Report for 2002NE1B: Relating landscape scale characteristics with phosphorus loss potential to surface waters

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PROBLEM AND RESEARCH OBJECTIVES

Runoff from agricultural land is a major source of nutrient loading into rivers in Nebraska (NE Department of Environment Control, 1991). Agricultural runoff and leaching contributed about 11 % of the total nutrient loading into the Gulf of Mexico (Maede, 1995). Part of the problem is manure produced by dairy, beef, and swine operations. In Nebraska over 5.1 million Mg of feedlot beef cattle manure are produced annually (Eghball and Power, 1994). Application of manure of this magnitude often only on agricultural lands close to the concentrated animal farm operation results in concentrated and stratified P levels on the soil surface.

The effects of manure on soil P available to crops are commonly evaluated with standard soil P testing such as Bray-P, Olsen-P, Mechlich-3 P depending on soil characteristics (Olsen and Sommers, 1982, Mechlich, 1984). Extensive research has studied the relationship between standard soil P test with P runoff (Sharpley, 1995; Sharpley et al., 1981, Mcdowell and Sharpley, 2001). Some techniques of runoff analyses (e.g. sodium hydroxide extraction, iron oxide-impregnated filter paper strips, and ion exchange resins or capsules) have also been correlated with runoff P bioavailability (Pote et al., 1996, 1999). These research were done on controlled experimental treatments, conditions, and environmental setting and scale, with limited use for other conditions, and environmental settings and/or require extensive testing under conditions involving a range of manure management approaches (Oberle and Keeney, 1994; Sharpley et al., 1995). While better soil tests are part of the solution in estimating the effects of manure managements on soil nutrient status, it is necessary to extend these sample-scale analyses to a landscape scale if the information is to be most useful for assessment of future impacts of manure managements on water quality. The key to this is a modeling approach that integrates the soil analysis for biologically available P (BAP) with other available soil databases.

The modeling approach requires mathematical models constructed to represents physical processes and mechanisms. Examples of models that are made to represent the impact of management practice on major physical processes are the "erosion-productivity impact calculator, EPIC" (Sharpley and William, 1990), the "chemicals, runoff, erosion from agricultural management system, CREAMS" (Knisel, 1980), and the "groundwater loading effects of agricultural management system, GLEAMS" (Knisel et al., 1993). These models simultaneously involve hydrology, erosion processes, runoff and sediment N and P loading, soil nutrient dynamics, and fate of applied pesticide. Despite uncertainties inherent in the modeling approach, the approach provides flexibility to evaluate and compare a wide range of existing and potential manure management practices.

The *objective* of this study was to evaluate the effects of manure on soil P level and soil P stratification at the first 15 cm depth and to predict soil P dynamics over a range of manure and soil managements using a modeling approach. Our specific objectives were: 1) To measure BAP of soils which have or have not received animal manure, using a group of standard agronomic and environmental tests, and, 2) To use a simulation model, GLEAMS, to predict the dynamics of soil P status and P stratification, and its effects on runoff water quality of different landscape settings upon imposing various manure and soil management scenarios.

METHODS

Field Site Selection

Three sites having the same soil type, Moody silty clay loam (fine-silty, mixed, mesic Udic Haplustolls), were selected to represent the range of soils present in areas of Nebraska with heaviest concentrations of livestock (primarily the northeast). For identification the sites were named as Haskell, Nebuda, and Roeppert. All three sites are in dryland corn-soybean production.

The Haskell site is located on a toposequence of a rolling landscape having convex shape from summit to shoulder, rectilinear backslope, and concave footslope (Fig. 1). This site was delineated from a larger area used for manure study from 1999-2001 at the Haskell Agricultural Laboratory, Concord, NE. Details of this study are presented in detail by (Ginting et al., 2003). During this study the area were divided into 18 strips allocated in a randomized complete block design with three replications of site specific and uniform application of cattle feed-lot manure (CAM) treatment, site specific and uniform application swine manure (SWM) treatment, uniform application of commercial N fertilizer treatment, or control (CTL) check (no treatment). Since our concern was on manure effects on soil P dynamics, only soil from strips with uniform application of CAM, SWM, and CTL were sampled. The manures were applied annually (before planting) in 31 March 1999, 15 Nov. 1999, and 19 April 2001 for corn growing in 1999, 2000, and 2001, respectively. Manure was incorporated into 15-cm topsoil by disking within 24 hours after application. Rate of application was based on corn N needs, adjusted with soil nitrate test. Rate of manures application and corresponding P applied is presented in Table 1.

The Nebuda site is near West Point, NE ($96^{o}66'$ W long., $41^{o}89'$ N lat.). The field site is approximately 4 ha and has received feedlot beef manure for at least the last five years. Manure has been surface applied and incorporated by shallow disking. The field landscape is convex with an eroded intermittent channel that occurs in the middle extending from upland to bottomland of the field (Fig. 2). The Roeppert site is also near West Point, NE ($96^{o}67'$ W long., $41^{o}88'$ N lat.). The field site is approximately 5 ha and has no manure history with landscape form similar to the Nebuda site.

Soil Sampling

In May 2002, soil samples were collected in three transects (at summit and shoulder, backslope, footslope and toeslope positions) across the field. At the Haskell site, samples were taken from strips treated with uniform applied CAM, SWM, and CTL. At each of the three position, 8 to 10 soil cores (each 1.8 cm diameter) were collected at 0-5-, 5-10-, and 10-15 cm depths, and then composited by each depth. All soil samples were air dried and ground to pass 2 mm sieves and analyzed for total P, Bray and Kurtz-1 P, iron strip P, and water extractable P. On selected samples soil clay, silt and sand content were also measured.

GLEAMS Model Description

GLEAMS is an extension of CREAMS that considers vertical pathways of pesticide and nutrient cycling and transformation, and estimates pesticide and nutrient loadings at edge-of –field and bottom of root zone loadings. GLEAMS includes four components, i.e. hydrology, erosion, pesticide, and plant nutrients. Field operations that modify the response of each component to climate (updateable parameters) could be represented. Examples are dates of planting, harvest and crop rotation, date- rate-method of application of fertilizers, manure, and pesticide, irrigation, fertigation, chemigation, tillage systems and implements, terracing, contour tillage, residue management. Because P dynamics and loadings in runoff water and sediment were the focus of our study, only hydrology, erosion, and nutrient components were considered. The hydrology and erosion components have been described in detail by Knisel et al., 1989, Leonard et al., 1987; Leonard et al., 1990.

Model Parameterization

The main concern of any model-whether it is realistic, able to portray the functioning and the emergent properties of the system-depends greatly on parameterization. For this purposes model first needs sensitivity analysis and calibration against a measured properties/behavior of a system and then used the calibrated model parameters in the prediction of future properties/behavior of the same system (and other resembling system). For this purpose two-step approach was taken. First calibrate model parameters using the manure treatment of the detailed experiment at Haskell site. General or non-site specific parameters (constants that controls the effects of climatic variables on hydrology, erosion, and nutrient components, constants that partitioning P flows among P pools and decomposition) are left unchanged. During the sensitivity analysis and model parameter calibration, parameters that caused deviation (between the simulated and measured P) of less than 10% were taken as the best fit. Second, the calibrated parameters are used to predict the P dynamics and its effects on runoff P losses from the field at Haskell and Nebuda sites. Site-specific parameters and initial conditions were either measured or estimated using readily available database.

Hydrology Component

Drainage area, hydraulic slopes, field length:width ratio, and other topography-related information were derived from topographic measurements (Figs. 1 and 2). Effective saturated conductivity immediately below the root zone and effective rooting depth were estimated from Dixon and Cuming County Soil Surveys. Runoff curve number of 78 was selected for row crops with straight rows and good hydrologic condition. The elevation and latitude of the sites were estimated to be the same with those of the closest weather station, where the daily climatic parameters from 1 Jan 1982-31 Dec. 2002 were obtained. Monthly maximum and minimum air temperature, solar radiation, wind speed, and dew point for each year were derived from the daily records. These monthly values for each year were used for yearly updates. Daily dew point was estimated from the relative humidity and the mean daily temperature.

Preliminary GLEAMS simulation indicated that P loss was responsive to P stratification. Therefore each soil P sampling depths (0-5, 5-10, and 10-15 cm) was regarded as a horizon, identified as Ap_1, A_{P2}, $A_{P3,}$ respectively. The rest of the depth of AP and A horizons was regrouped as A, and all the B (B_1, B_2, and B_3) horizons were made as B-horizon. This scenario results in total of 5 horizons representing the soil profile. Physical property measured for the first 3 top horizons was texture (clay and silt). Other mean soil physical properties (porosity, bulk density, field capacity, and wilting point, and evaporation constant) for all horizons were estimated using the textural information Soil chemical properties (pH, base saturation, and CaCO3) were estimated using available sources.

Crop and tillage data (Table 1) was used for updateable parameters (e.g. crop rotation cycles, crop and irrigation management data, and potential crop productivity). Based on Table 1, continuous corn with no irrigation management was simulated. Default GLEAMS leaf area data of corn for grain were used and not adjusted in the simulation.

Erosion Component

For the Haskell site execution sequence of erosion was "overland". The overland profile was represented by 5 points, each having distance (from the upper end of overland profile) and slope information derived from the overland profile transect (Fig. 1). In this simulation soil erodibility value of 0.29 was fixed for all parts of overland profile. The crop and tillage data (Table 1) was used for the number and dates of parameter (crop factors, management factors, and hydraulic roughness factor) updates. The updateable parameters were applied uniformly for all parts of the overland profile. The practice factor was set as one (no contouring factor) because practices was done up-and-down the slope. The crop factor ranged from 0.3 (after harvest with corn residue on surface) to 0.7 (after autumn moldboard plow and field cultivation prior to planting when soil residue was minimum). The hydraulic roughness factor, Manning's "n" value, ranged from 0.14 (smooth after field cultivation) to 0.046 (rough, after moldboard plowing).

For the Nebuda site execution sequence of erosion was "overland-channel" (Fig. 2). The overland profile was represented by 5 points with distance and slope information derived from Fig. 2. Derivation of overland profile parameters and overland updateable parameters were done with the same procedure as the Haskell site. Channel profile was divided into 3 segments based on the slope of the channel and channel top-width parameter. The channel top-width parameter is one of the channel updateable parameters. However, to represent the increase of channel top-width in up and down stream direction, the channel top-width was used to divide the channel into three segments. In this case channel top-widths do not change during field operations (same value for all the updates) and during simulation period. Other updateable channel parameters are Manning's "n" and depth to non-erodible layer.

Nutrient Components

Soil profile horizons scenario follows that in hydrology component. Initial crop residue was estimated to be 5000 kg ha^{-1}. For each horizon, initial N values (total N concentration, nitrate-N concentration, potentially mineralizable nitrogen, organic N from animal waste in plow horizon) were estimated. The P values from control treatment at Haskell site was used as the initial P values for the A_{p1}, A_{p2}, and A_{p3} horizons of the cattle treatment because no soil-P analysis was performed at the initiation of experiment in April 1999. This is based on assumption that the P values of control in 2002 would be pretty similar to that when the experiment started. Nitrogen concentration, 2.3 mg L-1, in rainfall was adapted from Chapin and Uttomark (1983). No N and P in irrigation because no irrigation was applied.

Updateable plant nutrient parameter changed with management practices (animal waste application and any tillage to incorporate and mixed manure with soil). Number of manure application every year (one), number of tillage operations, and date of harvest every year is derived from Table 1. Potential corn grain yield was 15 Mg ha^{-1}. Dry matter ratio (ratio of total dry matter production to grain), C:N ratio, and N:P ratio was estimated to be 2.0, 40, and 5, respectively based on a continuous corn experiments in eastern Nebraska. Rate of manure application, and parameters for manure N, P and organic matter are based on managements (Table 1) and manure analysis (Table 2). Manure is incorporated into top 15 cm depth. Depth of tillage by disking and field cultivation is 15 cm, and depth filled cultivation followed by ridging is assumed to be 20 cm. Mixing efficiency of tillage equipment uses GLEAMS default value.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Extractable P

Extraction showed a high stratification of both water and Bray extractable P levels. The highest level of extractable P was found in the 0-5 cm (Figs. 3 to 5). This is expected because of manure surface application and shallow incorporation as well as plant residue accumulation overtime. The 5-10 cm had lower P levels compared to the surface 0-5 cm.

For the Nebuda site, the extractable P levels were high at all transects at the 0.5 cm depth compared to the other two lower depths (Fig. 3). The level of P in the channel of the Nebuda site (transect 3) was high at all positions, except for the lowest elevation level. At the lowest point of the channel, the extractable P level was as low as what would be found in unmanured soil. We postulate that rapid and accelerated flow occurring close to the exit of the field resulting in high soil erosion. This high erosion resulted in deep cuts that possibly eroded the P enriched soil out of the field.

The Roeppert site has no manure history except of inorganic starter P application. The levels of both water and Bray extractable P were much lower in comparison to the Nebuda site. The water extractable P was lower than 5 mg kg^{-1} at all depths, while the Bray P levels reached only 35 mg kg^{-1} at the 0-5 cm depth (Fig. 4).

The Haskell site surface 0-5 cm depth was enriched with P due to swine and cattle manure additions (Fig. 5). In comparison to the Nebuda site, the P levels due to manure application were much lower. This can be explained by the short manure application history of the Haskell site compared to the Nebuda site. In addition, manure at the Haskell site was applied at agronomic rate for the last three years while the Nebula site probably utilized manure for disposal of cattle manure from near by animal feedlot. The 5-10 cm depth soil P levels were also higher compared to the control (check) at the Haskell site, indicating some vertical mobility of the applied P to lower depths.

The significance of the results is that soil is enriched with P within few years after manure application. In landscapes that are susceptible to erosion, the P enriched soil can be a significant source of P in runoff from fields. Based on the soil test and climate factors, the expected level of erosion is reported below in preliminary GLEAMS modeling.

Preliminary model prediction

The GLEAMS simulation for the Haskell and Nebuda sites were done for 20 years. The model simulation was responsive to the P stratification, indicating that the model was sensitive to soil P stratification of the top 5 cm. The model assumes the top 1 cm as the active erosion layer, where P and water interactions occurs the most. However the depth of sampling for this study was surface 5 cm of active layer where most of the P was present and erosion occurred. The simulation was done for ortho P in runoff, sediment ortho P, and sediment organic P. The simulation was then compared to the check or control at the Haskell site and for the Nebuda site compared to the unmanured Roeppert site.

For the Haskell site, runoff ortho P, sediment ortho P, and sediment organic P were high compared to the unmanured check (Fig. 6). However, the most significant loss from the Haskell site was the sediment associated organic P. Although the organic P is not immediately available for the growth of biological organisms in surface water, it is a potentially available source in the short and long-terms. Cattle manure also resulted in higher runoff ortho P and sediment ortho P compared to swine manure. This is associated with inherently high level of P in cattle manure compared to swine manure (Table 2). The results at the Nebuda site were similar to the Haskell site. Compared to the unmanured Roeppert site, there was larger loss of runoff orho P, sediment orh P, and especially sediment organic P (Fig. 7).

Following this preliminary simulation, sensitivity analyses will be done on the Haskell site to assess the reliability of model predictions. Additionally, various management scenarios will be used to assess the magnitude of P loss or the reduction of P losses.

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Table 1. Major field operations at Haskell Site, Concord, NE

Activities	DOY	Date and Description
		1999
Spring manure and tillage	90	31 Mar -1 Apr; swine 56 m^3 ha^{-1}; Cattle 78.4 Mg ha^{-1}, disked
Field cultivate and planting	120	30 Apr., 54000 seeds ha^{-1}
Field cultivation	165	14 June; field cultivation on all plots
Harvesting	277	4 Oct.; corn residue left in the field
Autumn manure applied	319	15-16 Nov.; Swine 12 m^3 ha^{-1}; Cattle 78 Mg ha^{-1}
Autumn tillage	320	16-17 Nov.; Disked the manure plots
		2000
Spring tillage	110	26 Apr.; Pre-plant cultivation on all field
Corn planting	122	1 May; 54000 seeds ha^{-1}
Corn harvest	251	7 Sep.
		2001
Cattle manure and tillage	109	19 - 20 Apr.; Manure application followed by disking
Swine manure and tillage	117	27 and 28 Apr.; Manure application followed by disking
Field cultivation	129	9 May; pre-plant cultivation on all plots
Corn planting	130	10 May; 54000 seeds kg ha^{-1}
Corn harvest	263	20 Sep.
Cattle manure and tillage	312	8 Nov, 76 Mg ha^{-1}, disked
Swine manure and tillage	319	15-16 Nov, 43 m^3 ha^{-1}, disked
		2002
Spring tillage & Planting	136	16 May, Disking
Soil Sampling	137	17 May, needed for model calibration
Harvest	254	11 September

Table 2. Analysis of beef cattle and swine manure applied annually at the Haskell site.

	Cattle manure‡			Swine manure		
Element†	1999	2000	2001	1999	2000	2001
Organic N (g kg^{-1} or g L^{-1})	8.53 $\pm$ 0.61	7.10 $\pm$ 0.82	5.8 $\pm$ 0.28	4.20 $\pm$ 0.34	3.46 $\pm$ 0.05	1.32 $\pm$ 0.02
NH_4-N (g kg^{-1} or g L^{-1})	2.18 $\pm$ 0.30	0.22 $\pm$ 0.03	0.49 $\pm$ 0.11	3.08 $\pm$ 0.03	3.22 $\pm$ 0.17	2.53 $\pm$ 0.01
NO_3-N (g kg^{-1} or g L^{-1})	8.58 $\pm$ 1.17	409 $\pm$ 120	323 $\pm$ 87	0.10 $\pm$ 0.00	0.10 $\pm$ 0.00	0.10 $\pm$ 0.61
Total N (g kg^{-1} or g L^{-1})	10.7 $\pm$ 0.87	7.72 $\pm$ 0.76	6.61 $\pm$ 0.43	7.29 $\pm$ 0.38	6.69 $\pm$ 0.20	3.86 $\pm$ 0.02
P (g kg-1 or g L^{-1})	3.69 $\pm$ 0.33	3.62 $\pm$ 0.33	3.47 $\pm$ 0.62	1.47 $\pm$ 0.16	1.39 $\pm$ 0.70	0.66 $\pm$ 0.02

†the unit is mass for beef cattle manure, and mass per volume for the swine manure.

‡Manure applied in Mar. 1999, Nov. 1999, and Apr. 2001 for the growing season of 199, 2000, and 2001, respectively. Values following + are standard errors.

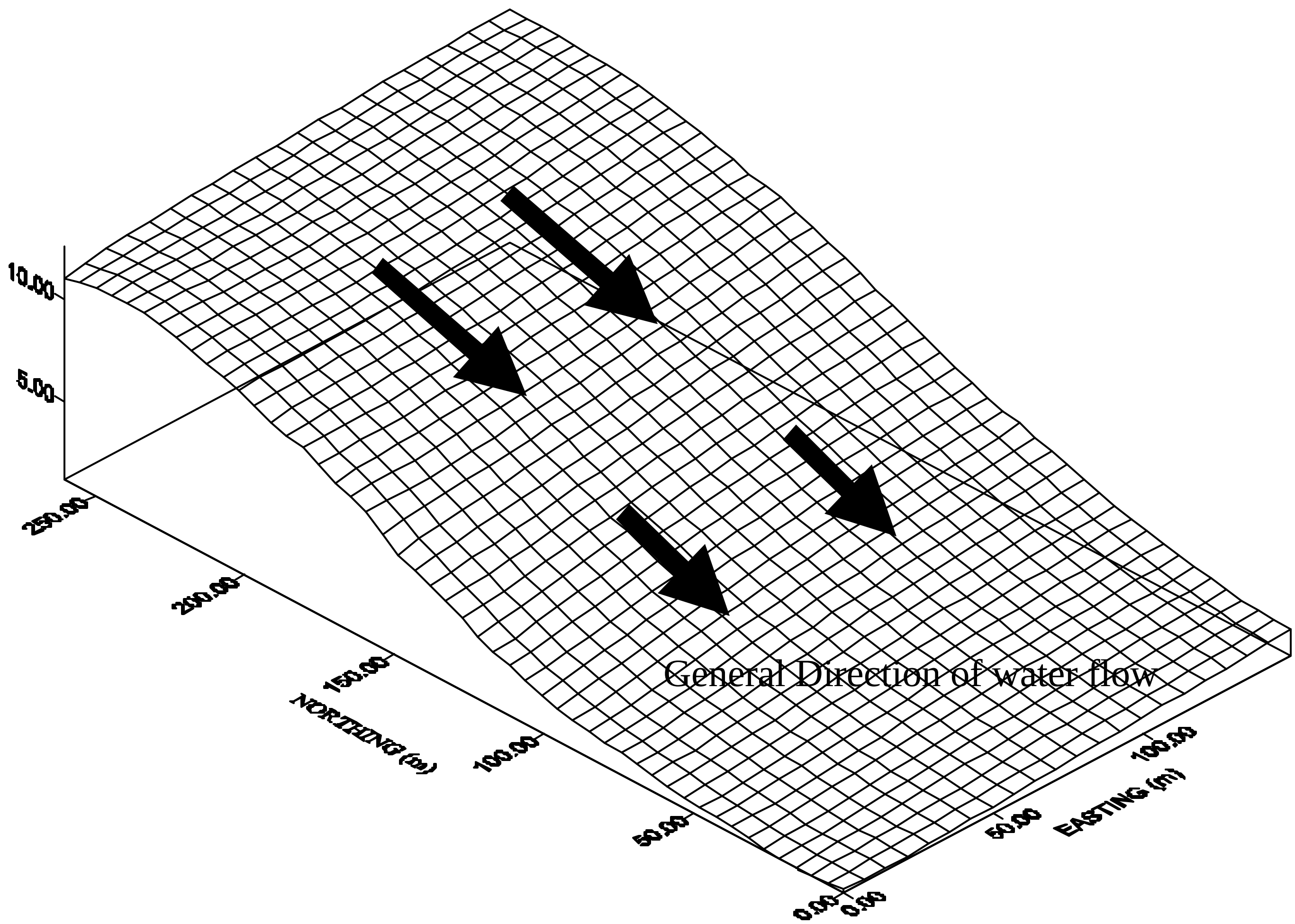

Fig. 1- Haskell field site landscape.

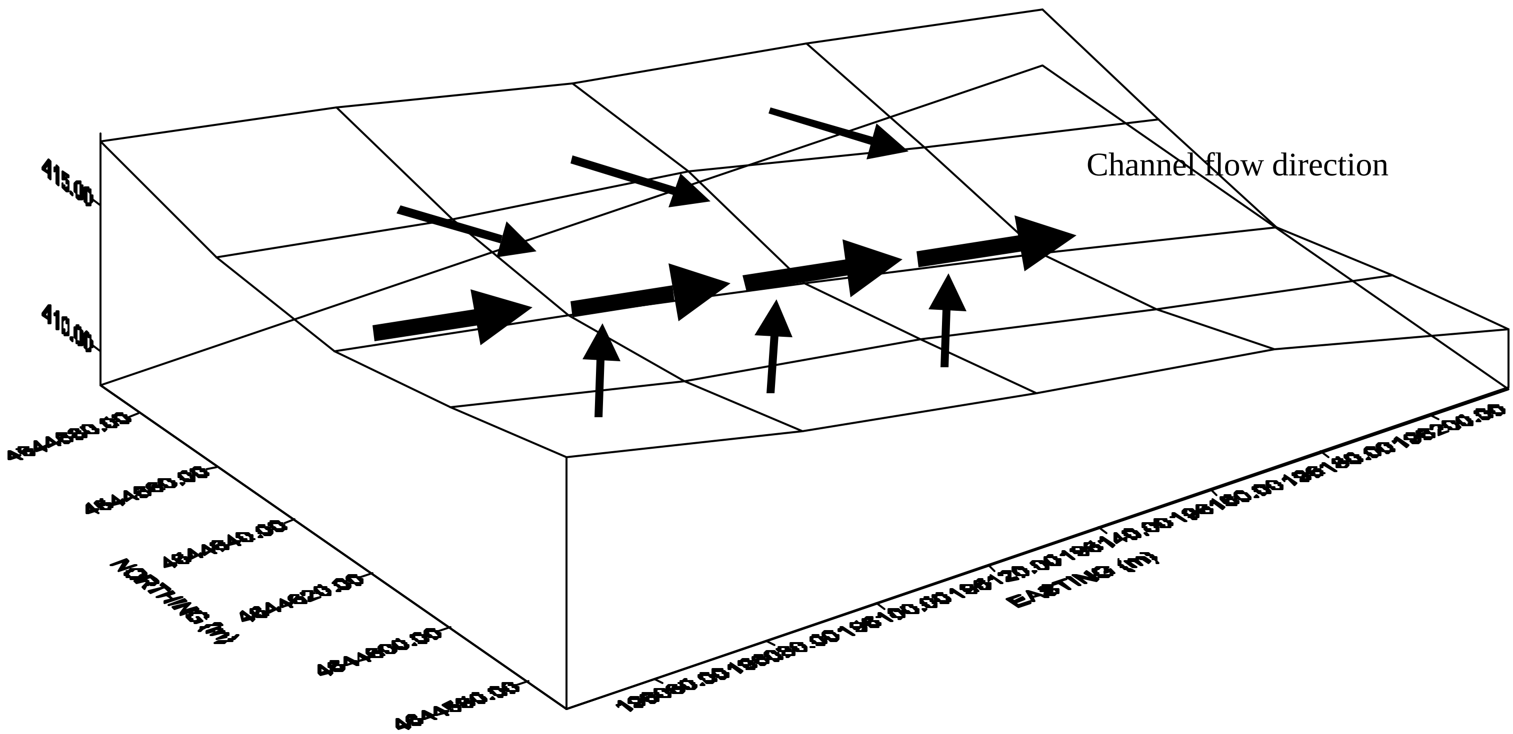

Fig. 2- Nebuda field site landscape.

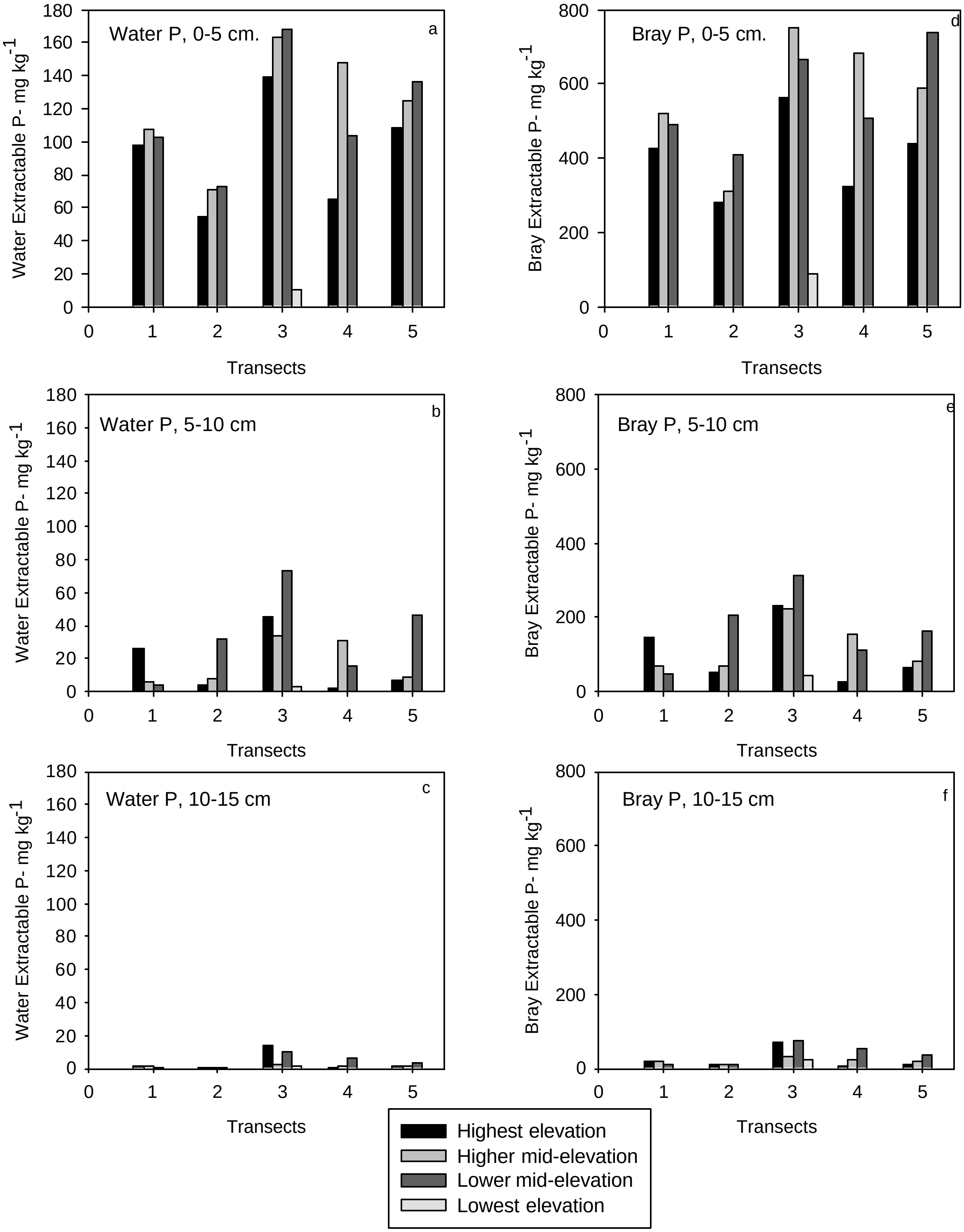

Fig. 3 Water and Bray Extractable P at the Nebuda site at depths of 0-5 cm, 5-10 cm, and 10-15 cm.

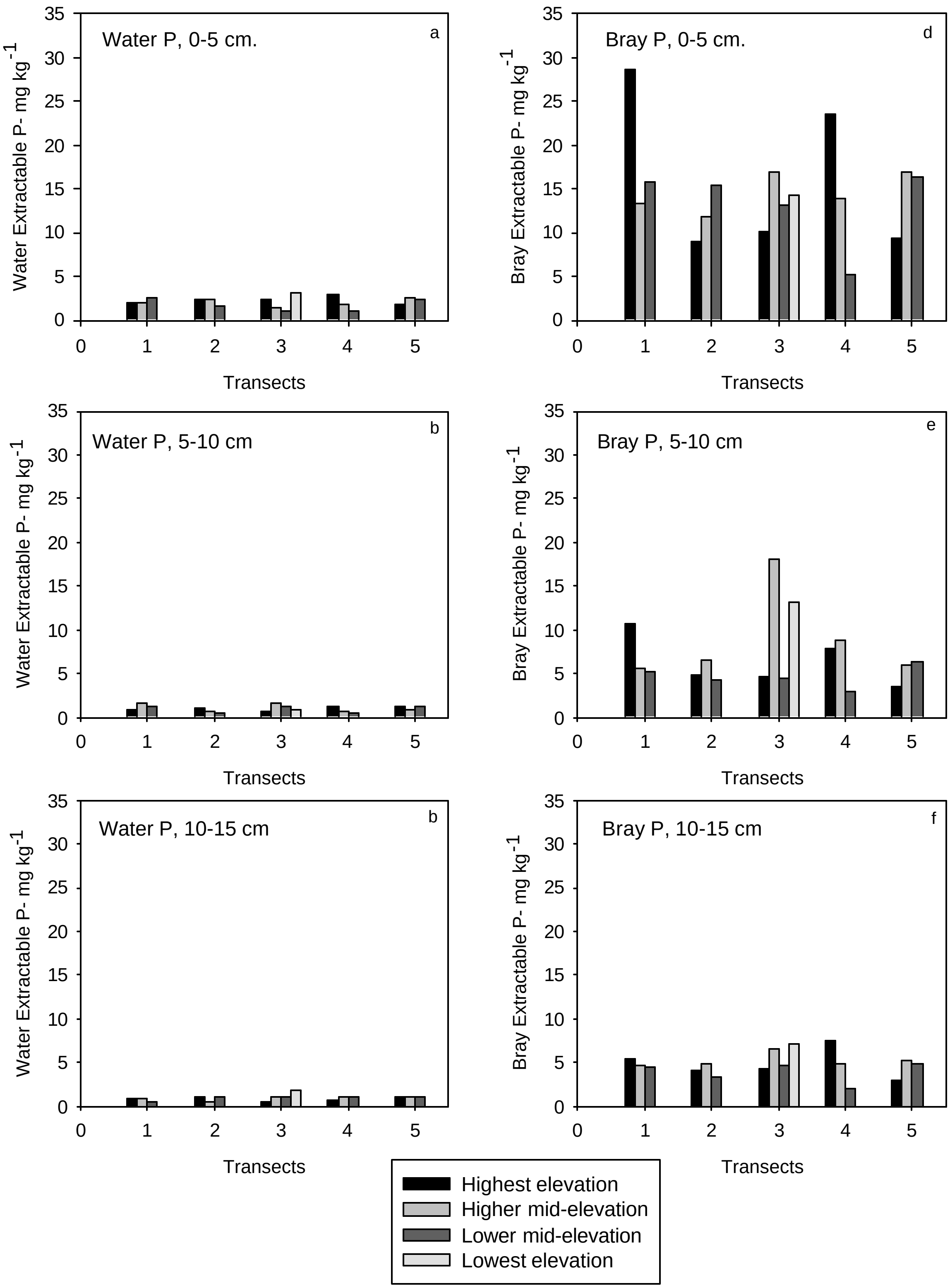

Fig. 4 Water and Bray Extractable P at the Roeppert site at depths of 0-5 cm, 5-10 cm, and 10-15 cm.

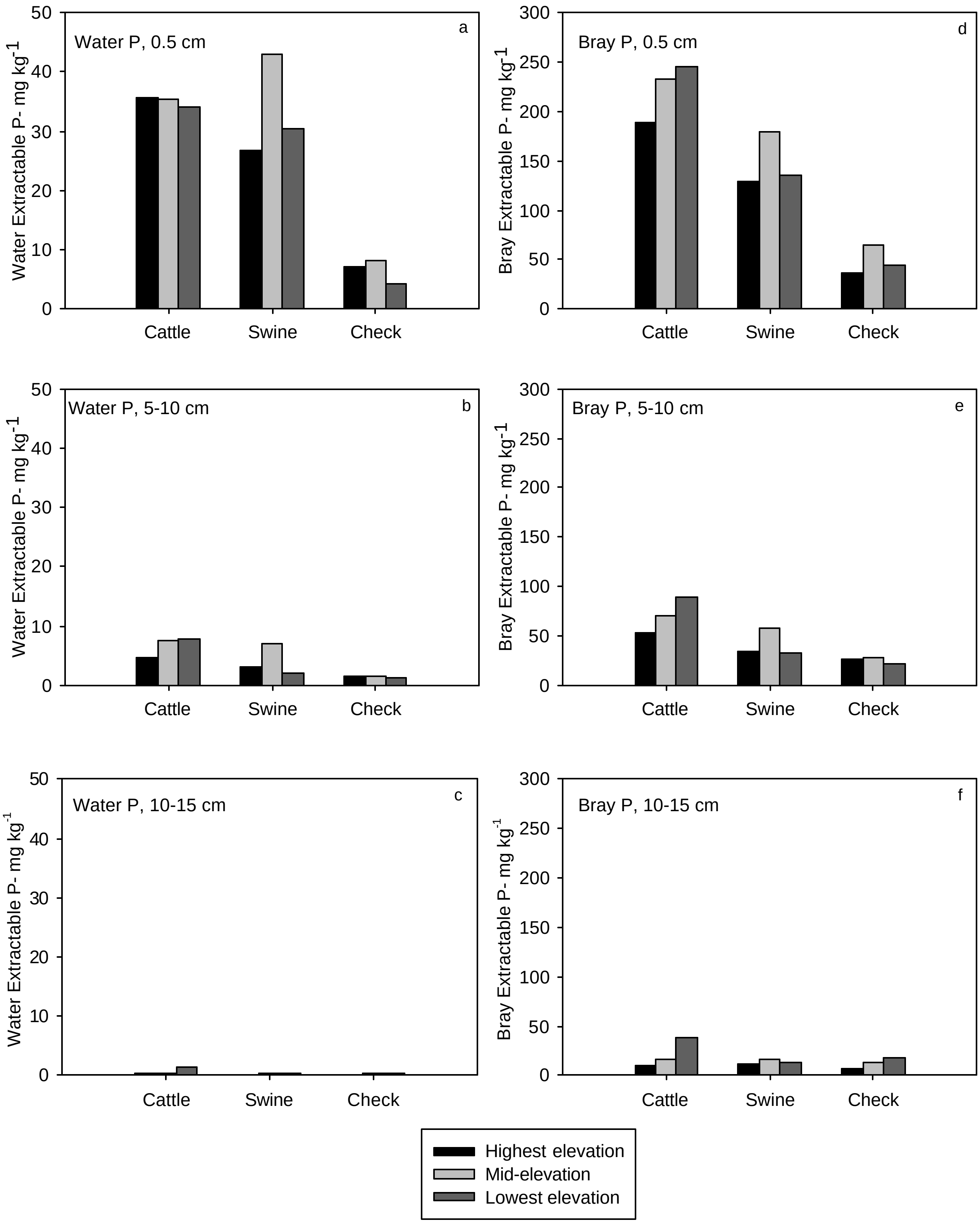

Fig. 5 Water and Bray Extractable P at the Haskell site at depths of 0-5 cm, 5-10 cm, and 10-15 cm.

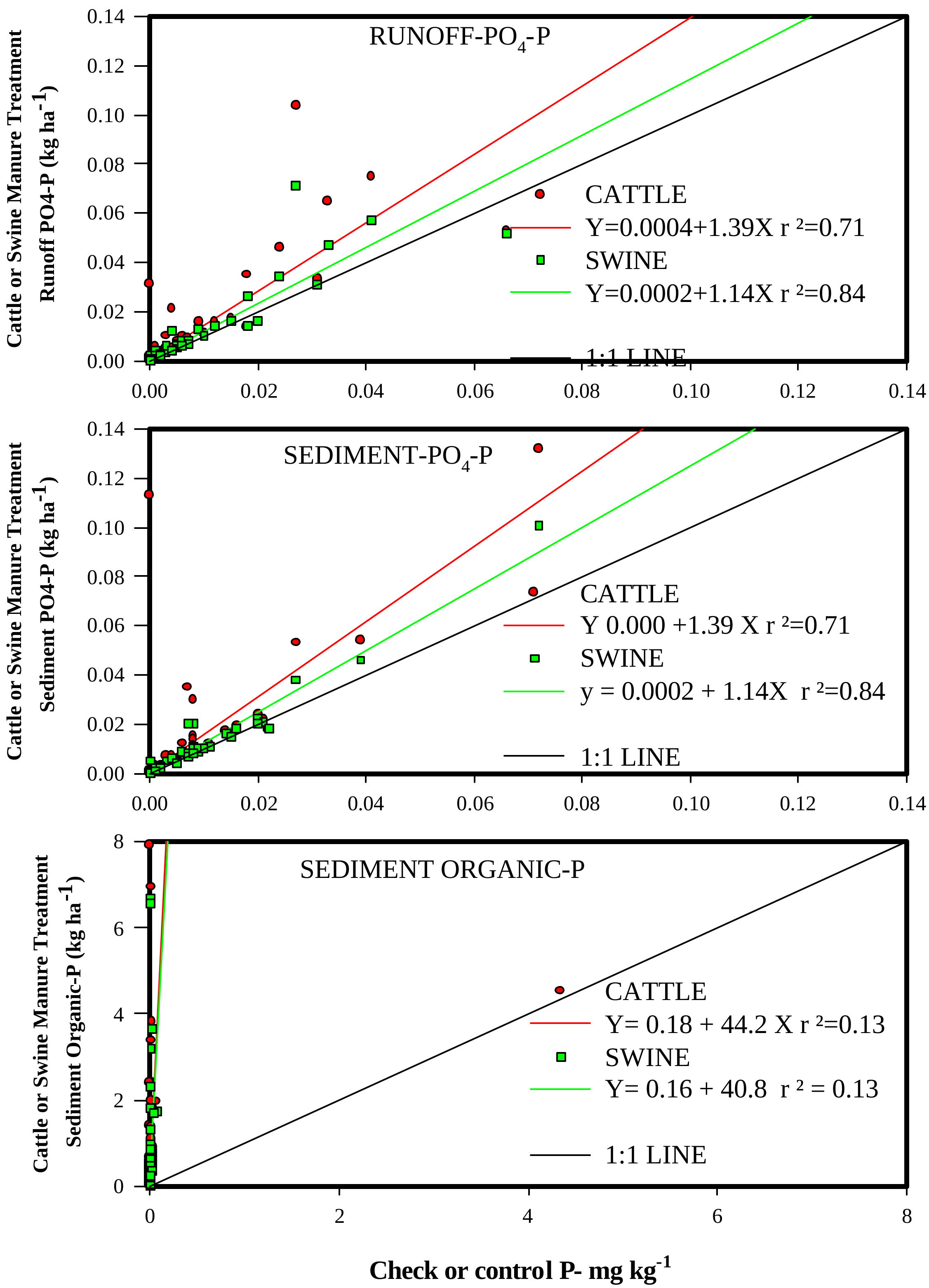

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Fig. 6 GLEAMS simulations of runoff ortho P, sediment ortho P, and sediment organic P of manure and check plots over a twenty year period at Haskell.

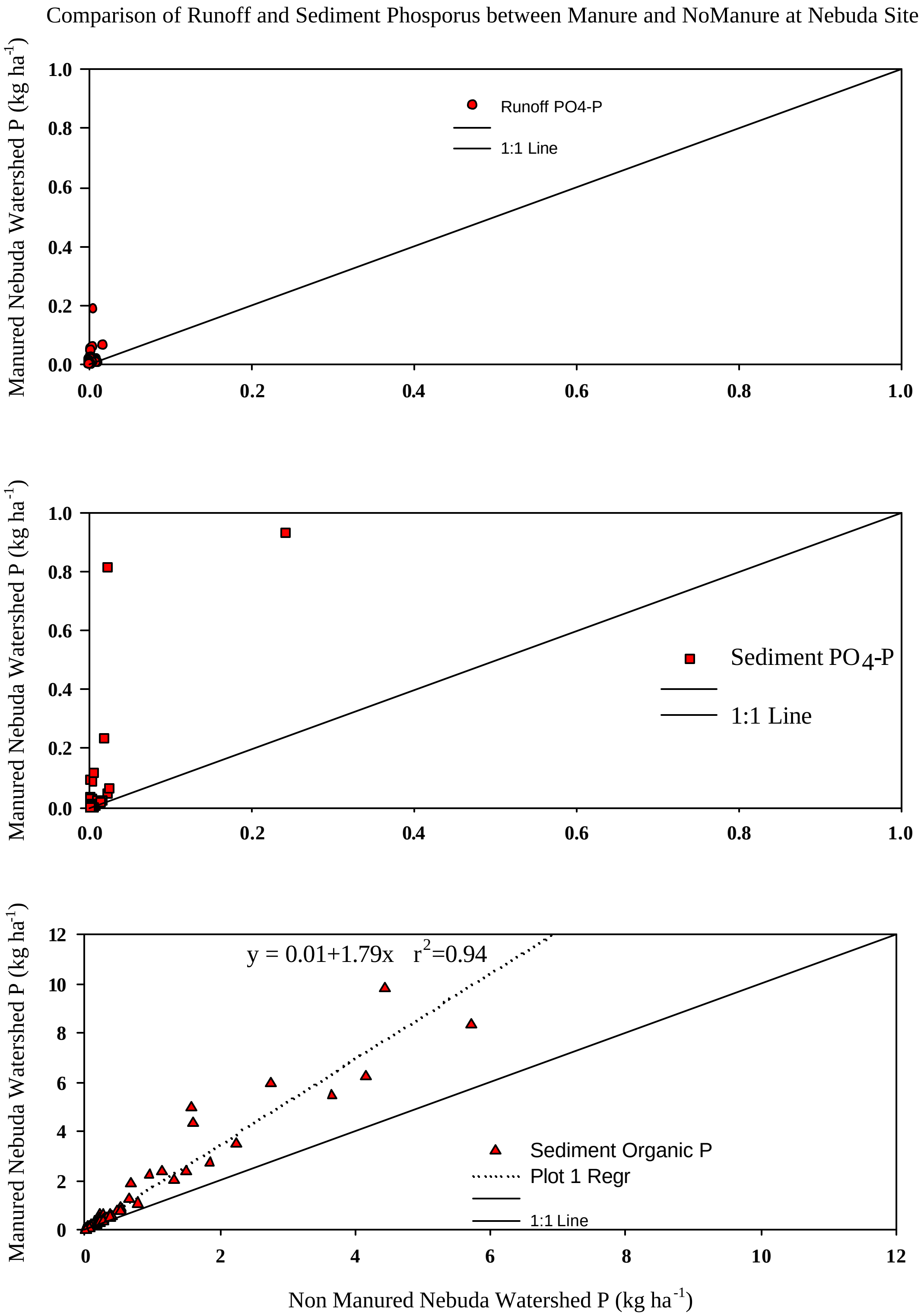

Fig. 7 GLEAMS simulations of runoff ortho P, sediment ortho P, and sediment organic P of manured Nebuda and unmanured Roeppert sites over a twenty year period.