CORN AND SOYBEAN YIELD RESPONSE TO P AND K AT DIFFERENT LANDSCAPE POSITIONS

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Abstract

Soil sampling for fertilizer recommendations is most often from the surface 15 to 20 cm (6 to 8 inches). The nutrient pool available to crops however might be quite variable when considering the spatial variation in the sub-soil nutrient pool. The objective of this research was to assess the potential interaction between claypan soil topsoil thickness (i.e., depth to the claypan) and soil-test phosphorus (P) and potassium (K) on corn and soybean crop response. Plots were established in 1996 on a corn-soybean field near Centralia, MO with varying topsoil thickness (5 to 119 cm). A range of soil-test P and K values was achieved with fertilization in the springs of 1996 and 1999. Both soil-test P and K decreased dramatically over the 1997 and 1998 cropping period, indicating minimal buffering capacity of the surface soil for fertilizer additions. Erosion classes based on topsoil depth significantly explained the majority of corn yield variation in 1997 and 1999. In three crop-years yield response to higher soil test values was best in areas of enhanced topsoil thickness. Generally, sub-soil P and K were negatively correlated with topsoil thickness, an explanation for why we observed a recurring crop response to surface soil-test P and K in areas with greater topsoil thickness.

Introduction

Previous work in Missouri has shown how soil electrical conductivity can be used to estimate topsoil thickness for claypan soils (Doolittle et al., 1994; Kitchen et al., 1999), where topsoil thickness was defined as the soil depth from the surface to the high-clay Bt horizon. Crop productivity on claypan soils as affected by topsoil thickness has been documented (Kitchen et al., 1999). Corn yield on a claypan soil with no topsoil was half that produced with a topsoil thickness of 38 cm (Thompson et al., 1991). Claypan soil topsoil thickness accounted for 63% of corn yield variation for a dry year, but only 22% of yield variation for a favorable weather year (Gantzer and McCarty, 1987). Reduction in crop yield with shallow claypan topsoil has been attributed to a root-zone that is less than ideal for root growth (Scrivner et al., 1985). The influence of topsoil thickness on crop growth and yield is caused by markedly different soil chemical and physical properties between the topsoil and soil within the claypan. Specific soil factors that contribute to yield reduction when topsoil above a claypan is shallow are: 1) a decrease in root-zone plant-available water capacity (Gantzer and McCarty, 1987; Thompson et al., 1991; USDA-NRCS, 1995); 2) clay accumulation and poor soil structure within the Bt horizon that restricted root penetration (Jamison et al., 1968; USDA-NRCS, 1995); and 3) low soil organic matter, fertility, and early-season oxygen levels not conducive for root growth (Jamison et al., 1968).

A premise of variable-rate fertilizer application is that the soil's nutrient supplying capacity for crop growth is different for various locations within a field. In practice this principle is applied by sampling the surface soil at different locations within the field (such as sampling by soil type or grid soil sampling and mapping) and applying fertilizers as determined by the soil-test results. The crop nutrient pool might also be quite variable within fields when considering variation in the nutrient pool with soil depth. Typically for immobile nutrients, such as with P and K, soil sampling is from the "plow layer," or the surface 15 to 20 cm (James & Wells, 1990). Early developers of soil testing programs found that, with many soils, immobile nutrients accumulate near the soil surface. This fact along with the difficulty of deep soil sampling resulted in sampling strategies directed at and calibrated with the surface "plow layer." However, if for any given location within a field the amount of nutrients varies greatly below that soil-sampled depth, the soil-test results may not be effective at predicting the soil's nutrient supplying capacity for crops. This research was initiated to answer the question of whether a more accurate prediction of crop nutrient needs can be achieved for claypan soils by using topsoil thickness along with soil-test results?

Objectives

Research objectives were: 1. Evaluate the potential interactions between soil-test P and K and topsoil thickness on soybean and corn grain production for Mexico-Putman claypan soils; 2. Examine the potential relationship between topsoil thickness and soil-profile P and K availability.

Materials and Methods

This study was conducted within a 36-ha field located near Centralia, Missouri from 1996 to 1999. The soils of the area are characterized as claypan soils, representing the Mexico-Putnam association (Fine montmorillonitic mesic Udollic Ochraqualfs). These soils are somewhat poorly drained with a diagnostic argillic (Bt) horizon occurring below the topsoil.

Topsoil Thickness Measurements

A topsoil thickness map of the entire field was produced from soil electrical conductivity (EC) measurements using electromagnetic induction. Four areas within the field (each 27.5 m x 41.0 m) were selected to obtain a range in variation in topsoil thickness. Two areas exhibited shallow to medium topsoil thickness (5 to 37 cm) and two areas had medium to deep topsoil (35 to 119 cm). Each area was sub-divided into 27 plots (4.6 m x 9.2 m) for a total of 108 plots.

Topsoil thickness was estimated for each plot by averaging two EC measurements, using the EM-38 manufactured by Geonics Limited, Mississauga, Ontario, Canada. Actual topsoil thickness was measured for 16 plots (4 plots in each area) by soil coring with a soil core auger. For these plots, the depth of the claypan horizon was determined by visual and tactile observations in the field. Electrical conductivity readings for these plots were averaged and inverted (i.e., 1/EC) and regressed against topsoil thickness. The inverse transformation provided excellent correlation between EC reading and topsoil thickness (r^2=0.98). The regression model was then used for all plots to estimate topsoil thickness.

Soil Sampling and P and K Treatments

In early May 1996, 15 to 20 soil samples (0-15-cm depth) were obtained and composited from each area, air dried, crushed to pass a screen (2.0 mm), and analyzed for available P and K. Available P was analyzed using the Bray P1 method and available K was analyzed using an ammonium-acetate extraction method (Brown & Rodiguez, 1983) by the University of Missouri Soil Testing Lab. Treatments of different fertilizer rates were derived using the build-up portion of the P and K fertilizer recommendation (Buchhloz, 1983). Generally the amount of fertilizer to "build-up" the soil test to a critical value, the soil-test value above which a nutrient is not expected to be non-limiting, is spread out over an eight-year period because of economics. Treatments for this study were determined using build-up periods of 8, 4, and 1 years for both P and K separately, and were laid out in a completely randomized design with three replications per area. The remainder of the plots in each area were unfertilized. Fertilizer treatments were hand broadcast prior to planting. Lime was added to response areas as needed.

In the spring of 1997 soil samples were taken from plots that did not receive fertilizer applications and analyzed for nutrient availability. Comparison to 1996 soil-test results revealed a large variation among control plots within each area. We concluded that soil sampling was needed for each experimental unit in order to correctly analyze crop response. Twenty surface sample soil cores were taken and composited for each plot in March 1997 and again in early May 1999 and analyzed for nutrient availability. An average CEC value of 12 meq/100 g was used when comparing K soil-test levels to the University of Missouri fertility index.

From the May 1999 soil sampling results we ascertained a wider range in soil-test P and K was needed to evaluate potential crop response to soil-test levels. Plots were thus treated a second time with P and K fertilizer additions in late May 1999. Plots either received P and K fertilizer based on a 1-year build-up portion of the recommendation (using averaged control-plot soil tests taken in 1999) or 1.5 or 2.0 times that amount. Fertilizers were hand broadcast prior to planting.

Surface soil was sampled by plot again in November 1999. At this same time, the sub-soil of each plot was sampled (composite of 4 cores) from a depth of 15 to 90 cm on 15-cm increments using a 5.0-cm diameter Giddings hydraulic soil sampling probe. Soil-test results from these various dates were matched as closely as possible to crop years for analyzing crop response (i.e., 1997 soil sampling for 1996 and 1997 crops, spring 1999 soil sampling for the 1998 crop, and fall 1999 sampling for the 1999 crop) as opposed to analyzing crop response based upon fertilizer applications. Table 1 summarizes fertilization and soil sampling over the 4 years.

Crop Management and Harvesting

The cropping system consisted of a high agrichemical minimum-till corn-soybean rotation. Herbicides were pre-plant broadcast and incorporated. Herbicides used were metolachlor (Dual) 2.34 L ha^{-1} and imazaquin (Scepter) 0.78 L ha^{-1} for soybean, and atrazine 2.24 kg ha^{-1} and metolachlor 2.34 L ha^{-1} for corn. Corn received 190 kg N ha^{-1}. Soybeans were drilled in 19-cm rows. Soybeans were hand harvested and threshed by a stationary combine in 1996 and harvested by a plot combine in 1998 from an area 3.5 m x 4.6 m (eight center rows) within each plot. Corn was planted in 75-cm rows. Corn ears were hand harvested from an area 1.5 m x 6.0 m (two center rows wide) within each plot, and sacked for removal from the field. Grain was shelled using a stationary electric sheller.

Data Analysis

Interpretation of the effect of topsoil thickness was accomplished using an erosion classification procedure. We hypothesized that variation in crop response to topsoil thickness and fertility factors would follow erosion/deposition patterns. An erosion class for each of the 108 plots was determined from estimated topsoil thickness as follows: non-eroded (NE), 20 to 38 cm of topsoil; eroded (ER), 20 cm of topsoil; depositional (D), 38-65 cm of topsoil; and deep depositional (DD), >65 cm of topsoil. A stepwise regression procedure was performed on each year's grain yield using either soil-test P or K as a quantitative regressor and erosion class as a qualitative regressor (or dummy variable) (Kleinbaum and Kupper, 1978). The non-eroded class was the reference erosion class to which the other erosion classes were compared. Using this regression procedure, significant differences (F test, $P<0.05$) from the reference erosion class resulted in intercept (main effect) and/or slope (interaction effect) corrections but maintained the same R^2 value. The relationship of profile soil-test P and K amounts to topsoil thickness was analyzed using step-wise regression to include significant (F test, $P<0.05$) parameters.

Results and Discussions

Precipitation

Cumulative monthly precipitation for the four years of this study is compared to the 58-year mean in Fig. 1. Precipitation closely followed the long-term average in 1996 and was well above average during 1998, the two soybean years. During each of 1997 and 1999 (corn years) precipitation was above average early in the year, but monthly totals were below average during the cropping season. Droughty conditions during July and early August 1997 and July through September 1999 caused stress during corn pollination and seed fill. Stress was greatest in 1999, as might be predicted from the extended dry period.

Yield as Impacted by Topsoil Thickness and Surface Soil P and K

Ideally, in order to examine potential interactions between claypan topsoil thickness and fertility factors, a full range of soil-test levels over all topsoil thicknesses (or erosion classes) should be represented in the study. While the range in soil-test levels was narrowed after several years of cropping, we concluded nutrient levels varied sufficiently to perform this analysis.

Soybean

Little variation in soybean yield for either year was explained by soil-test P or K levels alone (Table 2). Analyzing yield with erosion class included did not change the results for 1996. In 1998 inclusion of erosion class in the analysis resulted in significant erosion class and nutrient effects for explaining yield. Over the range of soil-test P values of 10 to 30 kg/ha, soybean yield increased by about 500 kg/ha, with the D erosion class yielding 410 kg/ha more than the other erosion classes (R^2=0.22). Soil-test K and erosion class were better at explaining yield variation (R^2=0.42)(Fig. 2). Soybean response to soil-test K was not different for NE and ER soil classes. While the range of soil-test K was not as great for areas with greater topsoil thickness (erosion classes D and DD), yield response to increasing soil-test K was about double that for NE and ER.

Water was not considered limiting for either soybean year (Fig. 1) and yield was well above the long-term average for this area. Soybean is a crop reported to achieve maximum yield at a lower level of available P and K than other row crops (Ohlrogge & Kamprath, 1968; Cope & Rouse, 1973; Buchholz & Hughes, 1987). In some cases, farmers are encouraged to apply P and K fertilizer with more responsive crops and let soybeans grow using the residual P. Previous work has shown that the soybean plant has a relatively high K adsorption efficiency (Reid and York, 1955) and that even with low to medium soil test levels, it is difficult to find response to fertilizer P and K additions (DeMooy et al., 1973). However, under good soil moisture and growing conditions, fertility can be limiting for soybeans, as evidenced in 1998. Also, the results provide evidence that the crop will benefit more from fertilizer additions in deeper topsoil areas of the field. Economically, returns on fertilizer dollar investments would be greatest on areas where topsoil thickness was greatest.

Corn

Significant response to soil-test levels of either P or K was found in three out of the four tests (Table 3), but soil test alone explained very little yield variation (R^2 0.05).

For both crop years, erosion class was significant in explaining yield variation (note increases in R^2 values over soil test alone). Previous work on claypan soils has shown corn to be over five times more sensitive to topsoil thickness and water deficiency than soybean (Thompson et al., 1991). For both crop years in this study, water was limiting during pollination and seed fill (Fig. 1).

In 1997 yield was not influenced by soil-test P, but by erosion class alone. Depositional area yields were approximately twice the yields of ER and NE areas. July rainfall was very low and plants were water stressed during pollination in the ER and NE areas of the field. Concurrently, little to no water stress was observed in the D and DD areas. For these plots, remaining plant-available water at pollination varied from < 8 cm to over 30 cm in the top 1.2 m of soil and was positively related to topsoil thickness (r^2=0.87) (Spautz, 1998). Corn kernel weight and kernels per ear decreased and barren plants (no harvestable ear) increased as topsoil thickness decreased.

Yield was positively influenced by increasing soil-test K (Fig. 3). The rate of yield increase was approximately 800 kg/ha for every 100 kg/ha increase in soil-test K for ER, NE, and D classes. Yield response to increasing soil-test K for the DD area was even greater up to a soil-test level of 250 kg/ha of K. Adequate plant K has been shown to be critical in controlling transpiration and water movement within cells and tissue (Fisher and Hsiao, 1968; Brag, 1972). Under the droughty conditions experienced in 1997, a yield increase with increasing soil-test K was not surprising.

In 1999, dry conditions again prevailed during much of July and August. Yield increased with increasing topsoil thickness (Fig. 4). For the DD erosion class, yield increased with increasing surface soil-test P. Surprisingly, yield increased well beyond the critical soil-test level of 50 kg/ha (Buchholz, 1983), the point at which response to fertilizer P is not likely. (A plausible explanation for this result follows in the next section.) Even under water-stressed conditions, soil-test K did not influence yield as it did in 1997.

Topsoil Thickness and Profile Soil P and K

As this study progressed, we concluded that quantifying profile soil-test P and K, and not just the surface soil-test values, was important to understanding the potential interactions between these fertility factors and claypan soil topsoil thickness on corn and soybean yield. Thus, in the fall of 1999, each plot was sampled to a depth of 90 cm on 15 cm increments. The surface soil test would be affected by each fertilizer application, since tillage was within the top 15 cm. However, we assumed the subsoil P and K levels would be representative of the fertility of the soil's parent material. Subsoil fertility should remain relatively constant, at least over the period of this study. After summing P and

K soil-test values over the profile (0 to 90 cm) we found there to be a significant relationship to topsoil thickness (Fig. 5 and 6 for P and K, respectively). Soil-test K levels decreased with increasing topsoil thickness. Soil-test P levels decreased with topsoil thickness but increased again between 80 and 120 cm of topsoil. This finding is significant because knowledge of topsoil thickness may be used to help estimate the total nutrients in the rootzone and to predict the response of crop plants to fertilizer inputs. For example, yield response to surface soil-test P (as shown in Fig. 4) where topsoil was greatest may be in part the result of low sub-soil P levels. However, because of the topsoil thickness/profile nutrient pool relationship, it would be difficult to explore interactions of profile soil-test P and K levels and topsoil thickness using this dataset. As topsoil thickness changed, so did fertility.

Long-term total crop removal of nutrients will be greatest from field areas that produce more. Unless there has been excessive precipitation and a reduction in crop stand, grain production within a claypan soil field will usually be greatest where topsoil is deepest (Kitchen, 1999). Over time, field-average soil testing will underestimate the nutrient needs for those areas that demand more nutrients because of higher yields. Nutrients in the sub-soil will help offset this demand when surface nutrient levels are inadequate. The end result is reduced sub-soil nutrient levels in the more productive, deeper topsoil areas. Deeper topsoil in the footslope areas of the field may have been low in P and K before erosion moved the soil downslope. This is plausible if the increase in topsoil thickness downslope has occurred primarily as a result of cultivation and cropping over the past 150 years. Since fertilizer production and use has only been prevalent in the last 50 years, much of this eroded and re-deposited topsoil may have been nutrient-depleted.

Conclusions

Response to fertility was found to vary by erosion class for 3 out of the 4 crop years. Generally, crop response was to either soil-test P or K, but not to both within a year. Crop yield was most sensitive to soil-test levels in areas of deeper topsoil (i.e., areas of erosional deposition). Both soil-test P and K decreased dramatically over a two-year cropping period, indicating minimal buffering capacity of the soil for fertilizer additions. Generally, sub-soil P and K were negatively correlated with topsoil thickness, an explanation for why we observed a recurring crop response to surface soil-test P and K in areas with greater topsoil thickness.

In the future, improved fertilization programs may require more precision in the assessment of subsoil nutrients available for crops. Our research is indicating that subsoil nutrients vary significantly and may play an important role in meeting crop nutrient needs. Some areas in the U.S. currently advocate subsoil sampling to assess those nutrients. However, with the additional time and expense associated with obtaining subsoil samples, alternatives for assessing the profile nutrients would be appealing to producers.

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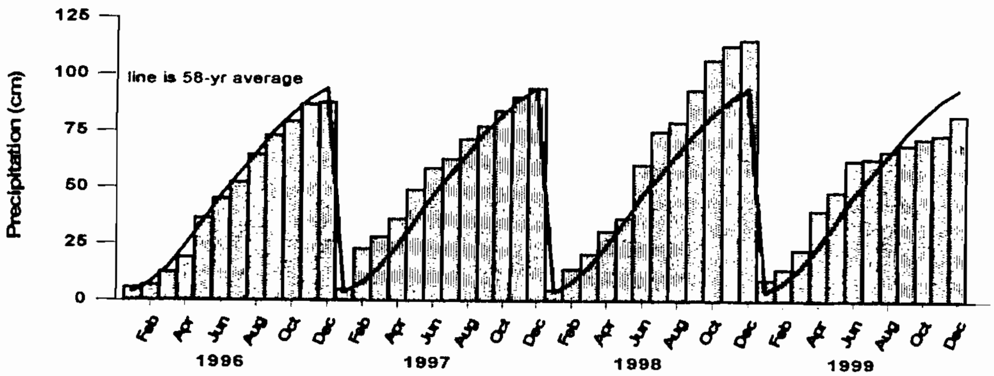

Fig. 1. Precipitation during the study years compared to the long-term average.

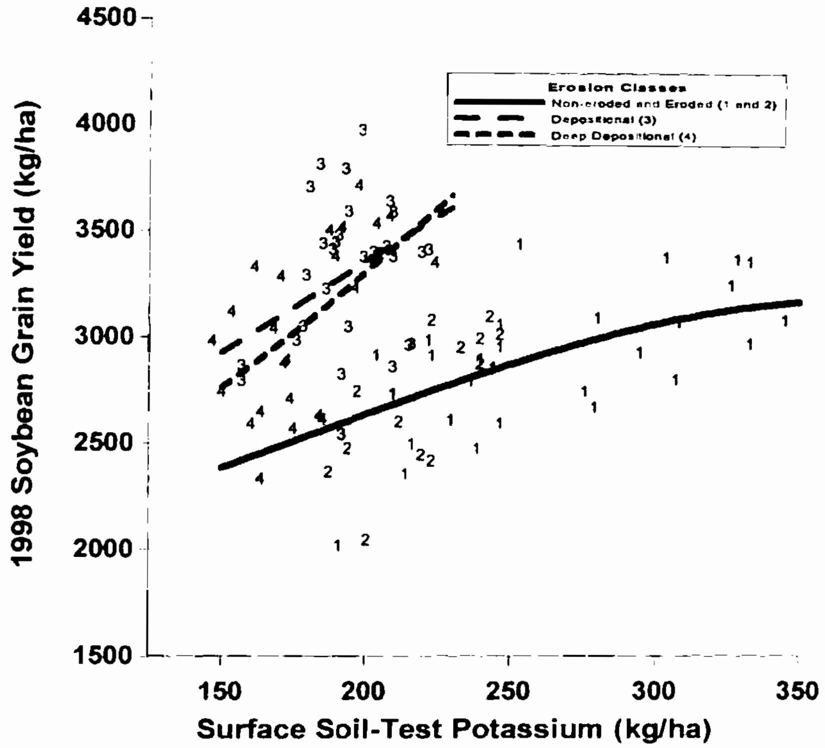

Fig. 2. 1998 soybean yield in response to surface soil-test K and erosion class. Different lines indicate significant ($P<0.05$) differences in yield response.

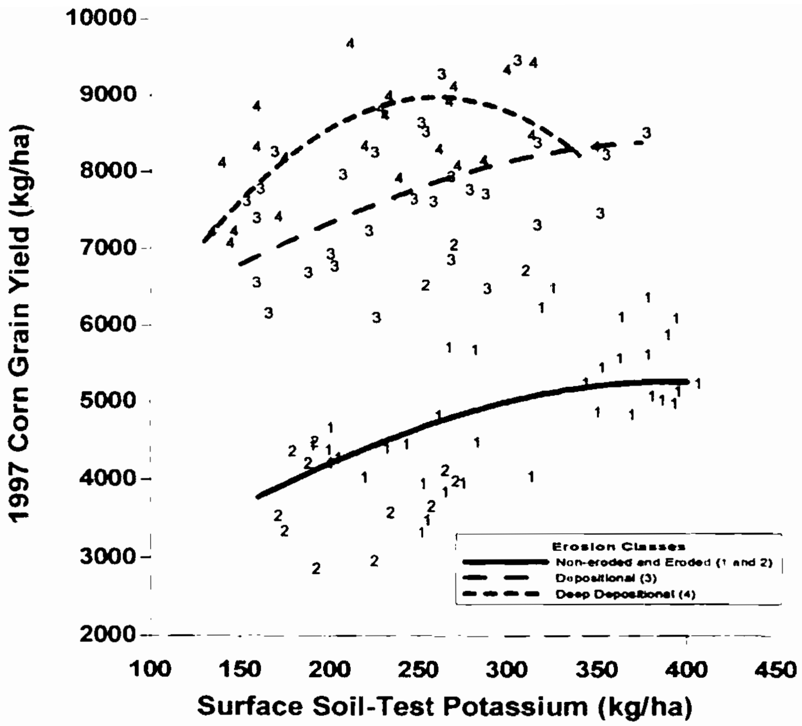

Fig. 3. 1997 corn yield in response to surface soil-test K and erosion class. Different lines indicate significant (P<0.05) differences in yield response.

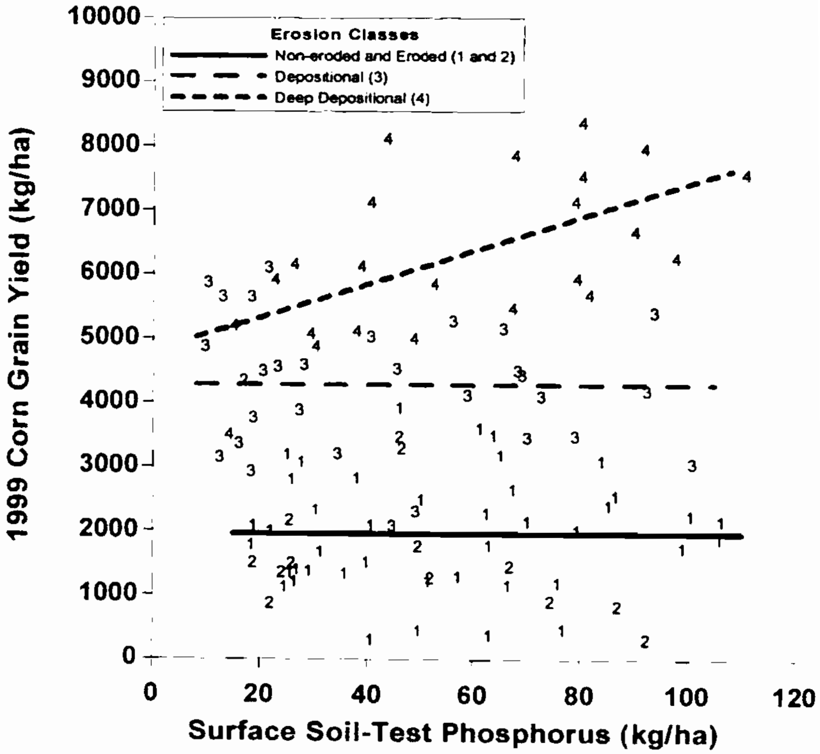

Fig. 4. 1999 corn yield in response to surface soil-test P and erosion class. Different lines indicate significant (P<0.05) differences in yield response.

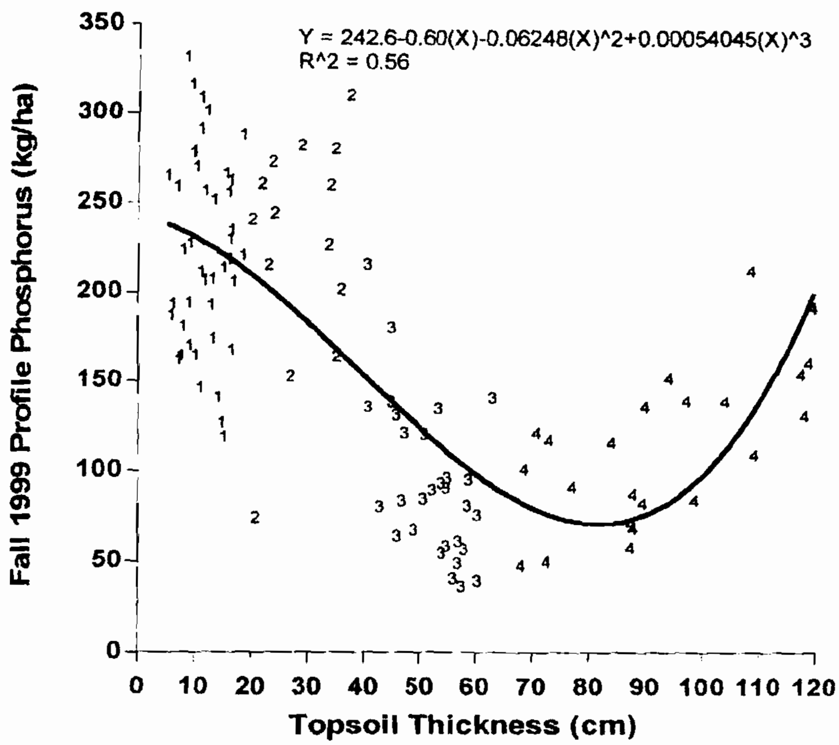

Fig. 5. Profile (0 to 90 cm) soil-test P in relation to topsoil thickness.

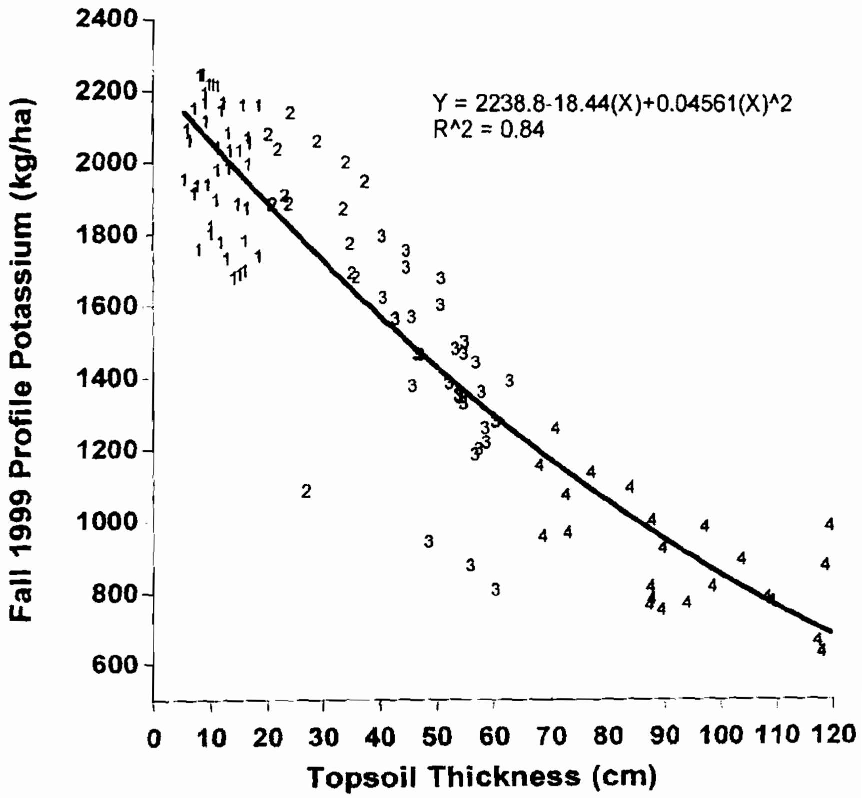

Fig. 6. Profile (0 to 90 cm) soil-test P in relation to topsoil thickness.

Table 1. Crop, fertilizer application, and soil sampling history for experimental plots near Centralia, Missouri.

	1996	1997	1998	1999
Crop	soybean	corn	soybean	corn
Fertilizer Application	pre-plant	-	-	pre-plant
Surface Soil Sampling	-	pre-plant	-	pre-plant and post-harvest

Table 2. Significant (f-test P≤0.05) regression analysis parameters when assessing the impact of fertility (P and K) and topsoil-derived erosion classes† on soybean yield.

	1996		1998	
	significant parameters	R^2	significant parameters	R^2
soil P		-	ns	-
soil K	K^2	0.11	ns	-

Table 3. Significant (f-test P≤0.05) regression analysis parameters when assessing the impact of fertility (P and K) and topsoil-derived erosion classes† on corn yield.

	1997		1999	
	significant parameters	R^2	significant parameters	R^2
soil P	P	0.03	ns	-
soil K	K^3	0.05	K	0.03
soil P + erosion class†	ER, D, DD	0.78	D, DD, DD x P	0.76
soil K + erosion class	K, K^3, D, DD x K, DD x K^2	0.83	D, DD	0.74

† Erosion classes are as follows: eroded (ER), ≤20 cm of topsoil; non-eroded (NE), 20 to 38 cm of topsoil; depositional (D), 38-65

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