M = moderately eroded; V = severely eroded; D = depositional phase.

Identical locations differed in quartile yield rank between 1992 (corn) and 1993 (soybeans). In 1993 and in 1995, all replicates of the depositional phase were characterized by the highest crop yield. In 1996, when there were only two DEP phase replicates, these were in the lowest two quartiles. In most cases, replicates of the four erosion phases differed in yield rank within and between years. This is partly due to the interaction of landscape, soil, and yearly weather pattern variability. The variable nature of the erosion-productivity relationship due to yearly weather pattern variation, on this and nearby similar farms, has been reported elsewhere (Fahnestock et al., 1995b; Ebeid et al., 1995; Salchow and Lal, 1999).

## CONCLUSIONS

The method described support the following conclusions:

- I. Erosion phase was significantly but weakly correlated with slope, aspect and plan and profile curvature. Quartile yield rank was significantly but weakly correlated with profile curvature and with erosion phase, suggesting that higher yields were associated with concave profile curvature and the DEP phase. Quartile yield rank was also correlated with Prin 2, showing that higher yields were associated with concave profile curvature and low slopes.
- II. Principal components analysis is most useful if attributes are highly correlated. Since the slope, aspect, and plan and profile curvature were not highly correlated, little data reduction was achieved through the use of PCA. However, the extent to which PCA succeeded in separating the replicates of the erosion phases, based on their attributes, verified why it was difficult to find significant differences between erosion phases when the yield results of the replicates were averaged.

**Table 2.** Correlation coefficients and their P values for 60 sample locations and 6 years of yield data. Erosion phases were coded 1 for slightly eroded through 4 for depositional.

	Quartile	Prin 1	Prin 2	Prin 3	Phase	Profile	Aspect
Prin 2	0.44 0.00						
Phase	0.23 0.05	0.56 0.00	0.33 0.01				
Aspect		-0.81 0.00	0.27 0.02	0.34 0.00	-0.33 0.00		
Slope	phase 4	0.69 0.00	-0.49 0.00	0.56 0.00	0.27 0.02		-0.46 0.00
Plan	3	0.82 0.00	0.35 0.00	-0.26 0.03	0.49 0.00	0.36 0.00	0.52 0.00
Profile	2 1	0.43 0.00	0.44 0.00	0.83 0.00	0.25 0.04	0.56 0.00	

- III. These values could be used to classify each harvested area by landscape position and landform, and compare erosion phases with identical physiographic attributes. Especially with yield monitor data, rather than data from small harvested areas, this approach could lead to useful generalizations.
- IV. Any generalizations about crop yields and physiographic attributes must consider the interaction of physiographic attributes with yearly rainfall pattern. These interactions are the subject of a future paper.

## REFERENCES

- Burt, T.P. and D.P. Butcher. 1985. Topographic controls of soil moisture distributions. *Journal of Soil Science* 36: 469-486.
- Ebeid, M.M., R. Lal, G.F. Hall and E. Miller. 1995. Erosion effects on soil properties and soybean yield of a Miamian soil in Western Ohio in a season with below normal rainfall. *Soil Technol.* 8: 97-108.
- Fahnestock, P., R. Lal and G.F. Hall. 1995a. Land use and erosion effects on two Ohio Alfisols. II. Crop Yields. *Journal of Sustainable Agriculture*. Vol. 7: 85-100.
- Fahnestock, P., R. Lal and G.F. Hall 1995b. Land use and erosion effects on two Ohio Alfisols. I. Soil Properties. *Journal of Sustainable Agriculture*. Vol. 7: 63-84.
- Golden Software Inc. 1996. *Surfer User's Manual*. Golden, Colorado.
- Hall, G.F. 1983. Pedology and geomorphology. p. 117-140. In: L.P. Wilding et al. (ed) *Pedogenesis and soil taxonomy. I. Concepts and interactions*. Developments in soil science IIA. Elsevier Science Publ. Co., New York.
- Hanna, A.Y., P.W. Harlan, and D.T. Lewis. 1982. Soil available water as influenced by landscape position and aspect. *Agron. J.* 74: 999-1004.
- Kirkby, M.J. 1978. *Hillslope Hydrology*. Wiley, London. 309pp.
- Lal, R. 1998. Soil erosion impact on agronomic productivity and environment quality. *Critical Rev. Plant Sci.* 17: 319-464.
- Manly, B.F. 1994. *Multivariate Statistical Methods – A primer*. Second Edition. Chapman and Hall. London. 215pp.
- Olson, K.R., R. Lal and L.D. Norton. 1994. Evaluation of methods to study soil erosion-productivity relationships. *J. Soil Water Conserv.* 49: 588-590.
- Salchow, E. and R. Lal. 1999. Crop yield variability due to erosion on a complex landscape in west central Ohio. In: R. Lal (ed) *Integrated Watershed Management in the Global Ecosystem*. CRC Press. Boca Raton, FL: 187-199.
- SAS Institute 1994. *SAS/STAT User's Guide*. Version 6. SAS Inst., Cary, NC.
- Soil Survey Staff. 1993. *Handbook No. 18. Natural Resource Conservation Service, Soil Survey Manual*, United States Department of Agriculture. Government Printing Office. Washington, D.C.
- United States Census Bureau. 1997. *Tiger files of Ohio Counties*, available on CD-ROM.
- Weyman, D.R. 1973. Measurements of the downslope flow of water in a soil. *J. Hydrol.* 20: 267-288.