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Exploring Cause and Effect Relationships of Soil Fertility on Corn Yield Variability [(1)]

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Abstract - In an experiment conducted to asses the potential causes of corn yield variability, the variation of phosphorus (P) and manganese (Mn), accounted for 79% of the variability in grain yield. Based on yield map the experimental field was divided in two general areas of management. One area (**a**) with grain yield below the average (11.30 Mg ha^{-1}) and another one (**b**) with grain yield above average. Three treatments were applied to the corn: (1) 92 kg of P_2O_5 ha^{-1}, banded at 10 cm beside of plants and incorporated into the soil; (2) Mn applied on the corn foliage at rate of 1.1 kg ha^{-1} at the four and eight-leaf growth stages and, (3) combination of treatment 1 plus 2. Also, with the use of CERES-Maize model we estimated the corn grain yield in area (**a**) by simulating two situations: (1) application of manure at 25 Mg ha^{-1} (dry matter basis), plus 100 kg ha^{-1} de ammonium phosphate at sowing time and 50 kg of N ha^{-1} applied side-dress as ammonium nitrate; (2) no manure, 100 kg ha^{-1} de ammonium phosphate at sowing time and 100 kg of N ha^{-1} applied side-dress as ammonium nitrate. The application of P and Mn fertilizers did not improve significantly the corn grain yield. Compared to the control, extra fertilizer application increase the grain yield by 1.25, 0,86, and 1.27 Mg ha^{-1} due to application of Mn, P, and combination of both fertilizers, respectively. These findings indicate that either yield was limited by constraints other than P and Mn, or application of P or Mn fertilizers did not adequately alleviate the deficiency of these nutrients in eroded soils. Corn grain yields measured in area (**a**) in 1997, ranged from 8.5 to 11.0 Mg ha^{-1} and averaged 10.5 Mg ha^{-1}. The grain yield of 10.9 Mg ha^{-1} simulated by CERES-Maize model without use of manure, was similar to the yield (10.5 Mg ha^{-1}) measured for area (**a**). With the use of manure, the CERES-Maize model simulated a grain yield of 14.1 Mg ha^{-1}, similar to the high grain yield (13.8 Mg ha^{-1}) measured on the best area of the field (area **b**).

Introduction - Site-specific farming has introduced a management system through which the farmers can begin analyzing and dealing with soil and crop variability. Site-specific farming is based upon the recognition that fields used for agriculture production are not uniform. Variations of soil physical properties, nutrient levels and water content occur from field to field and within fields. These spatial variations result from many factors such as topography, previous farming practices, and fertilizers applications inaccuracy.

Assessing variability is the critical first step in precision agriculture since it is clear that one cannot manage what one does not know [15]. The processes and properties that regulate crop performance and yield vary in space and time. Adequately quantifying the variability of these processes and properties and determining when and where different combinations are responsible for the spatial and temporal variation in crop yield is the challenge facing precision agriculture [12].

With site-specific technology, farmers are adjusting application rates of lime, manure, fertilizers, pesticides, seed rate, hybrid or variety, water and tillage. There are several steps in development a management plan for precision farming: (i) identify the variability, (ii) characterize variability, and (iii) rank the limiting factors and develop an action plan. The most meaningful factors to include in a management zone strategy will be those with the most direct effect on crop yield.

Spatial variability in crop yield is frequently related to variability in soil properties. In an experiment conducted to asses the potential causes of corn yield variability, Coelho et al. [4], found that variation in Mn, clay, NH_4, and P in the surface 15-cm soil depth, accounted for 79% of the variability in corn grain yield, as determined by the stepwise regression. This was partitioned into 61% associated with Mn, 11% with clay, 3% with NH_4, and 4% with P. The calculated value of Pearson's correlation coefficients (r) for these variables with grain yield were 0.78, -0.77, -0.33, and 0.51, respectively for Mn, clay, NH_4 and P. Corn grain yield ranged from 8.4 Mg ha^{-1} to 13.8 Mg ha^{-1} and averaged 11.3 Mg ha^{-1} with a standard deviation of 1.37 Mg ha^{-1}. Based on this information, an experiment was conducted in the following season (1998) to evaluate corn responses to P, Mn and manure and their interactions, in restoring productivity of the area with yield below of average.

Keywords: spatial variability, precision agriculture.

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(1) The reported research is part from a dissertation submitted by the senior author in partial fulfillment of requirement for a Ph.D. degree at the University of Nebraska.

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Material and Methods - The experimental site is a 53 ha field located in north central Buffalo County, NE in irrigated continuous corn under conventional tillage. The main soil is association of Typic Haplustolls, Typic Arguistolls and, Typic Ustorthents, with 5 to 11 % slope, representing respectively 50 %, 30 %, and 20 % of the total area. Based on a contour map of grain yield harvest in 1997, the experimental field was divided in two general areas of management: one area (**a**) with grain yield below the average of 11.3 Mg ha^{-1}, while the other (**b**) had yield above the average. In each area, four new plots close to existing plots were established to apply treatments of P, Mn and Mn plus P as identified by regression analysis.

Plots measuring 6 m by 9.6 m (12 rows by 6 m long) were divided in three subplots measuring 6 m by 3.2 m (4 rows by 6m long), for application of treatments. Also, control plots with no treatment were included. Three treatments were applied to the corn: (1) 92 kg of P_2O_5 ha^{-1} as triple super phosphate, banded at 10 cm to the side of plants and incorporated into the soil at the four leaf growth stage; (2) Mn was applied on the corn foliage at a rate of 1.1 kg ha^{-1} as $MnSO_4$ at the four and eight-leaf growth stages and, (3) a combination of treatment 1 plus 2. The $MnSO_4$ used was completely water-soluble and had a pH of 6.8 in solution. Data were analyzed statistically by analysis of variance and orthogonal comparison methods using the procedures of SAS system for mixed models [16].

The CERES – Maize model [9], was used in this study to simulate corn yields under different treatments. The data used as inputs to the model were collected in the first year of the experiment, as reported by Coelho [5]. With the use of CERES-Maize model we estimated the corn grain yield in area (**a**) by simulating two situations: (1) application of manure at 25 Mg ha^{-1} (dry-weight basis) before planting time and incorporated into the soil at 10 cm depth, plus 100 kg ha^{-1} of ammonium phosphate (11 – 48 – 0) at planting time and 50 kg of N ha^{-1} applied side-dress as ammonium nitrate and, (2) no manure, considering only the residue (2 Mg ha^{-1}) of the previous soybean crop, incorporated into the soil at 10cm depth, plus 100 kg ha^{-1} of ammonium phosphate (11 – 48 – 0) at planting time and 100 kg of N ha^{-1} applied side-dress as ammonium nitrate. A commercial maize hybrid (NC^+ 59) planted at a row spacing of 80 cm and 7.3 plants m^{-1} was used for both situations. Daily weather data for solar radiation, maximum and minimum temperature, and precipitation were obtained from the weather station at Kearney, NE. Irrigation inputs (300mm) were estimated from approximate sprinkler irrigation amounts used on the field. The precipitation from May/97 to October/97 was 334mm.

Results and Discussion - Although statistical analysis of data indicated a strong and positive relationship between the spatial variability of phosphorus and manganese in the soil and grain yield, the application of P and Mn fertilizers did not improve significantly ($Pr > F = 0.26$) the corn grain yield (Fig. 1). Compared to the control, extra fertilizer application increased the grain yield by 1.25, 0.86 and 1.27 Mg ha^{-1} due to application of P, Mn and combination of both fertilizers respectively. Even though extra fertilizer was applied to the area (**a**), it still had lower yield (< 11.5 Mg ha^{-1}) than area (**b**) (> 12.5 Mg ha^{-1}). Corn stand and number of ears per plant were not affected by the treatments, with $Pr > F$ of 0.49 and 0.69 respectively. The average of numbers of plants and ears per hectare were, respectively, 72.44 and 73.62 thousand.

Response to P and Mn fertilizers was erratic over the field. Soil test P and Mn levels did not accurately predict response or lack of response to P and Mn fertilizers application. Thus, the lack of response of corn to phosphorus and manganese indicates that either yield was limited by a constraint other than P and Mn, or application of P or Mn fertilizers did no adequately alleviate the deficiency of these nutrients in eroded soils. For example, results of experiments conducted by Larney et al. [10] show that P-fertilizer, while having some remedial action, was a poor surrogate in restoring the productivity of eroded soil even with adequate moisture under irrigation. This was explained due to its immobilization by an inherently high amount of calcium carbonate, which rendered it unavailable for plant uptake at higher soil pH values.

Nutrient deficiencies in eroded soil can usually be corrected by fertilizer application, but in general, the soil productivity is not restorable [2]. Phosphorus, K, N, or Zn applications to silt loam did not produce significant yield restoration in seven crops tested on artificially eroded soils [3]. The application of manure and crop residue are the main alternatives found to be efficient in restoring productivity of eroded soils by substituting for lost topsoil [10, 17].

According to previous research conducted in similar conditions and discussed before, the best alternative that farmer has for recovering the corn grain yield on degraded area (**a**) of this field is to use manure.

Measured and simulated values of grain yields are presented in Figure 2. Corn grain yields measured in area (**a**) in 1997, ranged from 8.5 to 11.0 Mg ha^{-1} and averaged 10.5 Mg ha^{-1}. The grain yield of 10.9 Mg ha^{-1} simulated by CERES-Maize model without use of manure, was similar to the yield (10.5 Mg ha^{-1}) measured for this area (Fig. 2). With the use of manure, the CERES – Maize model simulated a grain yield of 14.1 Mg ha^{-1}, similar to the high grain yield (13.8 Mg ha^{-1}) measured on the best area of the field (Fig. 2). On this area (**b**), the corn grain yield ranged from 12.0 to 13.5 Mg ha^{-1} and averaged 12.4 Mg ha^{-1} (Fig. 2). The restorative ability of manure as simulated by CERES-Maize model for area (**a**) agrees with other studies in that the beneficial effects of manure in restoring soil productivity were much greater that those for inorganic fertilizer [1, 6, 10].

Figure 3 shows yield maps of observed corn yield based on management practices used by farmer and simulated yield which would have been obtained by manure application to eroded area (**a**). As predicted by the model, this case study demonstrated the benefit of manure to recover the corn grain yield in eroded area (**a**), with 35% yield increase (3.7 Mg ha^{-1}) as compared to the use of chemical fertilizer. However, this may only be noticeable in the first year, due to the erosion problem that is present in the area (**a**).

Producers often want to know which of the cultural practices under their control most often increase their profit from a crop. Returns over variable cost can provide a good indication of the profitability of a particular practice [14]. According to Freeze et al. [7], the economics of manure as a soil amendment depend on all benefits and costs, which include loading, hauling and spreading cost, as well as specifics related to the location and nature of the application site (e.g., distance from manure source, extent of soil erosion, crop grown). The use of site specific management - SSM (Fig. 3) increased corn yield by 17% (1.9 Mg ha^{-1}). This translates to a change in economic returns of $112 per hectare per year. The importance of these results is that they permit comparison of SSM with field information and measure the return to whole field information since this can be attained without investment in SSM-technology. These estimates are conservative, as they ignore the benefit of manure in reducing the use of chemical fertilizer and improving soil structure and tilth, which reduces tillage power requirements. They also ignore the potential for residual yield benefit that may occur beyond the 2-yr horizon considered in this experiment.

Conclusions - Although it was possible to identify areas with low and high yields and determine the possible causes associated with them, the application of Mn and P fertilizers did not improve significantly the corn grain yield. Compared to the control, extra fertilizer application increased the grain yield by 1.25, 0.86, and 1.27 Mg ha^{-1} due to application of Mn, P, and combination of both fertilizers respectively. Even though extra fertilizer was applied to the area **(a)**, it still presented lower yield (<11.5 Mg ha^{-1}) than area **(b)** (>12.5 Mg ha^{-1}). These findings indicate that either yield was limited by constraints other than P and Mn, or application of P or Mn fertilizers did not adequately alleviate the deficiency of these nutrients in eroded soils. In both cases, soil erosion and related differences in pH and organic matter were the primary causes of variability in nutrient availability. Soil maps of available Mn and P showed that much of the area contained medium levels of soil Mn and low levels of soil P. Contour and soil survey maps still appear to be useful in understanding yield variability within a field. As predicted by the model CERES-Maize, this case of study demonstrated on this research the benefit of manure to recover the corn grain yield in eroded area **(a)**, with 35 % yield increase (3,7 Mg ha^{-1}) as compared to the use of chemical fertilizer.

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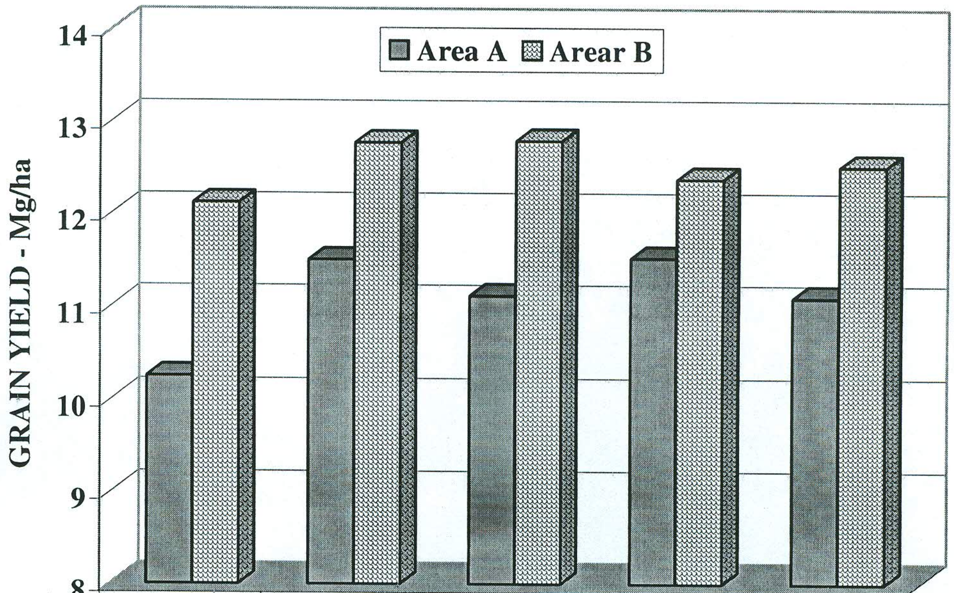
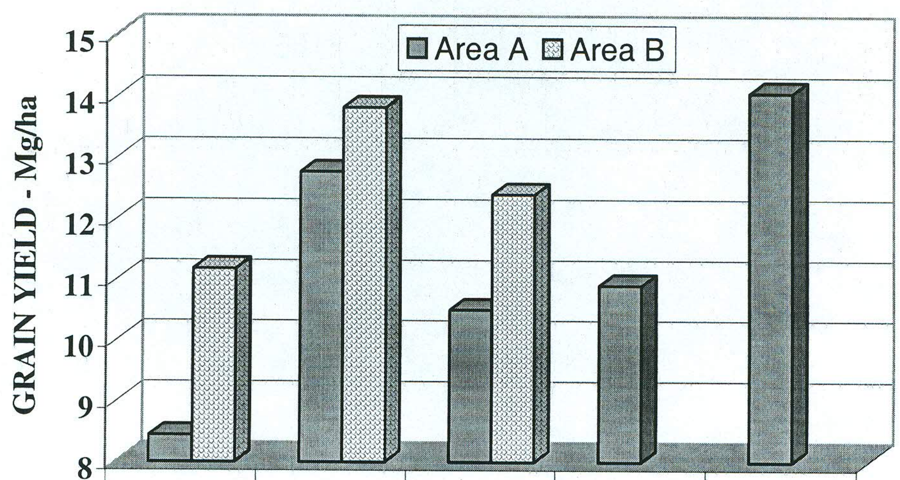


	Control	P	Mn	P + Mn	Average
Area A	10,25	11,5	11,11	11,52	11,10
Arear B	12,12	12,77	12,79	12,38	12,52

Figure 1 - Effect of phosphorus and manganese on corn grain yield. Gibbon, NE.



	MIN	MAX	AVER.	N0 MANURE	WITH MANURE
Area A	8,44	12,77	10,5	10,9	14,06
Area B	11,17	13,82	12,4		

Figure 2 - Comparison of observed (minimum, maximum, average) and simulated corn grain yields for areas (**a**) and (**b**) for different management, no manure and with manure application to area (**a**). Gibbon, NE.

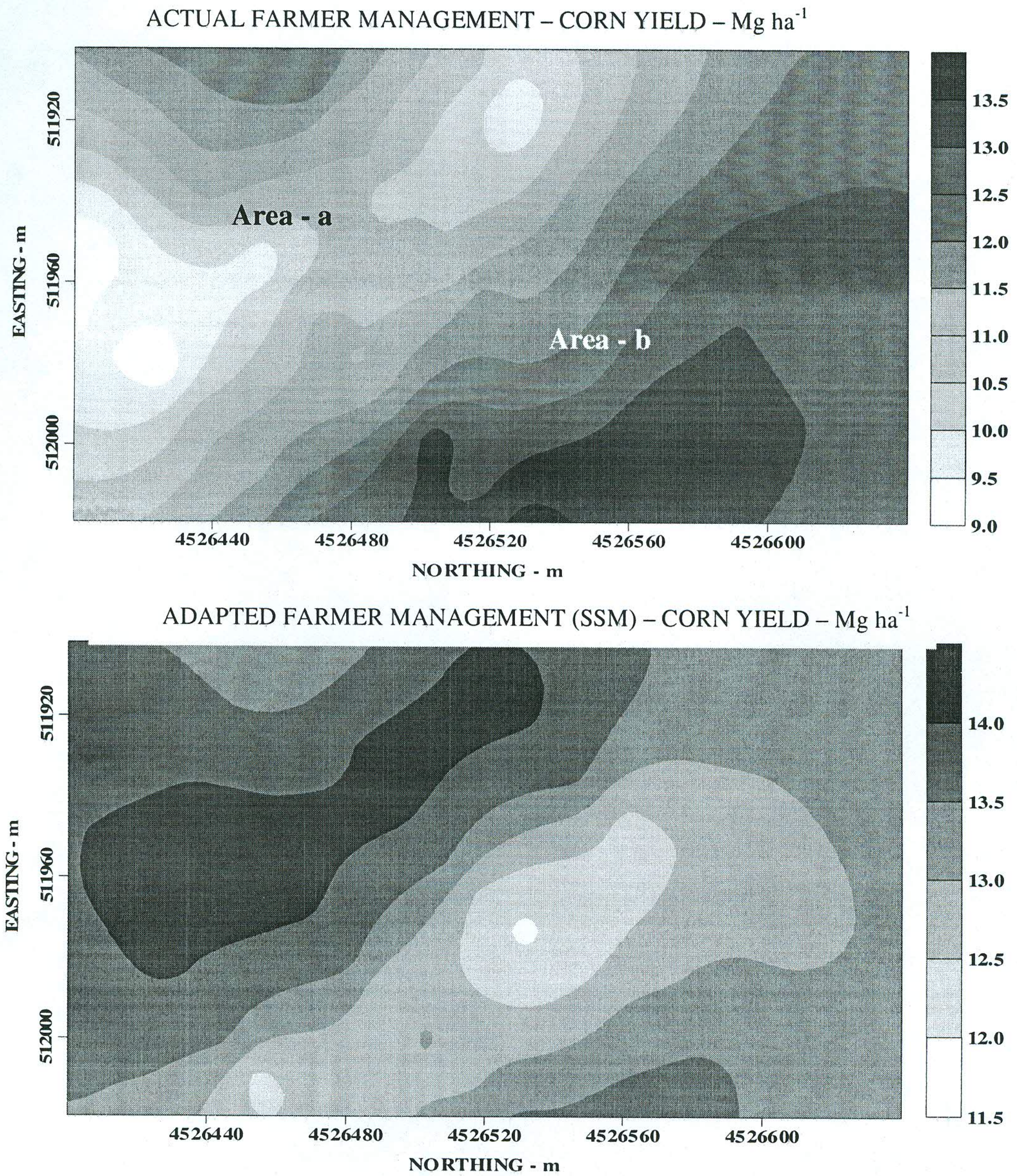


Figure 3 - Observed corn yield based on farmer management practices in 1997 (upper figure) and simulated yields (lower figure), which would have been obtained by manure application to eroded area (**a**). Gibbon, NE.