

PHOSPHORUS TRANSPORT AND VARIABILITY
IN TWO LOUISIANA COASTAL PLAIN SOILS

A Thesis

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ABSTRACT

Soil phosphorus (P) build-up from long-term application of poultry litter may increase P loss in surface and subsurface water and lead to eutrophication. Anoxic conditions during water saturation may aggravate the problem by increasing P solubility and mobility. However, the same level of soil P at different locations may not yield equal runoff P if the capacity of the soil to retain P varies across the landscape. This study examined: 1) effects of soil water oxygenation and concentration of soil organic matter (SOM) on development of anoxic conditions leading to decreased P sorption and increased mobility in a Ruston (fine-loamy, siliceous, thermic Typic Paleudult) soil; and 2) the spatial variability of P sorption parameters (Langmuir sorption maximum, initial isotherm slope and sorption at solution concentration = 1 mg/L) in Ruston and Darley (fine, kaolinitic, thermic Typic Hapludult) soils.

Batch Langmuir isotherms were developed for Ruston pasture (high SOM) and forest (low SOM) soils. Phosphorus movement through duplicate 5 cm long x 4.6 cm diameter columns of water-saturated soils with oxic or anoxic input solution was compared to P mobility predicted using the batch isotherms. The Eh of effluent (flow velocity ~ 2.5 cm/hr) indicated rapid development of reducing conditions regardless of input oxygenation. However, lower Eh values occurred in the pasture soil. Similar Ehs developed in the batch systems so that redox effect on P sorption was implicitly included in transport predictions. Accordingly, predicted and measured elution of a 200 mg/L P pulse were generally consistent, particularly for the higher SOM pasture soil. Whether discrepancies between predicted and measured P elution were due to precipitation reactions was examined using MINTEQ, but results were inconclusive.

Surface 0 to 5 cm samples of Ruston and Darley soils were taken on square grids (60 x 60 m and 30 x 30 m, respectively) and Langmuir isotherms developed for every location. Soil pH and SOM were also determined. Isotherm parameters were spatially correlated and well-described by exponential or Gaussian semivariograms. Correlations of P sorption parameters with pH or SOM were inconsistent between sites except for the relationship of P sorption maximum with SOM.

INTRODUCTION AND LITERATURE REVIEW

Eutrophication is defined as excessive vegetative or algal growth in a body of water. When this biomass dies, it decomposes and consumes oxygen from the water. This lack of oxygen often kills fish and alters the ecosystem. Algal and vegetative growth alone can make a body of water unusable for human activities.

Phosphorus is considered to be the limiting nutrient responsible for eutrophication in lakes and reservoirs, due to the fact that certain species of algae can obtain N from the atmosphere (Moore and Miller, 1994). If all nutrients for biomass growth are present except the limiting one, there is no problem. If the limiting nutrient does appear in sufficient quantity for biomass growth, eutrophication may occur.

Poultry litter is high in P. Litter from broiler chickens contains 8 to 25.8 g/kg P, with soluble reactive P levels up to 4.9 g/kg (Moore and Miller, 1994). Poultry litter is often applied as a fertilizer, or it may be simply dumped as waste in a non-agricultural location. As poultry farms become fewer and larger, this may mean more litter in one place. In Northern Louisiana, finding unforested land that is a suitable for litter disposal is sometimes a problem (Walthall and Nolfe, 1998).

If a soil is saturated with water, conditions will become anoxic and the redox potential will decrease. The activity of anaerobic microorganisms that use electron acceptors other than O₂ (such as Fe and Mn) for respiration will greatly increase. Iron and Mn ions are more soluble in reduced (ferrous and manganous) form than the oxidized (ferric and manganic) form (Gilmour, 2002). Thus, P becomes available if it is bonded to one of these acceptors when the acceptor is chemically reduced.

Soil organic matter (SOM) is chemically diverse. It consists primarily of C (52-58%), O (34-39%), H (3.3-4.8%) and N (3.7-4.1%). Other prominent elements in SOM are P and S (Sparks, 1995). At the molecular level, SOM consists of humic and non-humic substances. The non-humic substances consist of carbohydrates, proteins, peptides, amino acids, fats, waxes and low-molecular-weight acids. These substances are particularly vulnerable to attack from soil microorganisms (Sparks, 1995). Since SOM is a substrate for soil microbiota, higher levels of it tend to stimulate greater microbial activity and could increase the possibility of P being released under anoxic conditions, where it is comparatively free to move through the soil. A list (Sylvia, et al., 1998) of potentials for redox pairs with significance to microbiological activity is given in Table 1.

Table 1. Redox pairs and electrical potentials.

Redox Pair	Potential (V)
O_2 / H_2O	0.82
Fe^{+3} / Fe^{+2}	0.77
NO_3^- / NO_2^-	0.43
NO_2^- / NO^-	0.36
$FADH / FADH_2$	-0.22
CO_2 / CH_4	-0.24
SO_4^{-2} / HS^-	-0.23
$NAD / NADH$	-0.32
H^+ / H_2	-0.42

Thus, anoxic / oxic conditions and the concentration of SOM are variables that influence P mobility in soil. These properties are related in natural (unmanaged) soils – poorly drained, wet soils are higher in SOM due to decreased degradation as a result of anoxic conditions (Sparks, 1995). In soils amended with poultry litter year after year, this causal relationship may be reversed – elevated levels of SOM may induce more rapid development of reducing conditions upon saturation with water or more strongly

reducing conditions. It was of interest, therefore, to examine the interaction of oxic / anoxic conditions and level of SOM on P mobility in a common Louisiana coastal plain soil.

The mobility of a solute in the soil solution is typically described on the basis of its partition between solution and sorbed phases, and this partition is commonly modeled with a sorption isotherm. Whether sorption isotherm data, as determined using a batch-type experiment under assumed oxic conditions, are applicable to predicting P mobility under varying redox conditions was unclear and likely doubtful. Therefore, the transport part of this study also examined applicability of batch isotherm data to describing P mobility. Any discrepancies between measured and predicted P movement, such as enhanced mobility (diminished sorption) under anoxic conditions, might be attributed to increased availability of P as discussed above.

Other soil properties besides redox status and SOM level affect P sorption. These include mineralogy, pH and texture (Brady and Weil, 2002). For example, a study by Walthall and Nofle (1998) showed that P sorption capacity for a Kirvin (clayey, mixed, thermic Typic Hapludult) soil in Louisiana was directly related to the percentage of clay found in different samples of this soil. The dependency of P sorption on different soil properties, coupled with expected spatial variability of these properties, suggested that P sorption may also be spatially variable across the landscape. If this were the case, it might be possible to exploit such variability to reduce potential off-site movement of P in runoff from soil amended with poultry litter. Where the capacity of the soil to sorb P was high, greater amounts of poultry litter might be safely applied than elsewhere and vice versa. Thus, the spatial variability of P sorption in two representative Louisiana coastal

plain soils was examined in a second part of this study and P sorption variability related to readily measured soil properties.

Since it is impractical to sample and analyze every location of interest in an area, some form of interpolation is needed to estimate the value of interest in locations that cannot be examined. The statistical process of kriging has been used to study chemical and nutrient variability in a number of experiments, including one (Needelman et al, 2001) that employed and studied the efficiency of kriging to analyze soil P concentrations (as related to runoff potential). Surprisingly, computerized searches of research literature yielded no direct results for spatial variability with respect to P sorption properties.

The overall purpose of this study was to gain a better understanding of the spatial and temporal variability of soil properties that affect P sorption and mobility in areas of the Louisiana coastal plain where poultry litter is commonly applied. The first part of the study - transport - examined the transient but potentially significant effects of oxic and anoxic conditions, coupled with the amount of organic C in the soil, on P movement. The second part of the study - variability - examined the spatial variability of P sorption (and other) properties for two representative soils. A better understanding of conditions and properties that control P retention in Louisiana coastal plain soils will hopefully aid efforts to reduce off-site P movement and the potential for eutrophication of downstream waters.

MATERIALS AND METHODS

Transport Study

Soils

The soil used in the transport portion of the study was a Ruston (fine-loamy, siliceous, thermic Typic Paleudult) Ap soil from adjacent pasture (bermudagrass; *Cynodon dactylon (L.) Pers.*) and forest (loblolly pine; *Pinus taeda L.*) sites. It was taken from the LSU Ag Center Calhoun Research Station in Calhoun, Louisiana. Soil properties are given in Table 2.

Table 2. Chemical data for the Ruston soil.

Soil	OC	pH	Bray 2 P	H ₂ O-extractable P	
				Measured [†]	Fitted [‡]
	g/kg			mg/kg	
Pasture	19.8	4.9	185	3.7	15.4
Forest	8.73	5.1	129	5.8	18.7

[†] 1:5, soil:H₂O; 24 hr. contact

[‡] Fitted parameter, S_i , from $S = (\Delta S + S_i) = S_T k C / (1 + kC)$, modified Langmuir, where ΔS is the measured change in solution concentration.

Modeling Sorption and Transport

The applicability of batch sorption isotherms for describing P mobility in these soils under oxic (oxygenated input solution) and anoxic (de-oxygenated input solution) conditions was assessed by comparing P elution from columns of these soils to predictions from the convection-dispersion equation [1], in which P retardation was based

$$\mathbf{R} (\partial \mathbf{C} / \partial t) = \mathbf{D} (\partial^2 \mathbf{C} / \partial x^2) - \mathbf{v} (\partial \mathbf{C} / \partial x) \quad [1]$$

on batch sorption data. The transport model was where C is concentration (mg/L), R is the retardation factor (dimensionless), D is dispersion coefficient (cm²/d), v is pore water velocity (cm/d), t is time(d) and x is distance (cm). The retardation factor is given by

$$\mathbf{R = (1 + \rho/\theta [\partial S/\partial C])} \quad \mathbf{[2]}$$

where S is sorbed concentration (mg/kg), ρ is bulk density (kg/L) and θ is volumetric water content (dimensionless).

The Langmuir equation [3] was used to describe the dependence of S on C,

$$\mathbf{S = k S_T C / (1 + k C)} \quad \mathbf{[3]}$$

where k is the bonding strength constant (L/mg) and S_T is the adsorption maximum.

Inasmuch as the soils used in the transport study (and spatial study, discussed below) contained an initial, unknown quantity of P, [3] was modified to allow for estimation of initial concentration of P from batch desorption/sorption data as described below. In particular,

$$\mathbf{S = (\Delta S + S_i) = S_T k C / (1 + kC)} \quad \mathbf{[4]}$$

where ΔS is calculated from the measured change in batch solution concentration of P ([C_{initial} – C_{final}] x solution volume / soil mass) and S_i is the initial concentration of P in the soil (mg/kg).

Sorption, Experimental

Batch sorption data were generated using five grams of pasture or forest soil, to which was added 25 grams of a range of phosphate solutions (0, 10, 30, 100 and 200 ppm P) in centrifuge tubes, and the suspension was equilibrated for 24 hours by shaking on a rotary shaker (New Brunswick Scientific C1 Platform Shaker). Afterwards, suspensions were spun on a centrifuge (Beckman Model TJ-6 Centrifuge) for 10 minutes at 3000 rpm.

The supernatant was filtered through a Whatman 0.45 μm pore-size filter and analyzed by ICP (Perkin Elmer Optima 3000) spectroscopy or colorimetry (4500-P E. Ascorbic Acid method / Sequoia-Turner Model 390 spectrophotometer). The Eh of duplicate (0 input P concentration) suspensions was separately monitored using an Orion Model 96-78-00 Pt redox electrode. Sorbed P was calculated by the change in solution concentration and data for ΔS and C was fit to the modified Langmuir isotherm [4].

Transport, Experimental

To study P transport, cylindrical glass columns (4.6 cm diameter by 5.0 cm long) were packed with the Ruston soils and equilibrated (~ 10 pore volumes) with solutions that approximated the composition of saturated soil pastes. The approximate composition of the soil solution at saturation was determined by equilibrating deionized water with soil over a decreasing range of soil to solution ratios. Suspensions were equilibrated for 24 hours by shaking on a rotary shaker, and then spun on a centrifuge for 10 minutes at 3000 rpm. The supernatant was filtered through a 0.45 μm pore-size filter and analyzed by ICP. Solution concentrations of Al, Ca, Mg, K, Na, P (assumed to be $\text{H}_x\text{PO}_4^{x-3}$) and S (assumed to be SO_4^{2-}) were expressed as a function of soil:solution ratio and fit to (visually) appropriate polynomials by regression. Regression models were then extrapolated to a ratio equal to that for the saturated soil ($1/\rho_B - 1/\rho_S$, where ρ_S is the soil particle density) to give estimated composition of the soil solutions. These are given in Table 3. Input solutions were either bubbled with air (oxic) or placed under vacuum suction and bubbled with N_2 for 24 hours (anoxic). The input solutions were then pumped through a ~ 6 ml volume cell to measure input Eh (air-tight and fitted with an Orion 9678 BN combination Pt electrode). An identical cell was used to measure output

Eh and eluent was collected (approximately 8 ml per 24 minutes) in fractions. Once the effluent Ehs stabilized, a phosphate solution (200 mg/L P) was applied and then eluted with simulated soil solution which was identical to the input solution but P-free. Upon elution of the P pulse, a 1 M Cl solution (dispersion tracer) was applied and eluted. Nine different column studies were performed.

All effluent fractions were filtered through 0.45 µm filters and those fractions that were to be analyzed by ICP were acidified to < pH 2 with HCl and stored refrigerated pending analysis. Other samples were colorimetrically analyzed for inorganic P (4500-P E. Ascorbic Acid method) soon after collection. Concentrations of Al, Fe, Ca, Mg, Mn and S in effluent fractions were also measured by ICP. The pH and COD (chemical oxygen demand) of effluent were also tracked using other samples. The COD was determined with a CHEMetrics heating block and pre-mixed reagent vials for concentrations ranging from 0 to 150, 1,500 and 15,000 mg/L.

Table 3. Composition of the Ruston forest and pasture soil equilibrating input solutions. Prepared from NaH₂PO₄, NaCl, CaCl₂•2H₂O, AlCl₃•6H₂O, MgSO₄•7H₂O, MgCl₂•6H₂O and KCl.

Soil	PO ₄ -P	Al	Ca	Mg	K	Na	SO ₄ -S	Cl	pH
----- mg/L -----									
Forest	1.72	11.27	28.98	8.88	16.08	9.71	6.23	120.58	3.32
Pasture	25.40	4.36	42.82	16.60	33.05	36.28	29.79	134.28	6.53

Potentiometric readings for Cl (mV) and all pH readings were taken with an Orion model 420A pH meter. An Orion 9417BN chloride electrode and an Orion 900200 double junction reference electrode were used to measure Cl concentration as recommended by the manufacturer.

Bulk density and volumetric water content were determined by weighing the soil columns. Pore water velocity was calculated by dividing flow rate by volumetric water content. These and other transport parameters for the soil columns are given in Table 4.

Transport Data Analysis

Dispersion coefficient, D , was calculated by fitting [1], with $R = 1$ (no sorption, $\partial S/\partial C = 0$), to Cl pulse elution data. Flux boundary conditions and a uniform initial concentration of Cl were assumed. The influence of the small-volume, effluent Eh cell was accounted for by assuming it to be perfectly mixed. The nonlinear least-squares algorithm of van Genuchten (1981) was used to optimize D .

Table 4. Conditions (soil type and oxic or anoxic input solution) for column studies and transport parameters (as defined for [1] and [2]). Phosphorus pulse duration, t_p , also included.

Col	Soil	Oxic	Rep	θ	ρ	D	v	t_p
					kg/L	cm ² /d	cm/d	d
1	Pasture	Yes	1	0.481	1.381	39.1	51.13	0.246
2	Pasture	Yes	2	0.481	1.361	101.5	54.28	0.167
3	Forest	Yes	1 [†]	0.395	1.620	8.0	64.49	0.117
4	Pasture	No	1	0.478	1.381	53.7	53.74	0.217
5	Pasture	No	2	0.480	1.381	16.2	51.84	0.317
6	Forest	Yes	1	0.390	1.620	2.9	68.62	0.267
7	Forest	Yes	2	0.398	1.602	10.4	61.71	0.267
8	Forest	No	1	0.409	1.579	10.0	60.99	0.128
9	Forest	No	2	0.390	1.618	7.8	63.95	0.122

[†] Equilibrating solution for the pasture soil (higher P concentration) used.

Given estimates of dispersion coefficient, P mobility was simulated using the Langmuir isotherms obtained from the batch study. In this case, the retardation factor, R , in [1] is nonlinear and forces use of a numerical method to obtain an approximate solution. An implicit finite difference method was used to solve [1]. Solutions were graphed and visually compared to the experimental P elution data to assess agreement of predictions based on the batch isotherm data.

Spatial Variability Study

Soils and Sampling

Ruston and Darley (fine, kaolinitic, thermic Typic Hapludult) soils were used. The Ruston soil was from a pasture site at the Calhoun Research station and the Darley soil was from a pasture at the Hill Farm Research Station, Homer, Louisiana. Both were sampled on square grids. The grid for the Darley soil measured 4 points on the x-axis and 10 points on the y-axis, with points 30 meters apart. That for the Ruston soil measured 7 points on the x-axis and 7 points on the y-axis, with points 60 meters apart. Augur samples of surface 0 to 5 cm and 5 cm to Bt soil were taken from each point. After air-drying, samples were machine-ground with a BICO Type UA pulverizer. Phosphorus sorption data for the surface 0 to 5 cm samples were generated as described below and used in this part of the study.

Sorption Isotherms and Soil Organic C and pH

Twenty-five mL of a range of phosphate solutions (0, 5, 10, 30, 50, 75, 100 and 150 ppm P in DDI water) were added to five grams of soil. The suspension was equilibrated for 24 hours by shaking on a rotary shaker. Suspensions were then spun on a centrifuge for 10 minutes at 3000 rpm. The supernatant was filtered through a 0.45 μm filter. An aliquot of the 0 ppm P input samples was analyzed for inorganic P. Another aliquot of these samples and all other supernatant samples (5 through 150 ppm P input) were analyzed by ICP. Samples were acidified to pH 2 with 5 N HCl and stored refrigerated (4 °C). The difference in P concentration determined by ICP and colorimetrically was taken as organic P and was used as a correction factor for all

samples. The organic C content of all samples was determined by wet-digestion (Nelson and Summers, 1982). The pHs of 1:5, soil:water suspension were also measured.

Data Analysis, P Sorption Isotherms

A SAS (Version 8.1) program (Fig. 1) was employed to calculate unique values for S_T , k and the initial P content (S_i) for every soil grid location. R-squared values were calculated for each location as well.

```

TITLE 'PHOSPHORUS LANGMUIR (X,Y)';
DATA SPATIAL;
INPUT C S;
CARDS;
    0.713    -0.615277
    2.305    15.096403
    5.970    28.350849
    22.061   59.588248
    29.380   103.05808
    45.980   128.36805
    87.421   109.85597
    110.300  201.20051
PROC NLIN METHOD = DUD;
PARMS K = .2,
      ST = 200.00,
      S0 = 2.00;
MODEL S = (K*ST*C/(1.0+K*C))-SI;
BOUNDS 0.0<K,
        0.0<ST,
        0.0<SI;
RUN;

```

Figure 1. SAS (PROC NLIN) program with example data and starting values used to optimize parameters for the Langmuir isotherm.

Values for k , S_T and S_i were obtained, and these used to calculate dS/dC at $C = 0$ ($dS/dC = kS_T$) and S at $C = 1$ ($S = kS_T/[1 + k]$). The initial slope of the sorption isotherm, dS/dC at $C = 0$, is a measure of the tendency of the soil to sorb P. The adsorbate per unit of absorbent at a concentration of 1 mg/L in solution, S at $C = 1$, is a measure of the

level of sorbed P when solution P reaches a concentration greater than that commonly associated with eutrophic conditions of surface water.

Data Analysis, Spatial

Values of S_T , dS/dC ($C = 0$), and S ($C = 1$) for each point of the Ruston and Darley soils were plotted in two-dimensional graphical form and also plotted three-dimensionally. Data for S_T , dS/dC ($C = 0$), and S ($C = 1$) were analyzed using a geospatial statistical method – kriging. An isotropic experimental semivariogram [5] was first generated for values of each of the three parameters in both soils using the VARIOGRAM procedure of SAS (Version 8.1),

$$\gamma(\mathbf{h}) = (1/2 \mathbf{m}) \Sigma \{[z(\mathbf{x}_i) - z(\mathbf{x}_i + \mathbf{h})]\} \quad [5]$$

where $\gamma(\mathbf{h})$ is the semivariance of property z , separated by a lag distance of h , and m is the number of pairs of sampling points x_i at this distance of separation. In this procedure, a LAGDISTANCE value of 30 meters was used for the Ruston soil and 15 meters for the Darley soil, or half of the respective sampling distances. The MAXLAGS value was set at 6 for both soils, thereby restricting the maximum distance over which semivariograms were generated to approximately half the study site size.

Different types of theoretical models (spherical, Gaussian, exponential, linear, etc.) with estimated ranges and scales were used until a visual best-fit was obtained between the theoretical and experimental semivariograms. The two theoretical semivariogram models that appeared to best describe the data were the exponential [6] and Gaussian [7], shown below, respectively,

$$\gamma(\mathbf{h}) = C \{1 - \exp(-\mathbf{h}/r)\} \quad [6]$$

$$\gamma(\mathbf{h}) = C \{1 - \exp(-\mathbf{h}^2/r^2)\} \quad [7]$$

where C is the scale (or sill) and r is the range. Theoretical semivariograms were plotted alongside the experimental semivariograms, and various values for scale and range were input until the theoretical fit the experimental fairly well. An exponential form of the theoretical semivariogram was used for all but one of the parameters.

After an appropriate variogram model was determined, the KRIGE2D procedure was run to interpolate values for S_T , dS/dC ($C = 0$) and S ($C = 1$) for the Ruston and Darley soils. In addition to scale, range and form, a value for radius was also input in this procedure. The radius value represented the maximum distance where data points would be used in the local kriging procedure. The radius used was 90 meters for the Ruston soil and 45 meters for the Darley soil and isotropic conditions were assumed. Kriged values were calculated every 30 meters for the Ruston and every 15 meters for the Darley soil.

RESULTS AND DISCUSSION

Transport Study

Batch Sorption Isotherms

For the batch sorption study, best-fit curves of the Langmuir isotherm, together with optimized parameters, are shown in Fig. 2. The model adequately described P sorption, giving R^2 values > 0.99 for the pasture and forest soils. Maximum sorption values (S_T , [3]) were greater for the pasture soil (119 ± 4 mg/kg, standard error) than for the forest soil (90 ± 2 mg/kg). Bonding strength constants (k) were 0.145 ± 0.020 L/mg for the pasture soil and 0.143 ± 0.017 L/mg for the forest soil. Based on the respective shapes of the two isotherms, somewhat greater retardation of P mobility would be expected for the pasture, compared with forest, Ruston soil.

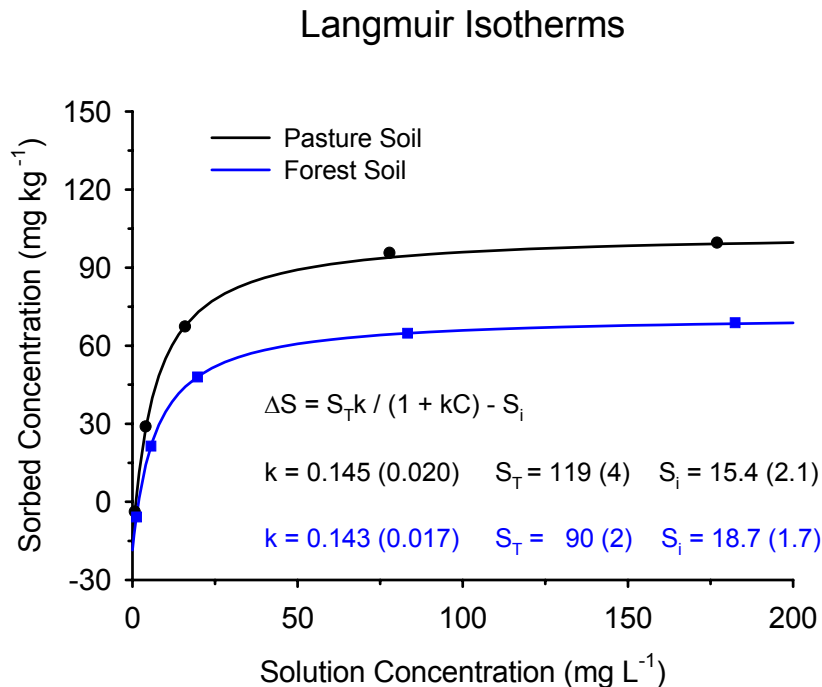


Figure 2. Langmuir isotherm curves fit to data for the pasture and forest soils. Values in parentheses following S_T and k are standard errors of estimates.

Values for Eh monitored in duplicate samples of the 0 ppm P input solution showed steady decreases, reaching ~ -150 mV for suspensions of both the forest and pasture soils after 24 hours of incubation. This suggested that if similar reducing conditions developed within the same time frame for soil columns (discussed below), effects of reducing conditions on P sorption/desorption and mobility in the column studies may be implicitly included in the batch sorption data.

Transport Data, Column Effluent Eh Values

Figure 3 shows how Eh typically decreased with increasing pore volumes of the input solution. Oxygen status of the input solution had a negligible effect on the Ehs of effluent from the pasture soil. However, the Eh values of effluent from the forest soil that had an oxic input solution were higher than that of the forest soil with an anoxic input solution. Thus, the effect of oxygenation on P mobility (if any) may be greater in the forest soil.

Rapid development of reducing conditions upon wetting of a previously air-dry soil is commonly observed (Breitenbeck, personal communication). Furthermore, this occurred despite decreasing levels of dissolved organic C (as indicated by rapid decrease in COD beyond the first few pore volumes of effluent. Data not shown). With the exception of the Ruston forest soil exposed to oxic input, all systems developed low Ehs comparable to the batch systems within ~ 10 pore volumes of effluent (or ~ 24 hours). Thus, should oxic/anoxic conditions affect P sorption/desorption and mobility in these soils, the greatest discrepancy between measured P mobility and that predicted on the basis of batch sorption data may occur for the forest soil with well-oxygenated input.

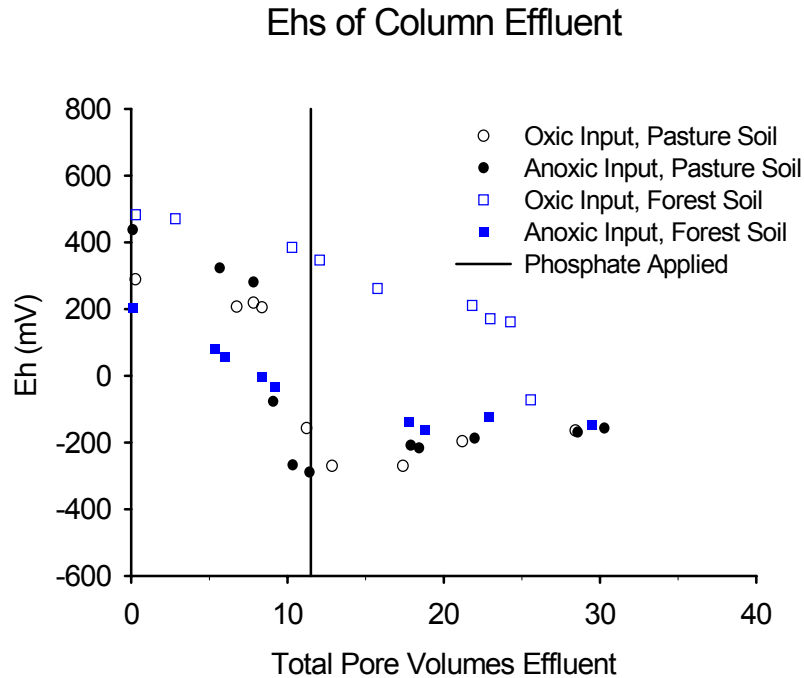


Figure 3. Column effluent Eh (mV) values with respect to pore volumes of effluent for both soils with differing oxygen status. Averages of two replicates are plotted.

Transport Data, Phosphorus Mobility

Different combinations of soil and oxygenation status were used to study P mobility in the Ruston soil (see Table 3, Materials and Methods). The column combinations were: pasture soil with an oxidic input solution (columns 1 and 2), pasture soil with an anoxic input solution (4 and 5), forest soil with an oxidic input solution (6 and 7), forest soil with an anoxic input solution (8 and 9) and forest soil with an oxidic input solution and higher initial soil P content (3). The following figures show values of P in soil column effluent predicted based on solute retardation governed by the Langmuir isotherm for batch sorption data compared to measured values of P in effluent (measured data for dissolved inorganic P as measured colorimetrically. However, these values differed negligibly from P determined by ICP spectroscopy, indicating little contribution of dissolved organic P to total dissolved P).

Pasture Soil, Oxidic Input

Elution predicted on the basis of the Langmuir isotherm for the pasture soil with an oxidic input solution (Fig. 4) described the data fairly well, indicating that P sorption / desorption in the column was adequately described on the basis of batch sorption data. Discrepancies between measured and predicted elution may be due to sorption non-equilibrium or P precipitation reaction(s). Since low Eh conditions existed despite an oxidic input solution, similar results were expected for the pasture soil using an anoxic input solution.

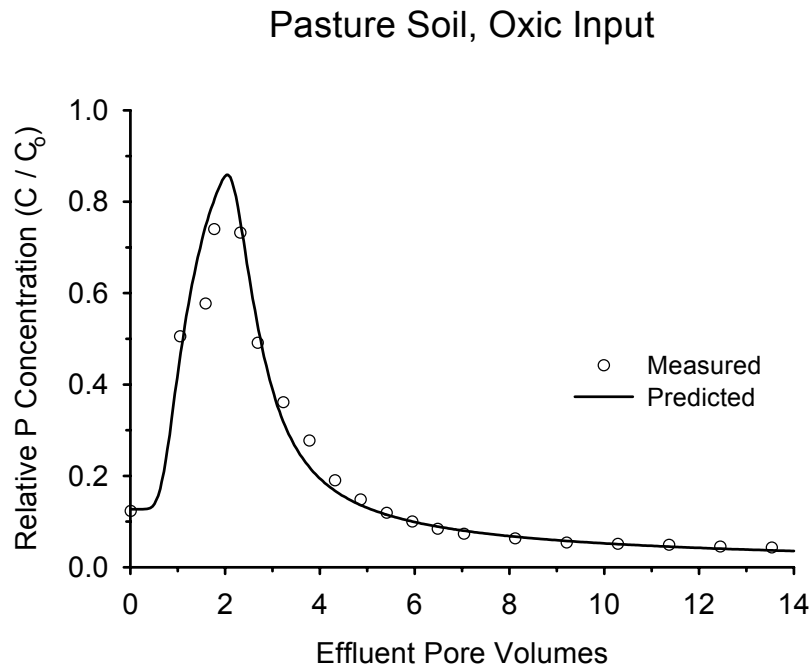


Figure 4. Comparison of measured and predicted P mobility for the pasture soil with oxidic input solution (column 1). Relative concentration (C/C_0) is the ratio of measured or predicted concentration to pulse concentration (200 mg/L).

Pasture Soil, Anoxic Input

Figure 5 shows similar data obtained using an anoxic input solution. The Langmuir isotherm again generally described P elution for the pasture soil, even with an

anoxic input solution. Thus, data for P sorption / desorption appear to provide a good basis for predicting P mobility in the pasture soil, regardless of the redox conditions in this soil.

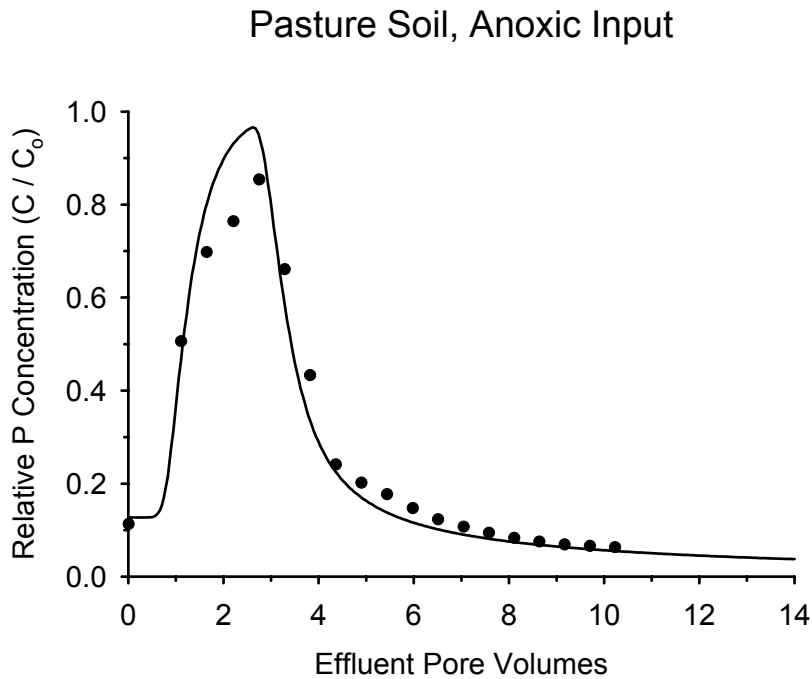


Figure 5. Comparison of measured and predicted P mobility for the pasture soil with anoxic input solution (column 4). Relative concentration (C/C_0) is the ratio of measured or predicted concentration to pulse concentration (200 mg/L).

Forest Soil, Oxic Input

Figure 6 shows displacement of P through the forest soil with an oxic input solution. Unlike results for the pasture soil, the Langmuir isotherm accurately predicted only P retardation for this soil. Neither the maximum concentration nor tailing were accurately predicted. Apparently sorption or precipitation kinetics in this soil was more important in controlling P mobility in this soil than in the pasture soil.

Forest Soil, Oxidic Input

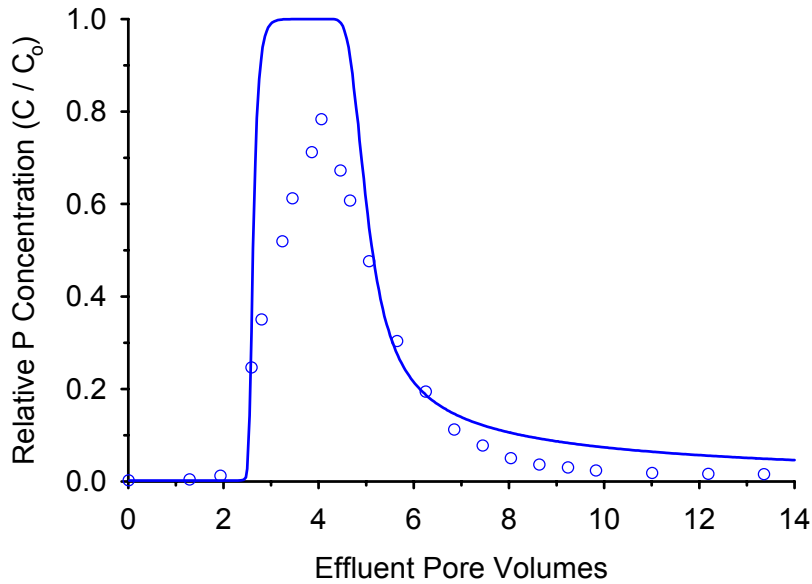


Figure 6. Comparison of measured and predicted P mobility for the forest soil with oxidic input solution (column 6). Relative concentration (C/C_0) is the ratio of measured or predicted concentration to pulse concentration (200 mg/L).

Forest Soil, Anoxic Input

Figure 7 shows that results obtained for the forest soil with an anoxic input solution were similar to the forest soil with an oxidic input solution. Only retardation, neither peak nor tailing, was accurately predicted by the batch isotherm data. Inasmuch as the Ruston forest soil with anoxic input developed similar Ehs to the corresponding batch system, discrepancy between measured and predicted P mobility cannot be attributed to any difference in redox status between batch and column systems or any effect of redox on P sorption or kinetics of sorption or precipitation.

Forest Soil, Anoxic Input

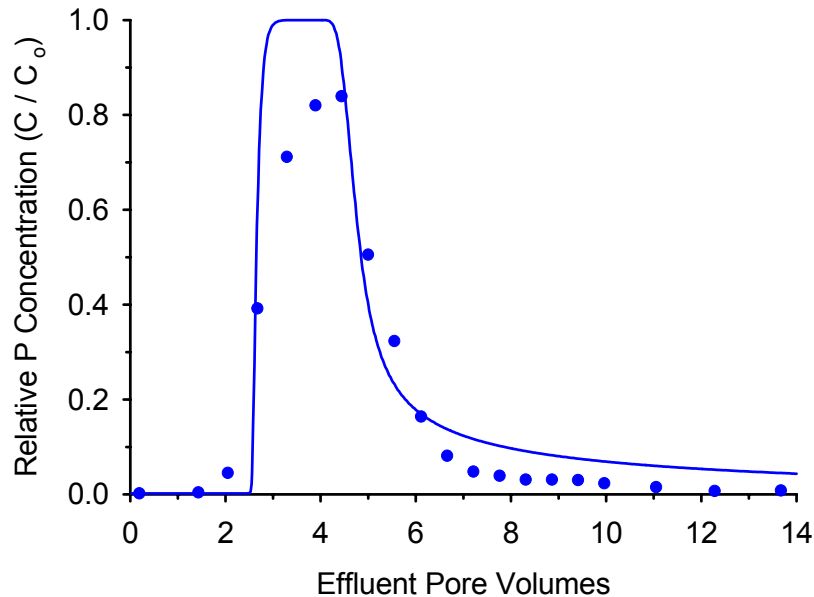


Figure 7. Comparison of measured and predicted P mobility for the forest soil with anoxic input solution (column 8). Relative concentration (C/C_0) is the ratio of measured or predicted concentration to pulse concentration (200 mg/L).

Among a host of differences between the pasture and forest soils (besides organic C content) was the composition of the native soil solution (see Table 3, Materials and Methods), particularly, the soil solution concentration of P. It seemed possible that the greater difference between native P concentration and pulse concentration for the forest soil compared to the pasture soil may have accentuated any kinetic limitations to use of the equilibrium Langmuir isotherm for predicting P sorption/desorption and mobility. Whereas for the pasture soil, there was a step from ~ 25 ppm P to 200 ppm P upon introduction of the pulse, for the forest soil the jump was from ~ 2 ppm P to 200 ppm P. Therefore, to test the influence of initial soil P on P elution through the forest soil, the same equilibrating solution used with the pasture soil was used with the forest soil. Figure 8 shows that P elution was better described, including peak maximum and tailing,

when the initial soil P concentration was higher. This suggests that applicability of the equilibrium Langmuir isotherm for predicting P mobility in not only the Ruston forest soil but perhaps also the Ruston pasture soil may be limited to fairly narrow solution concentration ranges. Thus, a more comprehensive model, incorporating sorption or precipitation kinetics, may be needed to predict P mobility under conditions of drastic changes in solution P concentration. Regardless, a more comprehensive model is needed for the low OC, low initial P content Ruston forest soil to accurately predict P mobility.

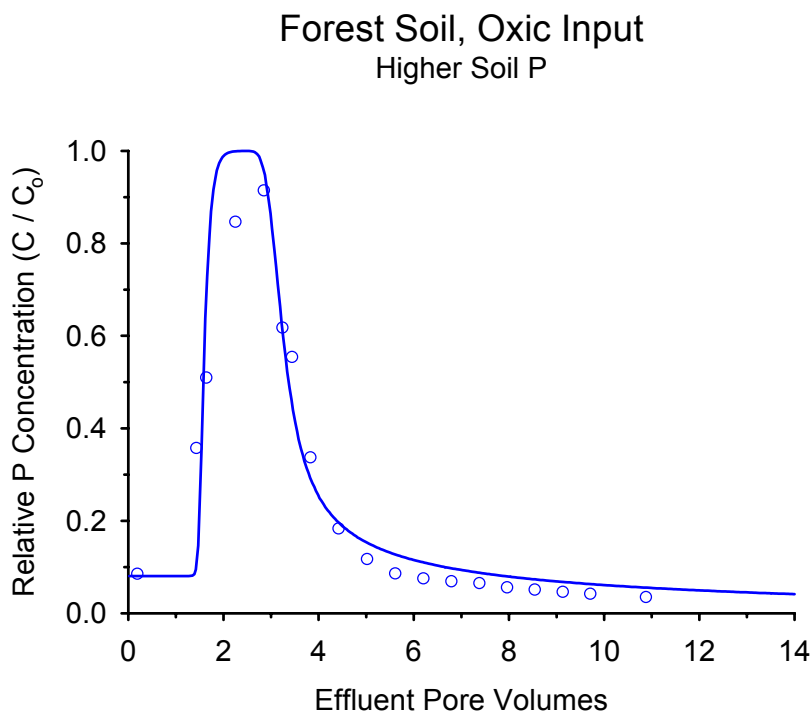


Figure 8. Comparison of measured and predicted P mobility for the forest soil with oxic input solution, higher initial soil P content (column 3). Relative concentration (C/C_0) is the ratio of measured or predicted concentration to pulse concentration (200 mg/L).

MINTEQ Analysis

Another chemical difference between the forest and pasture Ruston soils besides organic C and level of P was the higher concentration of Al in the soil solution of the forest soil. Its presence may have caused precipitation of P not accounted for in the batch

sorption data. Consequently, a MINTEQ (Version 4.01) chemical speciation study was performed to determine the possibility of precipitation being responsible for the difference between predicted and measured values for the column studies, particularly for the forest soil. Data for PO₄-P, Al, Ca, Fe, K, Mg, Mn, K, Na and SO₄-S from ICP analyses, as well as pH and Eh for five samples of effluent from each column were analyzed by the MINTEQ program: one sample before the P pulse, three samples during (beginning, middle, end) the P pulse and one sample after the P pulse. This range of effluent samples represents soil solution at the outflow end of the columns when, respectively, equilibrium with the (approximately) native soil solution presumably existed, during increasing concentration of P (three samples during pulse) and during desorption (or decreasing concentration) of P (sample column data are included in Appendix A). This range of solution compositions, therefore, largely covers the full range of solution composition that existed in a soil column during P elution. However, it does not include what may have existed at the inflow end when the pulse of 200 mg/L P was introduced to the native soil solution. Therefore, the effect of this abrupt change in composition on potential precipitation of P was also explored by running MINTEQ for the native soil solution (for the pasture as well as the forest soil) plus the P pulse at 200 mg/L. Default settings were used for the MINTEQ program, except that concentrations were entered in ppm (mg/L), and oversaturated solids were allowed to precipitate after the final answer was reached. Besides values of pH and Eh for each sample, along with concentrations of PO₄-P, Al, Ca, Fe, K, Mg, Mn, Na, and SO₄-S, Cl was added to achieve charge balance.

With the exception of one sample from the column study (forest soil, anoxic input solution, Column 8 - end of P pulse) where only 50.3 % of Al precipitated, Mn and Al precipitated at or near 100 %. Magnesium was completely dissolved for all 45 column study samples. Ferrous Fe was 100 % precipitated for each sample where it was present, but ferric Fe was split between dissolved and precipitated in varying percentages. In no case, however, was an Al-, Fe- or Mn-phosphate predicted. Perhaps the most curious finding of the MINTEQ study was that P and Ca precipitated (in varying percentages) for all of the pasture soil samples but did not precipitate for any of the forest soil samples. Although this may account for discrepancies seen between measured P elution from the pasture soil and that predicted on the basis of the batch sorption isotherm, greater discrepancies for the forest soil remained unresolved.

Analysis of the ions in the input solutions plus P pulse yielded comparable results for each solution despite large differences in the composition of the forest and pasture soil solutions. More than 90 % of Ca and Mg precipitated in both solutions, and 89 % of Al precipitated for the forest soil and 66 % of Al precipitated for the pasture soil. Phosphorus precipitation rates were also similar - 6.7 % of P precipitated for the forest soil and 8.7 % of P precipitated for the pasture soil. Thus, while P limited (< 10%) precipitation may have occurred on pulse input, this would seem too small to cause the the mass balance errors (difference in areas under measured and predicted elution curves) seen for the forest soils. Furthermore, additive concentrations (200 mg/L P + 29 mg/L Ca, e.g, Table 3, Materials and Methods) did not exist as the P pulse was introduced to columns – both input and resident solutions were diluted by mixing. In fact, preliminary spreadsheet calculations of potential P precipitation due to contact of pulse and native

soil solution, with mutual dilution upon mixing, suggested no precipitation with Al or Ca and served as a guide to choice of 200 mg/L for the P pulse. As important as dilution by mixing, P concentrations were nearly instantaneously further decreased by sorption not included in the MINTEQ calculations.

Although the MINTEQ results are not conclusive, they do suggest some potential for precipitation so that precipitation, or another type of time-dependent P-retention reaction, may be important in limiting the applicability of the Langmuir isotherm for describing P mobility in these soils.

Spatial Variability Study

If P sorption properties spatially vary over a landscape, poultry litter may, in principle, be applied at spatially variable rates – higher rates where P sorption by the soil is higher and lower rates where P sorption is lower- to minimize potential off-site losses of P in surface runoff. From a practical standpoint, the magnitude of variability must be sufficiently large to warrant use of this technology. Furthermore, variation in P sorption properties must occur over fairly wide distances. Short-range variability may not be feasible to identify because intensive soil sampling is prohibitive. Provided these conditions are met, however, spatial variability in P sorption may possibly be used as a guide for variable-rate poultry litter application.

The spatial component of this work determined k , S_T and S_i by fitting measured change in sorbed concentration of P (ΔS) and solution concentration of P (C) to the Langmuir isotherm [4], from which dS/dC ($C = 0$) and S ($C = 1$) were calculated, for each of the sampling locations at the Ruston and Darley study sites. Complete spatial data are given in Appendix B, but three of the values for the Ruston and Darley soils are

listed in Tables 5 and 6, respectively, which show data by location in two-dimensional graphical form (three-dimensional displays of all data in these Tables 5 and 6 are given in Appendix C).

Table 5. Spatial data for P sorption parameters S_T , dS/dC ($C = 0$) and S ($C = 1$) from 0 meters to 360 meters for the surface 0 to 5 cm depth Ruston soil.

S_T

360m	53.9	155.5	94.4	83.9	56.2	24.3	95.8
300m	106.2	203.9	127.2	208.5	203	103.5	62.1
240m	195.4	73.4	54.2	470.2	372.3	69.5	57.9
180m	114.7	154.3	211.8	180	219.3	75.6	72.8
120m	249.3	277.5	347.6	273.8	303.1	156.9	123.8
60m	266.3	139.8	377.1	125.4	437.2	373.4	223.1
0m	286.3	351.4	375.1	267	409.3	521.2	126
	0m	60m	120m	180m	240m	300m	360m

dS/dC ($C = 0$)

360m	1.078	1.258	0.749	0.662	0.641	3.187	0.488
300m	3.303	2.426	0.364	2.75	2.294	3.177	4.099
240m	1.016	1.976	1.695	1.1	1.24	1.001	1.257
180m	1.376	1.312	1.356	1.532	1.857	1.876	1.165
120m	4.637	5.217	5.11	1.829	13.64	6.543	5.125
60m	4.208	3.132	1.746	5.48	2.523	7.057	3.77
0m	5.382	4.322	4.126	1.914	1.997	7.61	3.2
	0m	60m	120m	180m	240m	300m	360m

S ($C = 1$)

360m	1.057	1.248	0.743	0.657	0.634	2.818	0.486
300m	3.203	2.398	0.363	2.716	2.268	3.083	3.845
240m	1.011	1.924	1.644	1.098	1.236	0.986	1.23
180m	1.36	1.3	1.347	1.519	1.842	1.83	1.147
120m	4.552	5.121	5.036	1.817	13.052	6.281	4.922
60m	4.142	3.063	1.738	5.251	2.508	6.926	3.708
0m	5.283	4.27	4.081	1.901	1.988	7.5	3.121
	0m	60m	120m	180m	240m	300m	360m

Table 6. Spatial data for P sorption parameters S_T , dS/dC ($C = 0$) and S ($C = 1$) from 0 meters to 270 meters for the 0 to 5 cm depth Darley soil.

S_T

270m	622.2	466.4	543.5	524.6
240m	409.8	476.4	606.8	1078.2
210m	504.9	365	389.5	573.8
180m	431.4	283.1	218.3	567.8
150m	207.1	449.9	263.7	499.9
120m	517.5	491.7	494.3	469.4
90m	523.7	468.4	445.8	446.1
60m	507.5	350.3	545	895.9
30m	403.3	556	631.9	517.9
0m	528.3	352	587.2	545
	0m	30m	60m	90m

dS/dC ($C = 0$)

270m	42.621	5.69	5.272	24.289
240m	4.344	3.478	3.823	12.076
210m	5.2	2.957	3.661	16.353
180m	2.847	2.916	25.301	10.902
150m	5.757	4.589	9.731	2.899
120m	2.277	8.605	9.787	11.125
90m	4.609	6.792	15.38	10.216
60m	13.5	6.095	15.914	4.032
30m	10.647	3.336	16.809	9.115
0m	16.272	4.189	14.739	10.028
	0m	30m	60m	90m

S ($C = 1$)

270m	39.888	5.621	5.221	23.214
240m	4.298	3.453	3.799	11.942
210m	5.147	2.933	3.627	15.9
180m	2.829	2.886	22.673	10.696
150m	5.602	4.543	9.384	2.883
120m	2.267	8.457	9.597	10.867
90m	4.568	6.695	14.867	9.987
60m	13.15	5.991	15.462	4.013
30m	10.373	6.316	16.373	8.957
0m	15.785	4.14	14.378	9.847
	0m	30m	60m	90m

The average R^2 value for the Langmuir isotherm fitted to the Ruston soil data was 0.9648. It was calculated by subtracting the residual from the corrected sum of squares and then dividing by the corrected sum of squares. The average R^2 value for the Langmuir isotherm fitted to the Darley soil data was 0.9738. Thus, the Langmuir model adequately described P sorption in the two soils. Consequently, the parameters S_T , dS/dC ($C = 0$) and S ($C = 1$) are meaningful for characterizing P retention behavior in these soils.

The average P sorption maximum for the Ruston soil (~ 202 mg/kg) was less than the average P sorption maximum for the Darley soil (~ 494 mg/kg). Bonding strength constant values were similar (~ 0.20 L/mg) for both soils (Appendix B). The average value for dS/dC ($C = 0$) was greater for the Darley soil (9.70 L/kg) than the Ruston soil (2.96 L/kg). The average value for S ($C = 1$) was also greater for the Darley soil (9.39 mg/kg) than the Ruston soil (2.88 mg/kg). Thus, the Darley soil appears to have a higher capacity to sorb P. At the gross scale of site to site comparison, P added to the Darley series soil (at least this example of the series) may be less subject to off-site movement in runoff and have less potential for downstream eutrophication than P added to the Ruston series site.

Within-site spatial analysis for these isotherm parameters found all were spatially correlated. Experimental semivariograms for S_T and dS/dC ($C = 0$) for the Ruston soil are shown in Figs. 9 and 10. Semivariogram models were defined (exponential [6] or Gaussian [7]) and model parameters are given in Table 7. All isotherm parameters for both soils were spatially correlated well beyond the minimum sampling distance. Thus,

kriging interpolation was possible. The point-kriged output and associated error are shown

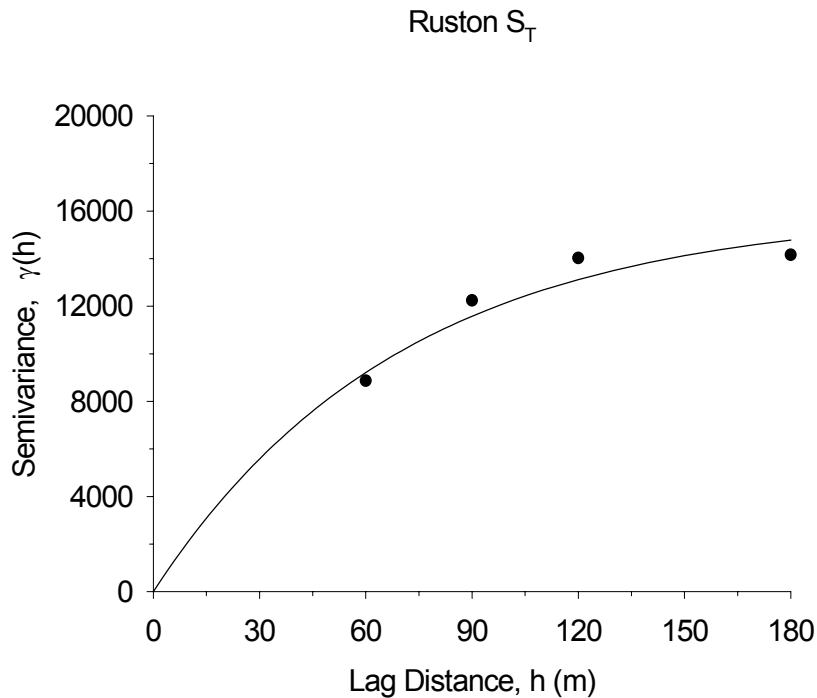


Figure 9. Experimental semivariogram for S_T for the 0 to 5 cm depth Ruston soil.

in Appendix D. On the basis of results for these two soils, one of the criteria for using spatially variable rates of poultry litter application may be met in North Louisiana coastal plain soils – no requirement for intensive soil sampling. Examination of additional soils and other examples of these soils, however, is needed to confirm this tentative conclusion. If further examination found commonality in semivariograms and semivariogram parameters (e.g., applicability of exponential or exponential-like or Gaussian models and similar ranges), the intensity of sampling could possibly be reduced. Or, at a minimum, if only prescriptions for field-specific (\gg sub-hectare scale) rates were needed, sub-sample spacing would be known at the outset.

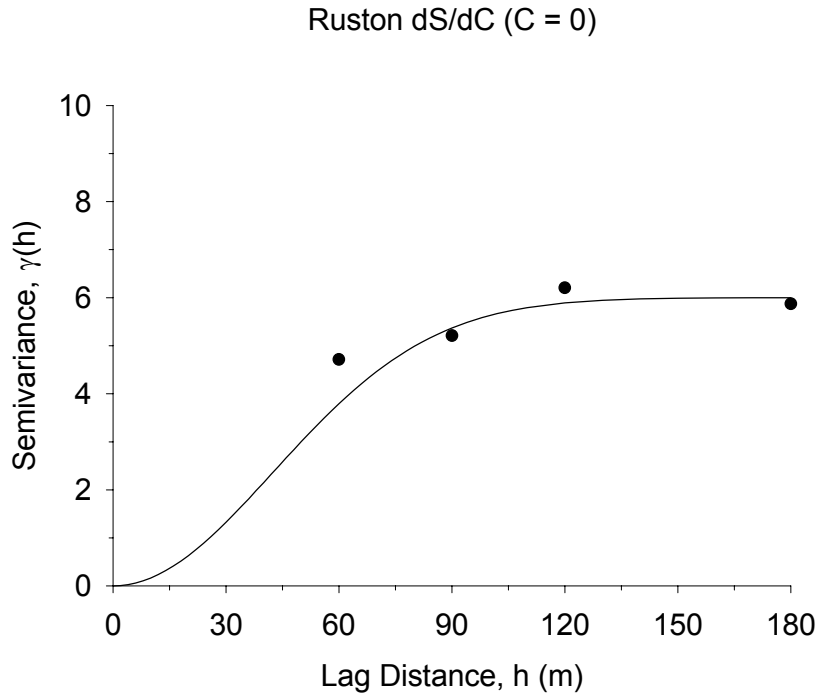


Figure 10. Experimental semivariogram for dS/dC (C = 0) for the 0 to 5 cm depth Ruston soil.

Table 7. Semivariogram models and parameters for P sorption isotherms from the 0 to 5 cm depths of Ruston and Darley soils.

Soil	Isotherm Parameter	Model	Scale, C	Range, r
				m
Ruston	S_T	Exponential	16000	70
Darley	S_T	Exponential	35000	60
Ruston	dS/dC (C = 0)	Gaussian	6	60
Darley	dS/dC (C = 0)	Exponential	7	70
Ruston	S (C = 1)	Exponential	6.5	60
Darley	S (C = 1)	Exponential	6	50

Since development of P sorption isotherms is laborious, it was of interest to examine correlations of sorption isotherm parameters with more easily or routinely (as in soil testing laboratories) sampled soil properties such as OC and pH. Both influence P sorption (Brady and Weil, 2002), as does texture (Nolfe and Walthall, 1998). Correlation

with routinely measured properties, coupled with co-kriging (David, 1977), would further reduce the need to develop sorption isotherms. Results of linear regressions of the isotherm parameters on OC and pH are shown in Table 8. The relationship of sorption maximum, S_T , to OC was highly significant for both soils. On the other hand, dS/dC ($C = 0$) and S ($C = 1$) were positively and significantly related to OC ($P < 0.0001$) in the Ruston, but these parameters were not significantly related to OC in the Darley. Only S_T for the Darley soil was significantly related to pH. Thus, results were inconsistent except for the positive and significant effect of OC content on an increased P sorption maximum.

Table 8. Linear regression of S_T , dS/dC ($C = 0$) and S ($C = 1$) as functions of OC or pH in the Darley and Ruston soils (dependent = slope x independent + intercept).

Soil	Dependent Variable	Independent Variable	Slope	Intercept	$P \leq$
Darley	S_T	OC	$144 \pm 37^\dagger$	105 ± 101	0.0003
	S_T	pH	-182 ± 93	1490 ± 510	0.0577
	dS/dC ($C = 0$)	OC	-0.36 ± 2.20	10.66 ± 6.08	NS
	dS/dC ($C = 0$)	pH	5.36 ± 4.89	-19.59 ± 26.75	NS
	S ($C = 1$)	OC	-0.23 ± 2.06	10.01 ± 5.68	NS
	S ($C = 1$)	pH	4.40 ± 4.58	-14.64 ± 25.08	NS
Ruston	S_T	OC	104 ± 37	71 ± 50	0.0072
	S_T	pH	-50 ± 108	492 ± 621	NS
	dS/dC ($C = 0$)	OC	3.12 ± 0.60	-1.06 ± 0.81	0.0001
	dS/dC ($C = 0$)	pH	1.88 ± 2.03	-7.83 ± 11.66	NS
	S ($C = 1$)	OC	3.07 ± 0.57	-1.06 ± 0.77	0.0001
	S ($C = 1$)	pH	1.75 ± 1.96	-7.18 ± 11.24	NS

[†] Standard error.

SUMMARY AND CONCLUSIONS

This two-part study examined: (1) possible enhanced mobility of soil P under anoxic conditions and (2) spatial variability of surface soil P retention properties. Under anoxic conditions, microbial reduction of Fe or Mn is expected to decrease P retention and thus enhance its mobility. If this occurs in a soil with a shallow impeding subsurface horizon (Bt with low hydraulic conductivity), lateral subsurface drainage would tend to enrich downstream surface water with P, increasing the likelihood of eutrophication. Although Nolfe and Wathall (1998) found circumstantial evidence for the occurrence of lateral subsurface P transport, effects of anoxic conditions on P mobility in a representative Louisiana coastal plain soil and soil organic matter content on the development of anoxic conditions had not been examined. The general topic of P sorption spatial variability had not been explored, yet knowledge of it may be useful in efforts to minimize possible environmental impacts of surface applications of poultry litter. If a wide range in P sorption from one location to another in a field exists, it may be then feasible to use spatially variable fertilizer application technology to tailor application rates to P retention characteristics. The extent of such variability among and within Louisiana coastal plain soils was unknown.

The first part of this study examined the effects of oxygenation and concentration of soil OC on P sorption and mobility in Ruston pasture (higher OC) and forest (lower OC) soil. The Eh of water passing through soil columns indicated rapid development of reducing conditions. This was the case with both the oxic and anoxic input solutions, but lower Eh values occurred in the pasture soil. This suggests that the effect of anoxic conditions on enhanced P mobility may be more important in lower OC soils. This was

confirmed, to some extent, by P transport studies. Whereas P mobility in the higher OC pasture soil under conditions of oxic or anoxic input was generally well-described using P sorption data from an independent batch study, the batch sorption isotherm for the forest soil led to only qualitative agreement with measured P mobility. Thus, retention / release processes other than equilibrium sorption were apparently more important in the forest soil than in the pasture soil. Adsorption or precipitation kinetics are possibilities. Assuming the approach to equilibrium is proportional to displacement from equilibrium, then the initially wider difference in P concentrations between the native soil solution and the 200 $\mu\text{g} / \text{ml}$ pulse for the forest soil than the pasture soil may have aggravated kinetic limitations. Effluent P concentrations from the forest soil equilibrated at a higher solution P concentration were better described by the transport model than results obtained when this soil was equilibrated with its low P, native soil solution. Phosphorus precipitation in the soil columns, unaccounted for by the Langmuir sorption isotherm, may have also contributed to discrepancies between measured and predicted P mobility in the Ruston forest soil. Results of a MINTEQ computer analysis of column effluent used to explore this possibility, however, were inconclusive.

The second part of this study sought to analyze how the P sorption isotherm (Langmuir) parameters, S_T , dS/dC ($C = 0$) and S ($C = 1$) spatially varied in two soils representative of North Louisiana coastal plain soils to which poultry litter is applied. Darley surface (0 to 5 cm) soil was sampled on a 30 x 30 m (4 x 10 locations) grid and Ruston surface soil was sampled on a 60 x 60 m (7 x 7 locations) grid. Measures of maximum P retention (S_T), maximum P retention rate (dS/dC , $C = 0$) and P retention at soil solution concentration \geq threshold levels for eutrophication (S , $C = 1 \mu\text{g}/\text{ml}$) in the

Darley were approximately twice those in the Ruston. Thus, gross variability in P sorption among Louisiana coastal plain soils may be useful in prescriptions for poultry litter application rates. Furthermore, sorption data for both soils (sites) showed spatial correlation well beyond the minimum sampling distance, so that geostatistical interpolation (kriging) was possible. These results suggest that site-specific application of poultry litter may be feasible, either at the high spatial detail (<< ha scale) possible using variable rate application technology or at the field-scale. However, whether highly detailed variable applications or even field-scale prescriptions ultimately would result in reduced P loadings to surface waters must be tested using field-scale water quality models and experiments before recommendations are possible.

The "big picture" of this study is to reduce the potential for P-induced eutrophication by developing a set of criteria that will allow the applicator to determine the amount of P that a specific location in a particular soil can safely retain. There are many factors that may affect the P sorption properties of a particular soil, and a few were examined in this study – temporal variability in oxygen status (as affected by soil OC under water-saturated, anoxic conditions) and spatial variability. Variable rate application technology depends on the accurate knowledge of position, linked to spatially variable plans for application. Global positioning system (GPS) equipment can now identify positional data to the centimeter level. When linked with a geographic information system (GIS), these technologies drive the machinery of precision agriculture. And since these technologies allow the applicator to be extremely accurate in the placement of material, only a set of criteria that accurately predict P desorption behavior is needed.

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APPENDIX A – SAMPLE COLUMN DATA

Column 1													
Tube No.	Empty	Filled	Net	PV	abs.	[P]	P(ICP)	mV	[Cl]	COD	Eh	pH	[Fe]
1	5.21	12.05	6.84	0.08	0.113	18.55				2470			
2	5.23	12.12	6.89	0.24			25.31						0.45
3	5.21	12.12	6.91	0.39									
4	5.19	12.21	7.02	0.56									
5	5.18	12.22	7.04	0.72							417		
6	5.13	12.24	7.11	0.88									
7	5.21	12.28	7.07	1.04	0.164	26.93							
8	5.23	12.30	7.07	1.20			29.36						0.24
9	5.21	12.29	7.08	1.37									
10	5.17	12.32	7.15	1.53									
11	5.15	12.35	7.20	1.70									
12	5.22	12.38	7.16	1.86									
13	5.20	12.30	7.10	2.02									
14	5.23	12.40	7.17	2.19	0.162	26.60							
15	5.23	12.41	7.18	2.35			27.12						0.17
16	5.18	12.37	7.19	2.52									
17	5.20	12.39	7.19	2.68									
18	5.22	12.41	7.19	2.85									
19	5.16	12.34	7.18	3.01	0.152	24.96							
20	5.19	12.33	7.14	3.18			26.69						0.14
21	5.20	12.41	7.21	3.34									
22	5.19	12.40	7.21	3.51									
23	5.26	12.42	7.16	3.67									
24	5.22	12.43	7.21	3.84									
25	5.21	12.40	7.19	4.01	0.149	24.47						6.55	
26	5.17	12.40	7.23	4.17			25.90					6.55	0.12
27	5.19	12.42	7.23	4.34								6.55	
28	5.17	12.40	7.23	4.50								6.55	
29	5.21	12.38	7.17	4.67								6.55	
30	5.23	12.46	7.23	4.83								6.55	
31	5.19	12.37	7.18	5.00								6.55	
32	5.19	12.37	7.18	5.16								6.55	
33	5.18	12.37	7.19	5.33								6.55	
34	5.18	12.36	7.18	5.50								6.55	
35	5.21	12.40	7.19	5.66								6.55	
36	5.19	12.54	7.35	5.83								6.55	
37	5.21	12.39	7.18	5.99								6.55	
38	5.16	12.35	7.19	6.16								6.55	
39	5.20	12.40	7.20	6.32							335	6.55	
40	5.20	12.40	7.20	6.49								6.55	
41	5.21	12.41	7.20	6.66								6.55	
42	5.17	12.31	7.14	6.82								6.55	
43	5.19	12.32	7.13	6.98								6.55	
44	5.16	12.36	7.20	7.15								6.55	

45	5.22	12.43	7.21	7.31								6.55
46	5.21	12.42	7.21	7.48								6.55
47	5.22	12.43	7.21	7.65								6.55
48	5.16	12.36	7.20	7.81								6.55
49	5.22	12.42	7.20	7.98	0.143	23.48						6.54
50	5.23	12.46	7.23	8.14								6.54
51	5.21	12.42	7.21	8.31								6.54
52	5.20	12.47	7.27	8.48								6.54
53	5.17	12.38	7.21	8.64							299	6.54
54	5.19	12.40	7.21	8.81								6.54
55	5.14	12.31	7.17	8.97								6.54
56	5.22	12.45	7.23	9.14								6.54
57	5.17	12.40	7.23	9.30								6.54
58	5.22	12.39	7.17	9.47								6.54
59	5.23	12.46	7.23	9.64								6.54
60	5.21	12.45	7.24	9.80								6.54
61	5.20	12.44	7.24	9.97								6.54
62	5.16	12.34	7.18	10.13								6.54
63	5.15	12.38	7.23	10.30							263	6.54
64	5.19	12.42	7.23	10.47								6.54
65	5.18	12.41	7.23	10.63								6.54
66	5.21	12.44	7.23	10.80								6.54
67	5.15	12.41	7.26	10.96								6.54
68	5.17	12.43	7.26	11.13								6.54
69	5.18	12.45	7.27	11.30								6.54
70	5.20	12.46	7.26	11.47								6.54
71	5.13	12.39	7.26	11.63								6.54
72	5.15	12.47	7.32	11.80								6.38
73	5.25	12.49	7.24	11.97	0.154	25.29						6.38
74	5.13	12.38	7.25	12.13								6.38
75	5.14	12.39	7.25	12.30								6.38
76	5.15	12.40	7.25	12.47								6.38
77	5.16	12.48	7.32	12.63								6.38
78	5.17	12.42	7.25	12.80								6.38
79	5.20	12.51	7.31	12.97								6.38
80	5.17	12.44	7.27	13.14								6.38
81	5.20	12.46	7.26	13.30								6.38
82	5.21	12.48	7.27	13.47								6.38
83	5.16	12.42	7.26	13.64								6.38
84	5.18	12.45	7.27	13.80								6.38
85	5.21	12.84	7.63	13.98								6.38
86	5.20	12.47	7.27	14.15								6.38
87	5.15	12.42	7.27	14.31								6.38
88	5.19	12.47	7.28	14.48								6.38
89	5.18	12.45	7.27	14.65								6.38
90	5.21	12.48	7.27	14.82								6.38
91	5.17	12.50	7.33	14.98								6.38
92	5.13	12.41	7.28	15.15								6.38
93	5.18	12.47	7.29	15.32								6.38

94	5.15	12.44	7.29	15.49								6.38
95	5.15	12.43	7.28	15.65								6.38
96	5.21	12.49	7.28	15.82								6.38
97	5.14	12.43	7.29	15.99	0.158	25.94						6.24
98	5.21	12.49	7.28	16.16								6.24
99	5.21	12.50	7.29	16.32								6.24
100	5.20	12.49	7.29	16.49							-146	6.24
101	5.21	12.50	7.29	16.66								6.24
102	5.21	12.50	7.29	16.83								6.24
103	5.18	12.47	7.29	16.99								6.24
104	5.17	12.47	7.30	17.16								6.24
105	5.17	12.50	7.33	17.33								6.24
106	5.19	12.49	7.30	17.50								6.24
107	5.21	12.51	7.30	17.66								6.24
108	5.11	12.41	7.30	17.83								6.24
109	5.23	12.58	7.35	18.00								6.24
110	5.18	12.49	7.31	18.17								6.24
111	5.10	12.40	7.30	18.34								6.24
112	5.19	12.56	7.37	18.51								6.24
113	5.15	12.46	7.31	18.67								6.24
114	5.16	12.47	7.31	18.84							-108	6.24
115	5.13	12.49	7.36	19.01								6.24
116	5.22	5.22	0.00	19.10								6.24
117	5.21	12.53	7.32	19.18								6.24
118	5.22	12.55	7.33	19.35								6.24
119	5.18	12.57	7.39	19.52								6.24
120	5.23	12.61	7.38	19.69								6.24
121	5.18	12.47	7.29	19.86	0.164	26.93						6.32
122	5.18	12.53	7.35	20.02							-122	6.32
123	5.19	12.54	7.35	20.19								6.32
124	5.17	12.46	7.29	20.36								6.32
125	5.16	12.45	7.29	20.53								6.32
126	5.22	12.56	7.34	20.70								6.32
127	5.16	12.44	7.28	20.86								6.32
128	5.21	12.50	7.29	21.03								6.32
129	5.19	12.54	7.35	21.20								6.32
130	5.14	12.43	7.29	21.37								6.32
131	5.19	12.54	7.35	21.54								6.32
132	5.20	12.49	7.29	21.71								6.32
133	5.10	12.40	7.30	21.87								6.32
134	5.21	12.57	7.36	22.04								6.32
135	5.18	12.48	7.30	22.21								6.32
136	5.21	12.57	7.36	22.38								6.32
137	5.19	12.49	7.30	22.55								6.32
138	5.18	12.48	7.30	22.71								6.32
139	5.20	12.56	7.36	22.88								6.32
140	5.16	12.46	7.30	23.05								6.32
141	5.16	12.46	7.30	23.22								6.32
142	5.17	12.54	7.37	23.39								6.32

143	5.13	12.43	7.30	23.56								6.32	
144	5.14	12.50	7.36	23.72								6.32	
145	5.17	12.48	7.31	23.89	0.162	26.60						6.22	
146	5.19	12.49	7.30	24.06								6.22	
147	5.22	12.59	7.37	24.23								6.22	
148	5.17	12.48	7.31	24.40								6.22	
149	5.13	12.50	7.37	24.57								6.22	
150	5.17	12.50	7.33	24.74								6.22	
151	5.15	12.47	7.32	24.90								6.22	
152	5.17	12.55	7.38	25.07								6.22	
153	5.20	12.52	7.32	25.24								6.22	
154	5.20	12.52	7.32	25.41								6.22	
155	5.15	12.49	7.34	25.58								6.22	
156	5.14	12.47	7.33	25.75								6.22	
157	5.18	12.51	7.33	25.92								6.22	
158	5.16	12.48	7.32	26.08								6.22	
159	5.17	12.48	7.31	26.25							-156	6.22	
160	5.18	12.50	7.32	26.42								6.22	
161	5.19	12.52	7.33	26.59								6.22	
162	5.19	12.58	7.39	26.76								6.22	
163	5.14	12.67	7.53	26.93	0.159	26.11						6.22	
164	5.18	12.77	7.59	27.10								6.22	
165	5.18	12.69	7.51	27.28								6.22	
166	5.17	12.75	7.58	27.45								6.22	
167	5.15	12.68	7.53	27.62								6.22	
168	5.17	12.75	7.58	27.80								6.22	
169	5.20	12.72	7.52	27.97								6.13	
170	5.20	12.79	7.59	28.14			100.50					6.13	2.80
171	5.19	12.78	7.59	28.32								6.13	
172	5.15	12.67	7.52	28.49	0.470	152.94						6.13	
173	5.16	12.75	7.59	28.67								6.13	
174	5.12	12.65	7.53	28.84							-183	6.13	
175	5.17	12.71	7.54	29.01	0.393	127.88						6.13	
176	5.15	12.73	7.58	29.19			162.96					6.13	2.75
177	5.16	12.60	7.44	29.36								6.13	
			113.22										
178	5.17	12.46	7.29	29.53	0.528	171.81						6.13	
179	5.18	12.00	6.82	29.69			181.63					6.13	2.85
180	5.18	12.00	6.82	29.85								6.13	
181	5.17	12.56	7.39	30.01	0.549	178.64						6.13	
182	5.18	12.63	7.45	30.18			168.00					6.13	3.14
183	5.17	12.58	7.41	30.35							-193	6.13	
184	5.14	12.54	7.40	30.52	0.271	88.18						6.13	
185	5.19	12.59	7.40	30.69			79.92					6.13	3.38
186	5.19	12.58	7.39	30.86								6.13	
187	5.18	12.63	7.45	31.03	0.135	43.93						6.13	
188	5.17	12.60	7.43	31.20								6.13	
189	5.19	12.62	7.43	31.38								6.13	
190	5.20	12.59	7.39	31.55	0.187	60.85						6.13	

191	5.18	12.59	7.41	31.72			57.08					6.13	3.44
192	5.17	12.53	7.36	31.89								6.13	
193	5.20	12.58	7.38	32.05	0.134	43.60						6.20	
194	5.20	12.62	7.42	32.22			42.38					6.20	2.76
195	5.13	12.49	7.36	32.39								6.20	
196	5.19	12.61	7.42	32.56	0.100	32.54						6.20	
197	5.14	12.57	7.43	32.74			33.73					6.20	2.98
198	5.18	12.61	7.43	32.91								6.20	
199	5.17	12.54	7.37	33.08	0.079	25.71						6.20	
200	5.19	12.62	7.43	33.25								6.20	
201	5.17	12.60	7.43	33.42								6.20	
202	5.18	12.55	7.37	33.59	0.063	20.50						6.20	
203	5.14	12.51	7.37	33.76			23.45					6.20	3.25
204	5.19	12.62	7.43	33.93								6.20	
205	5.16	12.55	7.39	34.10								6.20	
206	5.20	12.58	7.38	34.27								6.20	
207	5.18	12.56	7.38	34.44	0.050	16.27						6.20	
208	5.16	12.61	7.45	34.61			17.64					6.20	1.77
209	5.20	12.59	7.39	34.78								6.20	
210	5.17	12.50	7.33	34.95								6.20	
211	5.23	12.63	7.40	35.12								6.20	
212	5.22	12.62	7.40	35.29								6.20	
213	5.18	12.57	7.39	35.46	0.040	13.02						6.20	
214	5.18	12.58	7.40	35.63			14.89					6.20	2.26
215	5.17	12.51	7.34	35.79								6.20	
216	5.12	12.52	7.40	35.96								6.20	
217	5.14	12.54	7.40	36.13								6.10	
218	5.18	12.52	7.34	36.30							-189	6.10	
219	5.18	12.59	7.41	36.47	0.033	10.74						6.10	
220	5.20	12.61	7.41	36.64			13.99					6.10	3.00
221	5.15	12.55	7.40	36.81								6.10	
222	5.18	12.59	7.41	36.98								6.10	
223	5.17	12.58	7.41	37.15								6.10	
224	5.14	12.55	7.41	37.32								6.10	
225	5.14	12.55	7.41	37.49	0.032	10.41						6.10	
226	5.17	12.59	7.42	37.67								6.10	
227	5.16	12.57	7.41	37.84								6.10	
228	5.19	12.60	7.41	38.01								6.10	
229	5.14	12.62	7.48	38.18								6.10	
230	5.17	12.59	7.42	38.35								6.10	
231	5.17	12.59	7.42	38.52	0.027	8.79						6.10	
232	5.18	12.61	7.43	38.69			12.44					6.10	4.01
233	5.17	12.59	7.42	38.86								6.10	
234	5.15	12.56	7.41	39.03								6.10	
235	5.20	12.63	7.43	39.20								6.10	
236	5.15	12.58	7.43	39.37								6.10	
237	5.16	12.59	7.43	39.54	0.025	8.14						6.10	
238	5.17	12.61	7.44	39.71							-193	6.10	
			563.70										

239	5.15	8.72	3.57	39.84				181.7	0.006				
240	5.18	8.92	3.74	39.92									
241	5.16	8.90	3.74	40.01				178.3	0.007				
242	5.19	8.88	3.69	40.10									
243	5.17	8.92	3.75	40.18				179.5	0.007				
244	5.19	8.92	3.73	40.27									
245	5.15	8.88	3.73	40.35				156.8	0.018				
246	5.16	8.89	3.73	40.44				124.6	0.073				
247	5.22	8.96	3.74	40.52				106.7	0.160				
248	5.20	8.96	3.76	40.61				95.8	0.257				
249	5.19	8.95	3.76	40.70				87.8	0.364				
250	5.13	8.90	3.77	40.78				82.3	0.462				
251	5.18	8.96	3.78	40.87				82.7	0.454				
252	5.13	8.91	3.78	40.96				75.1	0.631				
253	5.23	9.05	3.82	41.04				72.1	0.719				
254	5.17	8.94	3.77	41.13				69.6	0.802				
255	5.14	8.91	3.77	41.22				66.5	0.917				
256	5.18	9.02	3.84	41.31				66.8	0.905				
257	5.18	8.96	3.78	41.39									
258	5.16	8.99	3.83	41.48				65.4	0.962				
259	5.18	8.95	3.77	41.57									
260	5.18	9.01	3.83	41.66				68.3	0.848				
261	5.17	8.94	3.77	41.74									
262	5.18	8.94	3.76	41.83				73.6	0.674				
263	5.19	9.02	3.83	41.92									
264	5.19	8.95	3.76	42.00				77.4	0.571				
265	5.20	8.96	3.76	42.09									
266	5.19	8.96	3.77	42.18									
267	5.19	8.94	3.75	42.26									
268	5.19	8.95	3.76	42.35				86.7	0.381				
269	5.15	8.90	3.75	42.44									
270	5.15	8.91	3.76	42.52									
271	5.18	8.86	3.68	42.61									
272	5.16	8.91	3.75	42.69				106.0	0.165				
273	5.18	8.92	3.74	42.78									
274	5.20	8.87	3.67	42.86									
275	5.18	8.92	3.74	42.95									
276	5.15	8.89	3.74	43.03				133.3	0.050				
277	5.16	8.84	3.68	43.12									
278	5.16	8.89	3.73	43.21									
279	5.17	8.85	3.68	43.29									
280	5.18	8.91	3.73	43.38				154.2	0.020				
281	5.17	8.85	3.68	43.46									
282	5.16	8.90	3.74	43.55									
283	5.21	8.89	3.68	43.63									
284	5.15	8.89	3.74	43.72				156.6	0.018				
285	5.14	8.92	3.78	43.80									
286	5.19	8.93	3.74	43.89									
287	5.13	8.81	3.68	43.97									

288	5.14	8.88	3.74	44.06				159.1	0.016				
289	5.15	8.89	3.74	44.15									
290	5.18	8.87	3.69	44.23									
291	5.13	8.88	3.75	44.32									
292	5.18	8.86	3.68	44.40									
293	5.17	8.92	3.75	44.49									
294	5.19	8.94	3.75	44.57									
295	5.19	8.88	3.69	44.66									
296	5.19	8.94	3.75	44.74									
297	5.15	8.84	3.69	44.83									
298	5.17	8.92	3.75	44.92									
299	5.18	8.87	3.69	45.00									
300	5.16	8.91	3.75	45.09				161.5	0.015				
301	5.20	8.89	3.69	45.17									
302	5.15	8.84	3.69	45.26									
303	5.17	8.93	3.76	45.34									
304	5.18	8.87	3.69	45.43									
305	5.23	8.93	3.70	45.51									
306	5.19	8.94	3.75	45.60				164.8	0.013				
307	5.19	8.88	3.69	45.68									
308	5.18	8.87	3.69	45.77									
309	5.19	8.88	3.69	45.85									
310	5.18	8.88	3.70	45.94									
311	5.19	8.02	2.83	46.01				163.0	0.014				
312	5.20	8.65	3.45	46.09				172.0	0.006				
313	5.21	8.62	3.41	46.16									
314	5.18	8.64	3.46	46.24				176.6	0.005				
315	5.19	8.65	3.46	46.32									
316	5.21	8.66	3.45	46.40				160.3	0.010				
317	5.19	8.65	3.46	46.48									
318	5.21	8.67	3.46	46.56				109.1	0.090				
319	5.22	8.74	3.52	46.64				97.1	0.151				
320	5.23	8.70	3.47	46.72				85.2	0.253				
321	5.18	8.66	3.48	46.80				79.3	0.326				
322	5.21	8.77	3.56	46.88				74.6	0.400				
323	5.22	8.79	3.57	46.96				70.4	0.479				
324	5.19	8.73	3.54	47.05				66.5	0.567				
325	5.18	8.74	3.56	47.13				64.0	0.632				
326	5.21	8.77	3.56	47.21				61.6	0.701				
327	5.21	8.77	3.56	47.29				59.0	0.785				
328	5.22	8.85	3.63	47.37				58.5	0.802				
329	5.23	8.80	3.57	47.46				58.1	0.816				
330	5.20	8.77	3.57	47.54				61.9	0.692				
331	5.22	8.79	3.57	47.62									
332	5.20	8.76	3.56	47.70				60.2	0.745				
333	5.19	8.75	3.56	47.79									
334	5.17	8.74	3.57	47.87				62.5	0.674				
335	5.19	8.75	3.56	47.95									
336	5.25	8.82	3.57	48.03				65.6	0.590				

337	5.20	8.76	3.56	48.11									
338	5.18	8.74	3.56	48.19				68.8	0.513				
339	5.20	8.76	3.56	48.28									
340	5.20	8.75	3.55	48.36									
341	5.20	8.75	3.55	48.44									
342	5.15	8.70	3.55	48.52									
343	5.21	8.76	3.55	48.60				85.0	0.255				
344	5.20	8.69	3.49	48.68									
345	5.15	8.70	3.55	48.76									
346	5.26	8.80	3.54	48.85									
347	5.16	8.71	3.55	48.93				110.9	0.083				
348	5.22	8.76	3.54	49.01									
349	5.19	8.73	3.54	49.09									
350	5.19	8.73	3.54	49.17									
351	5.18	8.66	3.48	49.25				153.0	0.013				
352	5.20	8.75	3.55	49.33									
353	5.15	8.69	3.54	49.41									
354	5.17	8.65	3.48	49.50									
355	5.22	8.76	3.54	49.58				168.8	0.007				
356	5.17	8.72	3.55	49.66									
357	5.20	8.68	3.48	49.74									
358	5.20	8.74	3.54	49.82									
359	5.23	8.72	3.49	49.90				170.8	0.006				

Tube No.	Al	Ca	Fe	Mg	Mn	P	S
2	1.258	176.175	0.454	49.349	3.075	25.312	62.292
8	0.931	67.215	0.244	26.878	1.567	29.363	34.463
15	1.023	56.077	0.17	22.693	1.459	27.12	33.271
20	0.916	53.946	0.138	21.861	1.058	26.686	33.196
26	0.897	51.56	0.122	21.024	0.881	25.898	32.684
170	0.817	37.211	2.796	13.62	2.242	100.502	11.385
176	0.785	30.2	2.747	11.106	1.961	162.961	1.476
182	0.73	32.601	3.141	12.024	2.142	167.997	7.94
186	0.796	35.763	3.379	12.926	2.2	79.916	
191	0.751	38.427	3.445	13.705	2.241	57.079	
194	0.796	40.848	2.758	14.378	2.284	42.376	
197	0.851	43.742	2.9975	15.274	2.401	33.732	
203	0.831	48.068	3.25	16.652	2.451	23.45	
208	3791	51.771	1.767	17.54	2.673	17.636	
214	0.809	55.901	2.261	18.747	2.837	14.894	
220	0.768	56.24	3	18.827	2.802	13.986	
232	0.769	55.45	4.006	18.439	2.627	12.438	

APPENDIX B – SPATIAL DATA

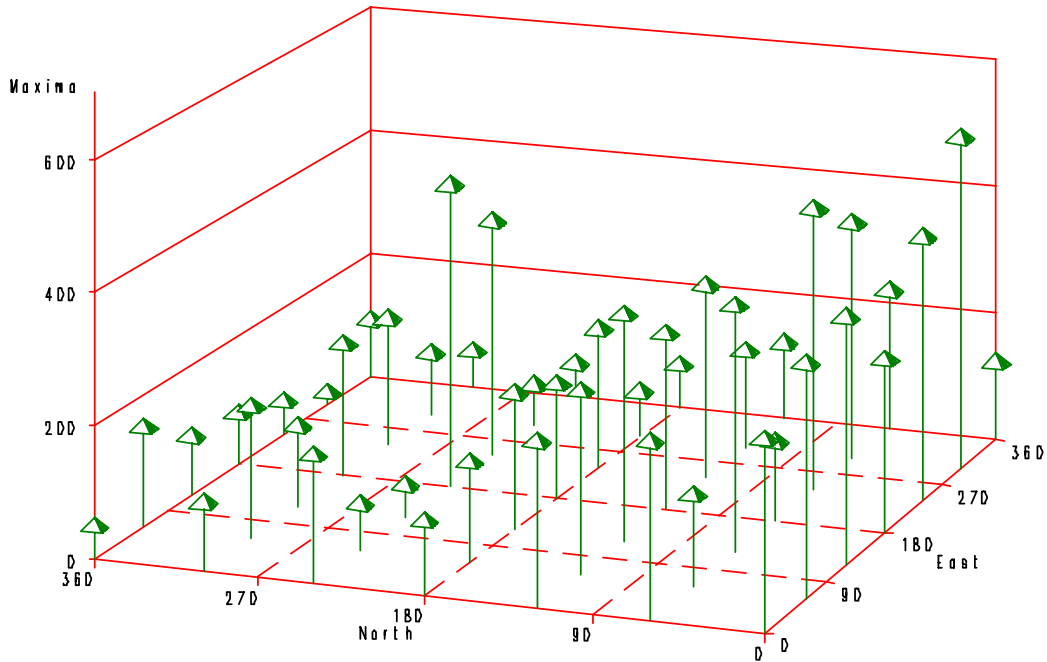
			Ruston 0-5						
Plot	k	St	dS/dC (C=0)	S (C=1.0)	R-sq	% OC	St/OC	pH	St/pH
0,0	0.0188	286.3	5.38244	5.2831174	0.9609	2.11	135.5361	5.43	52.7256
0,1	0.0158	266.3	4.20754	4.1420949	0.9324	1.27	210.1132	5.46	48.77289
0,2	0.0186	249.3	4.63698	4.5523071	0.9333	2.30	108.3858	5.67	43.96825
0,3	0.012	114.7	1.3764	1.3600791	0.9908	1.36	84.25806	5.83	19.6741
0,4	0.0052	195.4	1.01608	1.0108237	0.9324	0.99	198.2217	5.37	36.38734
0,5	0.0311	106.2	3.30282	3.2032005	0.9747	1.70	62.4974	5.06	20.98814
0,6	0.02	53.9144	1.078288	1.0571451	0.9122	0.80	67.5619	5.55	9.714306
1,0	0.0123	351.4	4.32222	4.2697027	0.9873	1.92	182.5845	5.6	62.75
1,1	0.0224	139.8	3.13152	3.0629108	0.9671	1.21	115.4339	5.63	24.83126
1,2	0.0188	277.5	5.217	5.1207303	0.9779	2.21	125.7799	5.71	48.59895
1,3	0.0085	154.3	1.31155	1.3004958	0.8867	1.36	113.348	5.7	27.07018
1,4	0.0269	73.4406	1.97555214	1.9238019	0.9721	1.55	47.40982	5.69	12.90696
1,5	0.0119	203.9	2.42641	2.3978753	0.9743	1.40	145.7629	5.71	35.70928
1,6	0.00809	155.5	1.257995	1.2478995	0.9735	0.80	194.8622	5.76	26.99653
2,0	0.011	375.1	4.1261	4.0812067	0.9793	1.92	194.8988	5.86	64.01024
2,1	0.00463	377.1	1.745973	1.7379264	0.9905	0.99	382.5456	5.78	65.24221
2,2	0.0147	347.6	5.10972	5.0356953	0.967	1.74	200.1355	5.82	59.72509
2,3	0.0064	211.8	1.35552	1.3468998	0.972	1.17	180.4812	5.8	36.51724
2,4	0.0313	54.1615	1.69525495	1.6438039	0.9779	1.06	51.05382	5.81	9.322117
2,5	0.00286	127.2	0.363792	0.3627545	0.9551	1.06	119.9015	5.7	22.31579
2,6	0.00794	94.3699	0.749297006	0.7433945	0.9966	0.52	182.7624	5.84	16.15923
3,0	0.00717	267	1.91439	1.9007615	0.9912	1.08	247.303	5.74	46.51568
3,1	0.0437	125.4	5.47998	5.2505318	0.9959			5.75	21.8087
3,2	0.00668	273.8	1.828984	1.8168475	0.9937	0.89	306.9912	5.71	47.95096
3,3	0.00851	180	1.5318	1.5188744	0.9886	1.04	172.7291	5.69	31.63445
3,4	0.00234	470.2	1.100268	1.0976994	0.984	1.23	382.3203	5.67	82.92769
3,5	0.0132	208.5	2.7522	2.7163443	0.9847	1.08	193.1187	5.62	37.09964
3,6	0.00789	83.8676	0.661715364	0.6565353	0.9832	0.61	137.4349	5.71	14.68785
4,0	0.00488	409.3	1.997384	1.9876841	0.9727	0.89	458.917	5.74	71.30662
4,1	0.00577	437.2	2.522644	2.5081718	0.9736	0.99	443.5135	5.71	76.56743
4,2	0.045	303.1	13.6395	13.052153	0.9871	1.61	188.8017	5.8	52.25862
4,3	0.00847	219.3	1.857471	1.8418704	0.9435	0.89	245.8844	5.72	38.33916
4,4	0.00333	372.3	1.239759	1.2356443	0.958	1.08	344.8349	5.69	65.43058
4,5	0.0113	203	2.2939	2.2682686	0.9845	0.99	205.9315	5.62	36.121
4,6	0.0114	56.2402	0.64113828	0.6339117	0.9133	0.52	108.9181	5.81	9.679897
5,0	0.0146	521.2	7.60952	7.5000197	0.9864	1.77	293.737	5.82	89.55326
5,1	0.0189	373.4	7.05726	6.9263519	0.9163	2.11	176.7697	6.07	61.51565
5,2	0.0417	156.9	6.54273	6.2808198	0.9649	1.55	101.2873	5.96	26.3255
5,3	0.0248	75.6345	1.8757356	1.8303431	0.9198	1.08	70.05484	5.88	12.86301
5,4	0.0144	69.4812	1.00052928	0.9863262	0.9439	1.46	47.74761	5.8	11.97952
5,5	0.0307	103.5	3.17745	3.0828078	0.962	1.17	88.19549	5.81	17.81411
5,6	0.131	24.3296	3.1871776	2.8180173	0.8485	0.61	39.86921	5.84	4.166027
6,0	0.0254	126	3.2004	3.1211235	0.9589	0.99	127.8195	5.8	21.72414

6,1	0.0169	223.1	3.77039	3.7077294	0.9754	2.02	110.5292	5.93	37.62226
6,2	0.0414	123.8	5.12532	4.9215671	0.9976	1.92	64.32545	6.05	20.46281
6,3	0.016	72.83	1.16528	1.1469291	0.9914	1.21	60.13629	5.99	12.1586
6,4	0.0217	57.9303	1.25708751	1.2303881	0.9677	1.27	45.70756	5.86	9.885717
6,5	0.066	62.1033	4.0988178	3.8450448	0.997	0.89	69.63172	5.89	10.54385
6,6	0.0051	95.7522	0.48833622	0.4858583	0.9771	0.59	161.8916	5.86	16.33997
	avg	avg	avg	avg	avg	avg	avg	avg	avg
	0.01954	202.254	2.95521673	2.8827039	0.96479	1.27	166.62	5.7412	35.29936
			Darley (0-5)						
Plot	k	St	dS/dC (C=0)	S (C=1.0)	R-sq	% OC	St/OC	pH	St/pH
0,0	0.0308	528.3	16.27164	15.785448	0.9841	2.39	220.6767	5.22	101.2069
0,1	0.0264	403.3	10.64712	10.373266	0.9502	3.33	121.0085	5.46	73.86447
0,2	0.0266	507.5	13.4995	13.149718	0.9863	3.05	166.3293	5.31	95.57439
0,3	0.0088	523.7	4.60856	4.5683584	0.9526	3.61	144.8898	4.93	106.2272
0,4	0.0044	517.5	2.277	2.2670251	0.982	2.39	216.1654	5.77	89.68804
0,5	0.0278	207.1	5.75738	5.601654	0.9552	2.39	86.50794	5.42	38.21033
0,6	0.0066	431.4	2.84724	2.8285714	0.9852	1.85	233.2545	5.78	74.63668
0,7	0.0103	504.9	5.20047	5.1474513	0.9756	2.58	195.5639	5.51	91.63339
0,8	0.0106	409.8	4.34388	4.2983178	0.963	1.64	249.4307	5.39	76.02968
0,9	0.0685	622.2	42.6207	39.888348	0.9353	2.30	270.5079	5.66	109.9293
1,0	0.0119	352	4.1888	4.1395395	0.9932	2.11	166.6388	5.64	62.41135
1,1	0.006	556	3.336	3.3161034	0.9905	2.77	200.7561	5.53	100.5425
1,2	0.0174	350.3	6.09522	5.990977	0.9276	2.49	140.8025	5.47	64.04022
1,3	0.0145	468.4	6.7918	6.6947265	0.9709	2.30	203.6418	5.17	90.59961
1,4	0.0175	491.7	8.60475	8.4567568	0.9764	3.16	155.4126	5.18	94.92278
1,5	0.0102	449.9	4.58898	4.542645	0.9891	2.41	186.4657	5.24	85.85878
1,6	0.0103	283.1	2.91593	2.8862021	0.9875	3.11	91.102	5.58	50.73477
1,7	0.0081	365	2.9565	2.9327448	0.9847	2.66	137.3797	5.72	63.81119
1,8	0.0073	476.4	3.47772	3.4525166	0.9587	2.30	207.1198	5.75	82.85217
1,9	0.0122	466.4	5.69008	5.6214977	0.9891	2.45	190.3418	5.67	82.2575
2,0	0.0251	587.2	14.73872	14.377836	0.9802	2.41	243.3711	5.7	103.0175
2,1	0.0266	631.9	16.80854	16.373018	0.9696	2.26	279.2848	5.28	119.678
2,2	0.0292	545	15.914	15.462495	0.9913	2.58	211.0959	5.69	95.78207
2,3	0.0345	445.8	15.3801	14.867182	0.9861	2.49	179.1885	5.57	80.03591
2,4	0.0198	494.3	9.78714	9.5971171	0.9846	2.68	184.7404	5.52	89.5471
2,5	0.0369	263.7	9.73053	9.3842511	0.9859	2.94	89.73912	5.42	48.65314
2,6	0.1159	218.3	25.30097	22.673152	0.9565	2.47	88.41257	6.41	34.05616
2,7	0.0094	389.5	3.6613	3.6272043	0.9566	3.15	123.8451	5.44	71.59926
2,8	0.0063	606.8	3.82284	3.7989069	0.9581	3.05	198.8741	5.21	116.4683
2,9	0.0097	543.5	5.27195	5.2213034	0.887	2.77	196.2427	5.12	106.1523
3,0	0.0184	545	10.028	9.8468185	0.9916	2.49	219.0618	5.5	99.09091
3,1	0.0176	517.9	9.11504	8.9573899	0.9855	2.81	184.4976	5.27	98.27324
3,2	0.0045	895.9	4.03155	4.0134893	0.9945	3.15	284.8595	5.5	162.8909
3,3	0.0229	446.1	10.21569	9.986988	0.9928	2.45	182.0572	5.28	84.48864
3,4	0.0237	469.4	11.12478	10.867227	0.9951	2.64	177.9315	5.6	83.82143
3,5	0.0058	499.9	2.89942	2.8827003	0.9551	2.53	197.9461	5.34	93.61423
3,6	0.0192	567.8	10.90176	10.696389	0.9944	2.86	198.2949	5.64	100.6738
3,7	0.0285	573.8	16.3533	15.900146	0.9847	2.96	194.0287	5.33	107.6548

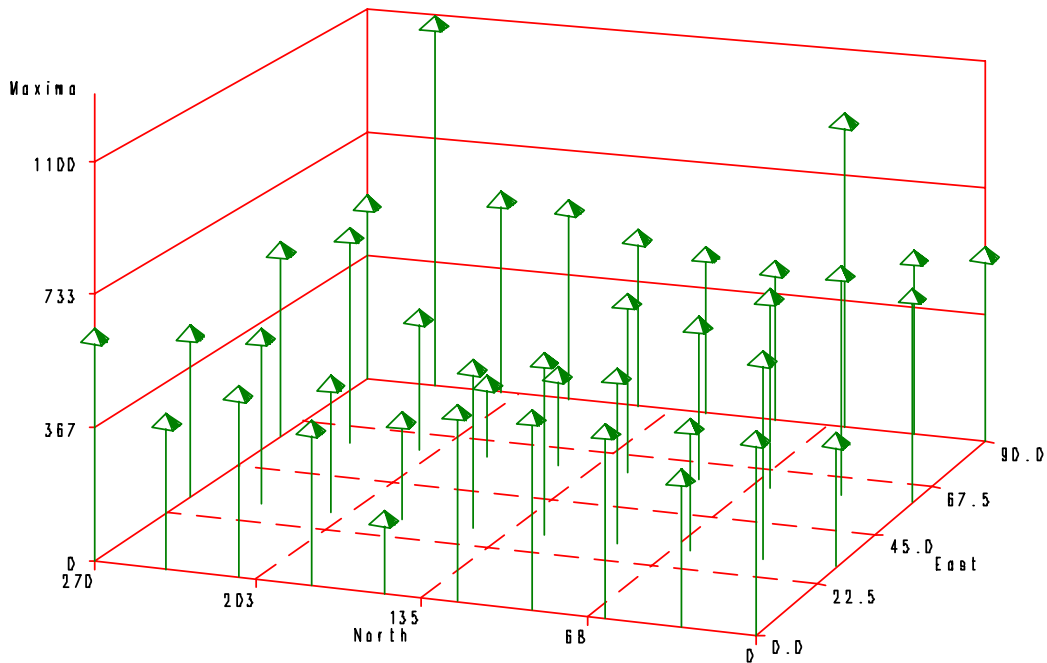
3,8	0.0112	1078.2	12.07584	11.942089	0.977	5.35	201.484	5.25	205.3714
3,9	0.0463	524.6	24.28898	23.214164	0.9864	2.68	196.0647	5.17	101.47
	avg	avg	avg	avg	avg	avg	avg	avg	avg
	0.02119	493.988	9.704243	9.3907933	0.97376	2.70	185.3754	5.466	90.93426

APPENDIX C - 3-D DATA

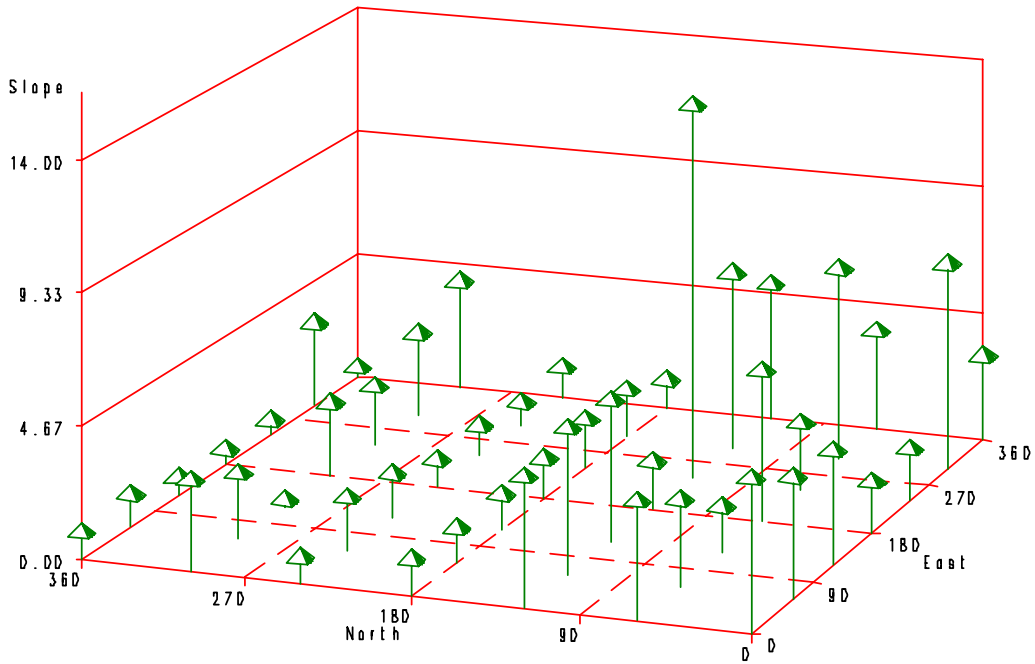
Ruston 0-5 Phosphorus Sorption Maxima



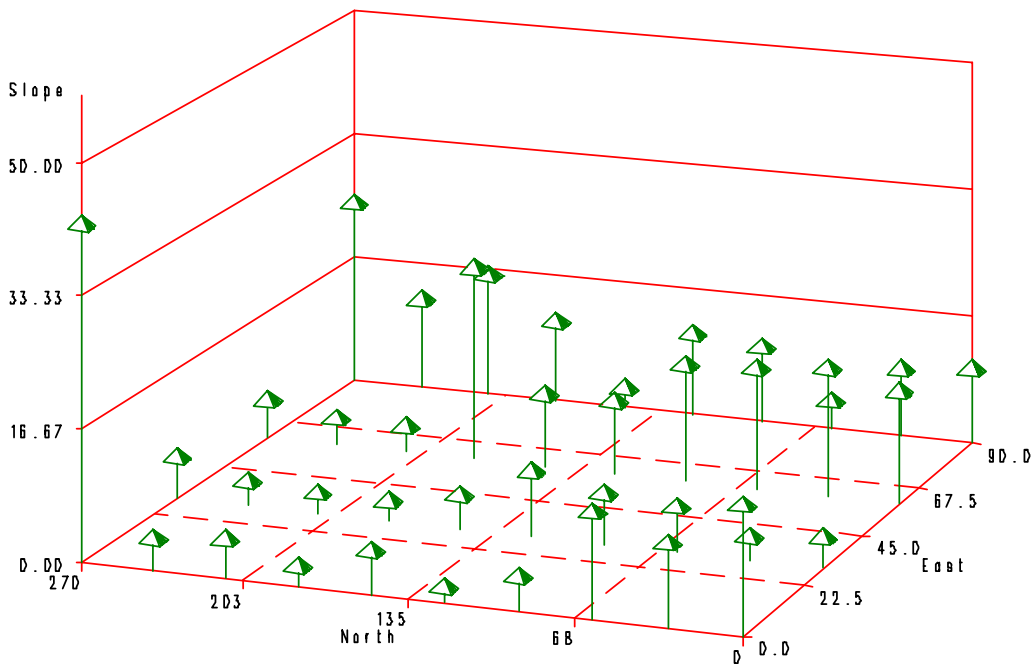
Darley 0-5 Phosphorus Sorption Maxima



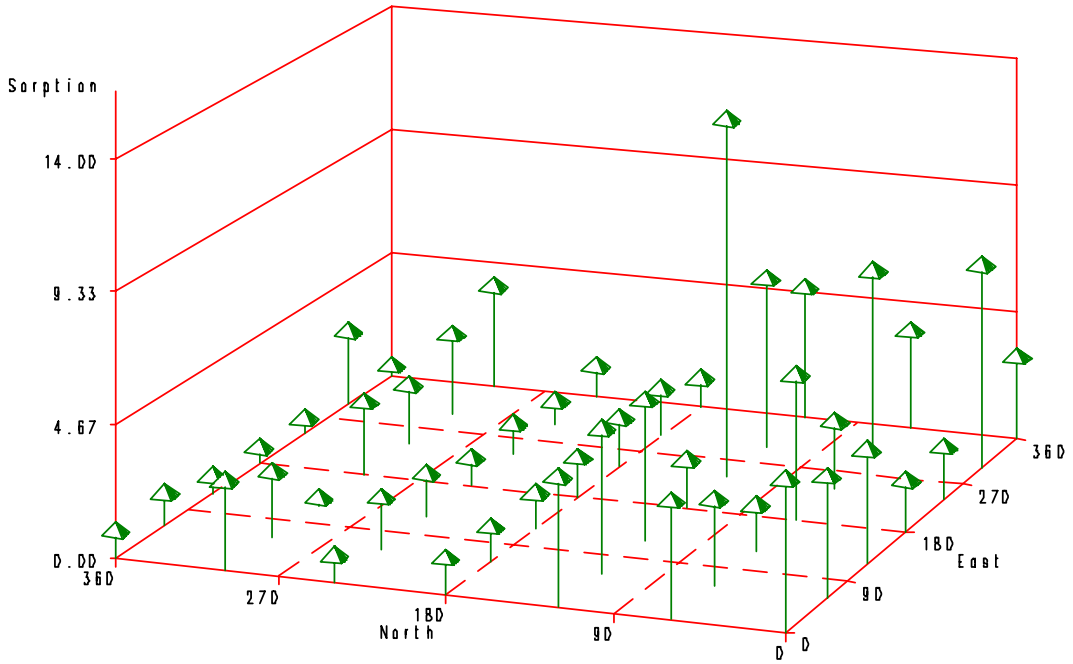
Ruston 0—5 dS/dC (C= 0)



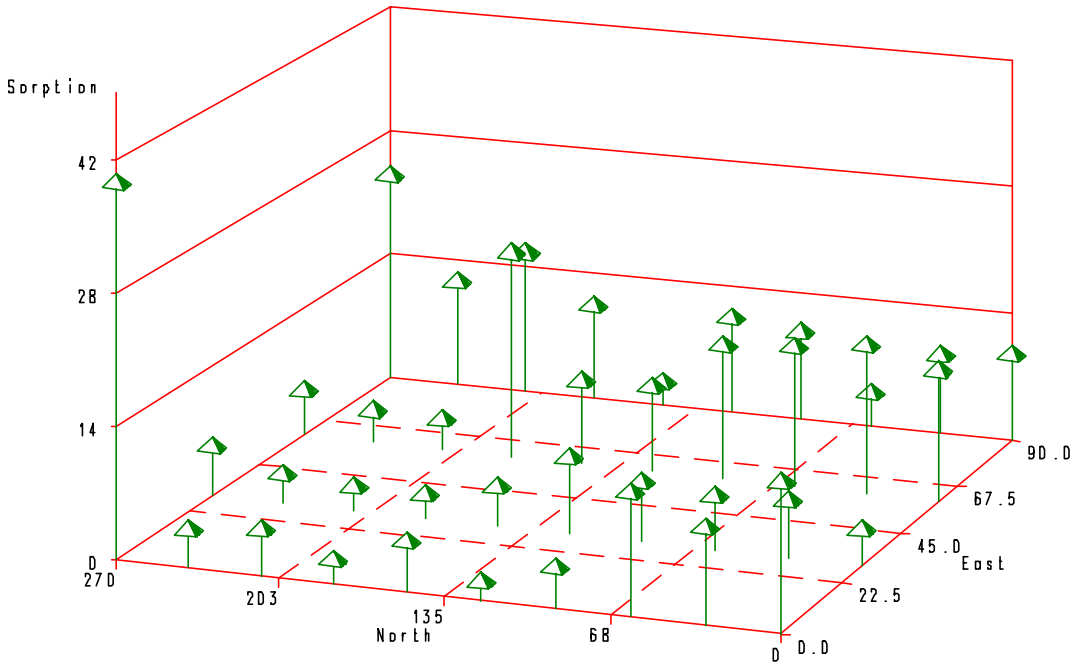
Darley 0—5 dS/dC (C= 0)



Ruston S (C= 1.0)

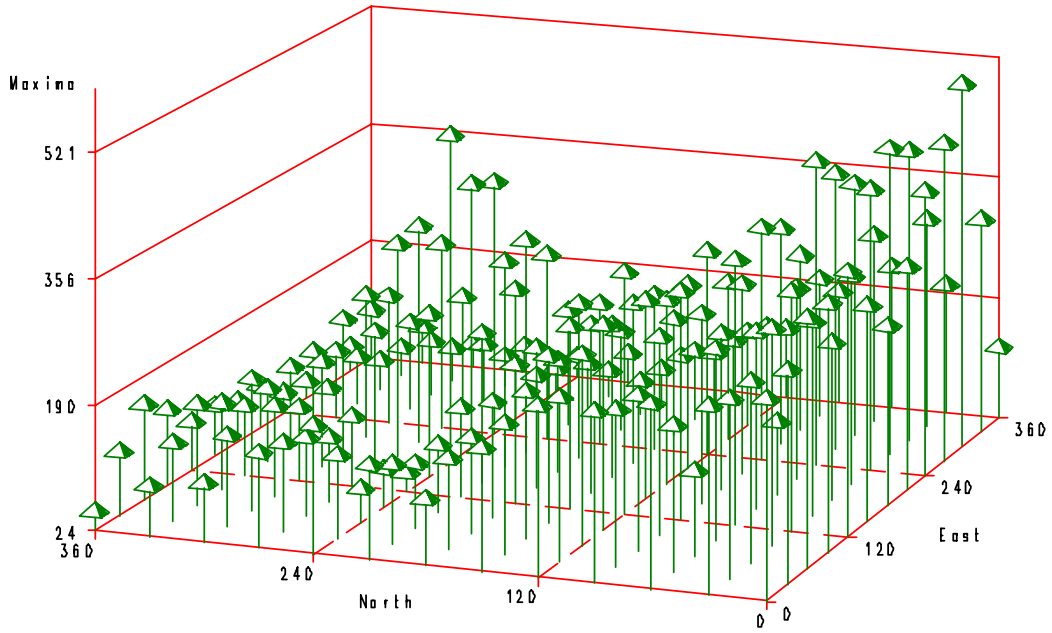


Darley S (C= 1.0)

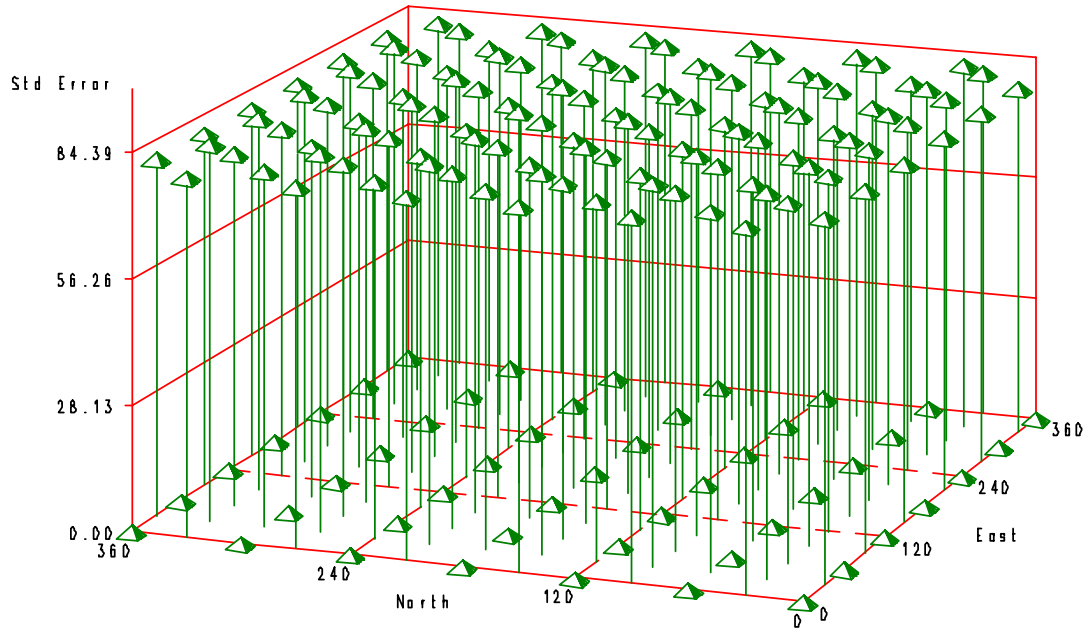


APPENDIX D – 3-D KRIGED DATA

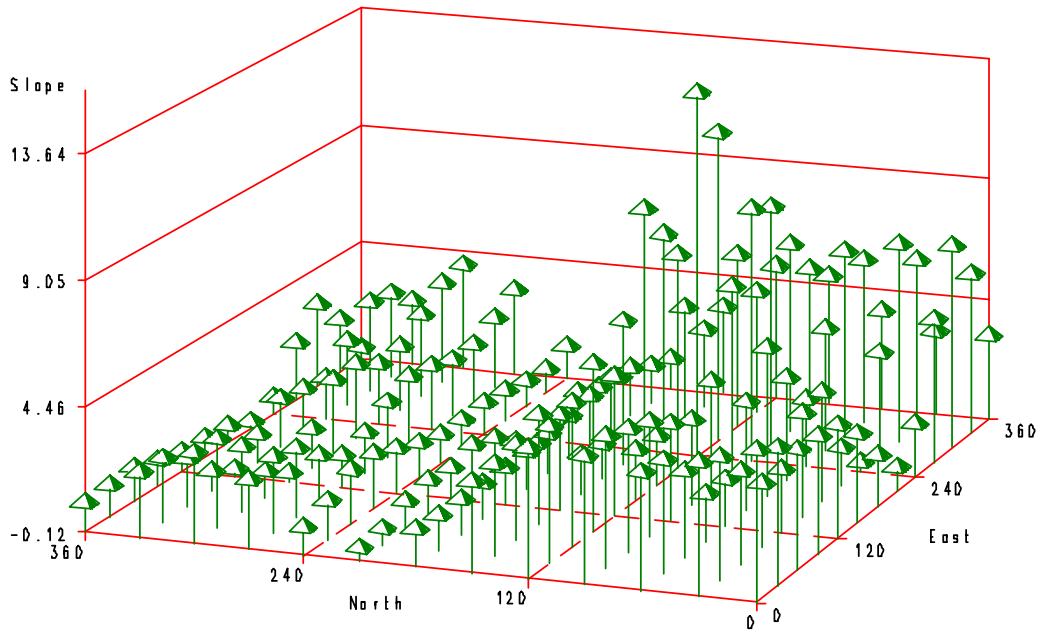
Kriged Ruston 0–5 P Sorption Maxima



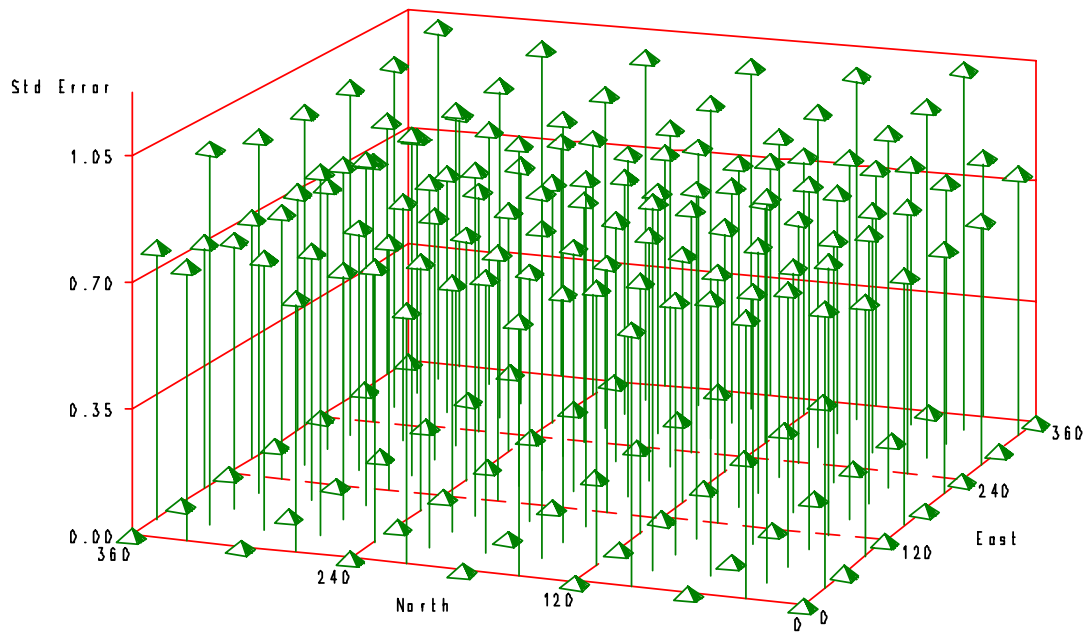
Standard Errors of Kriging Estimates



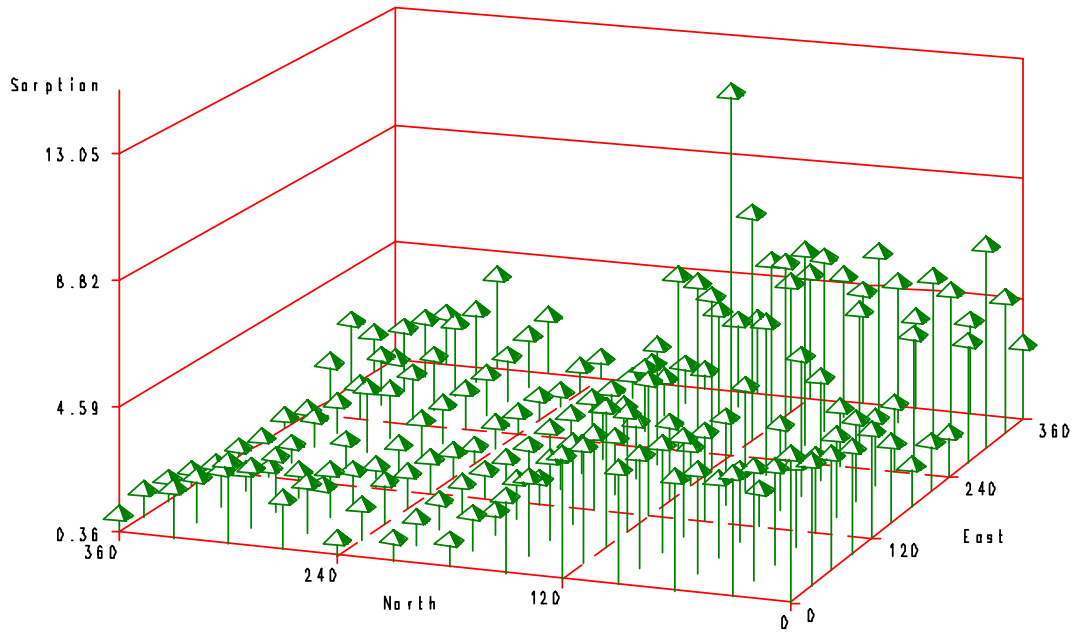
Kriged Ruston 0—5 dS/dC (C= 0)



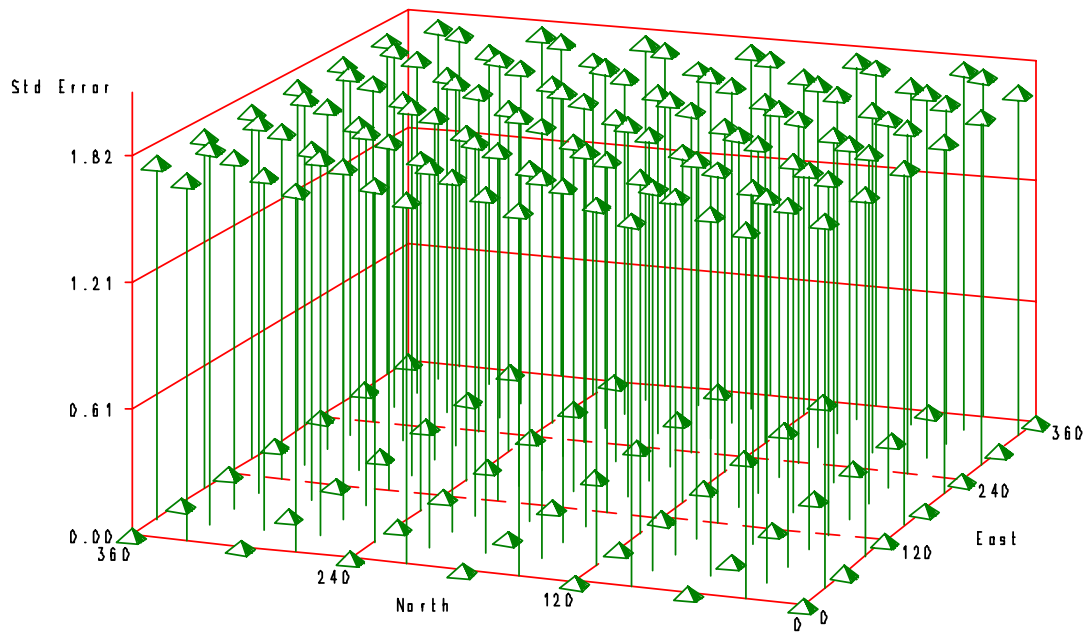
Standard Errors of Kriging Estimates



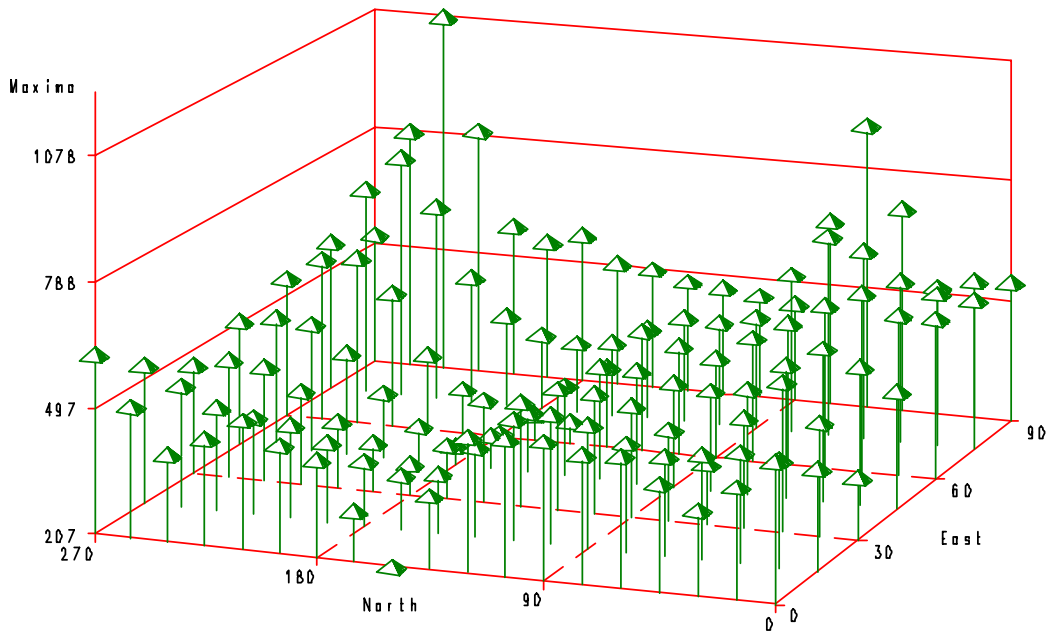
Kriged Ruston 0—5 S (C= 1.0)



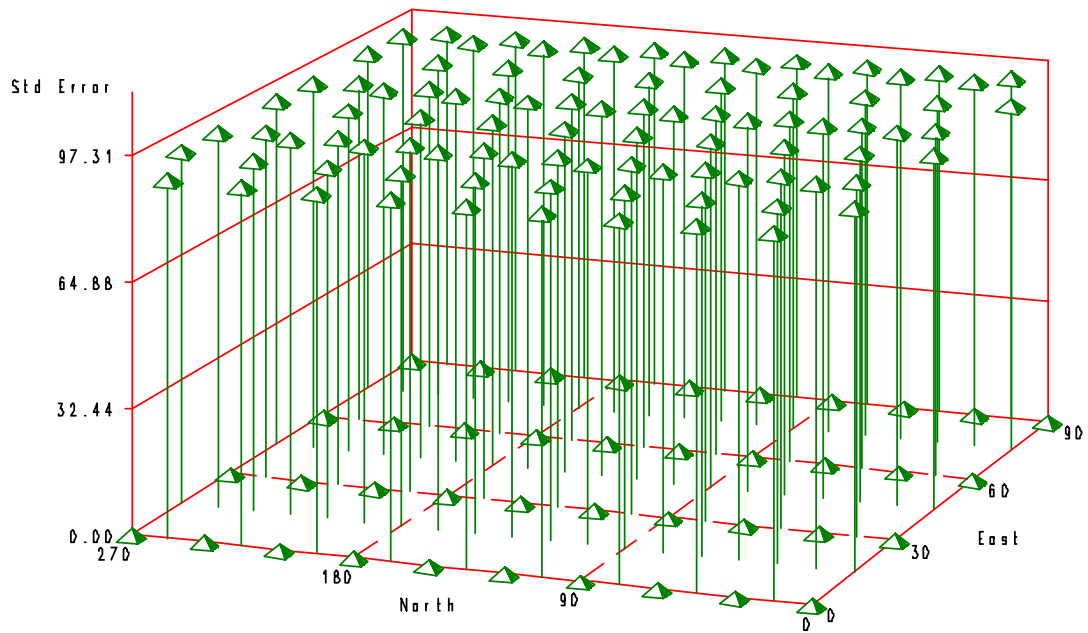
Standard Errors of Kriging Estimates



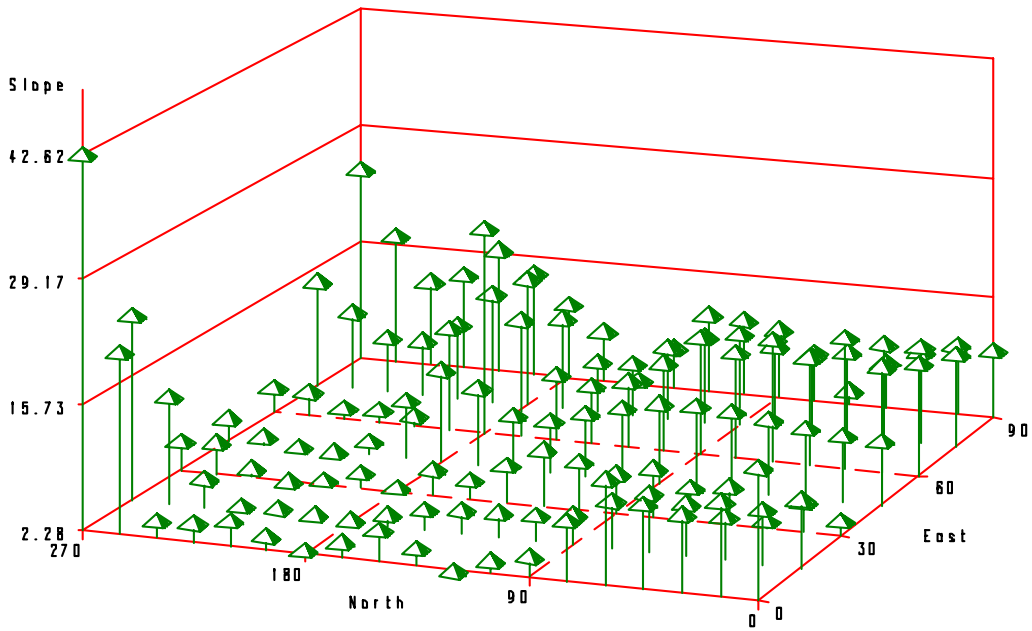
Kriged Darley 0-5 P Sorption Maxima



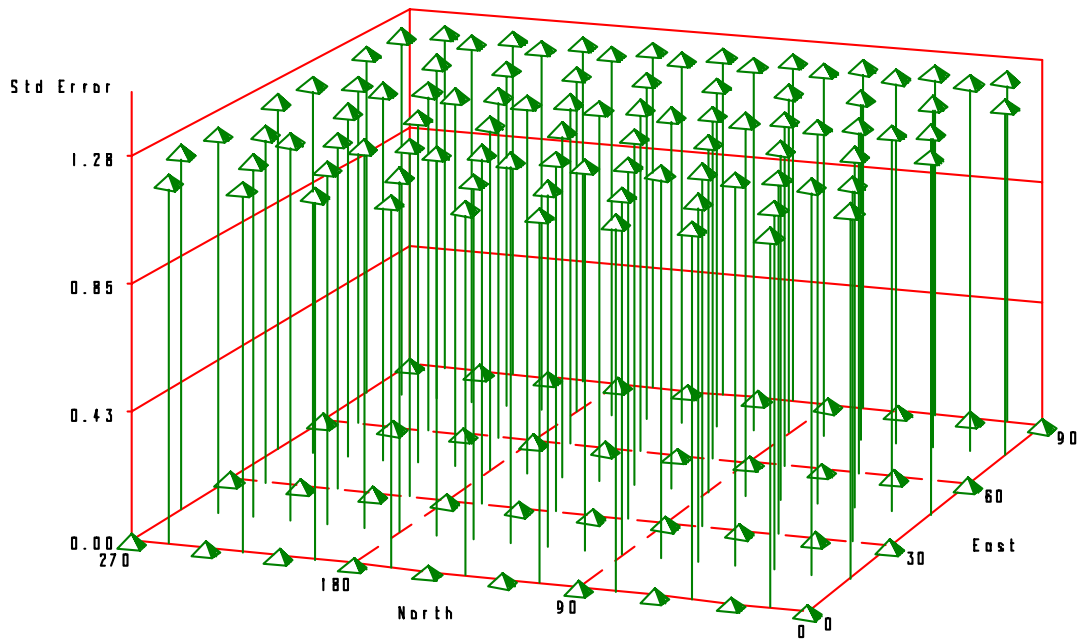
Standard Errors of Kriging Estimates



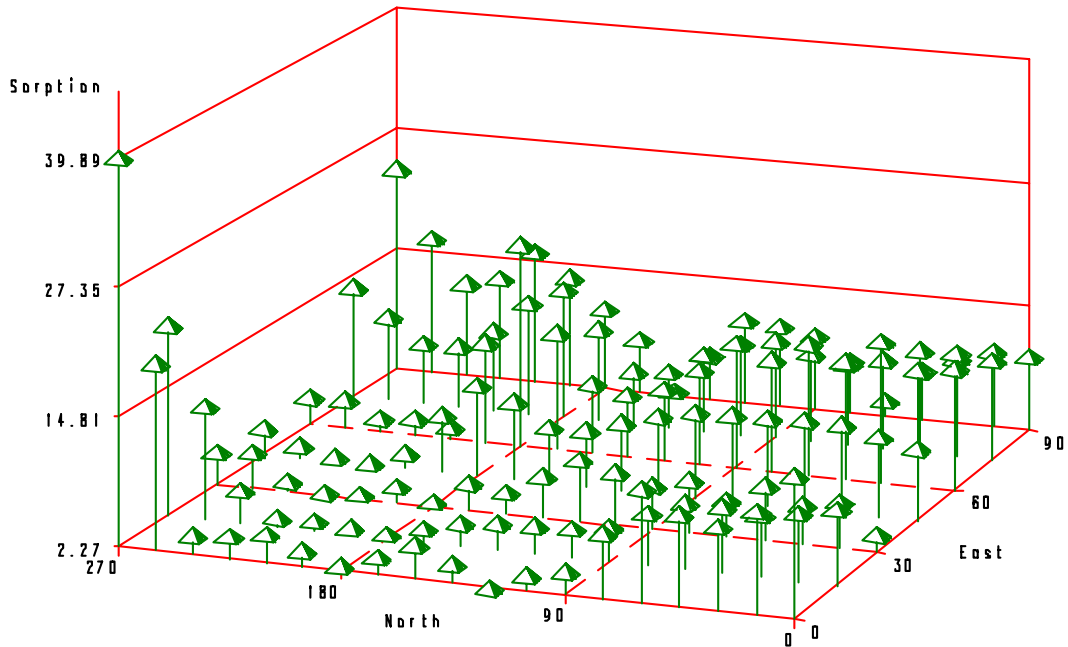
Kriged Darley 0—5 dS/dC (C=0)



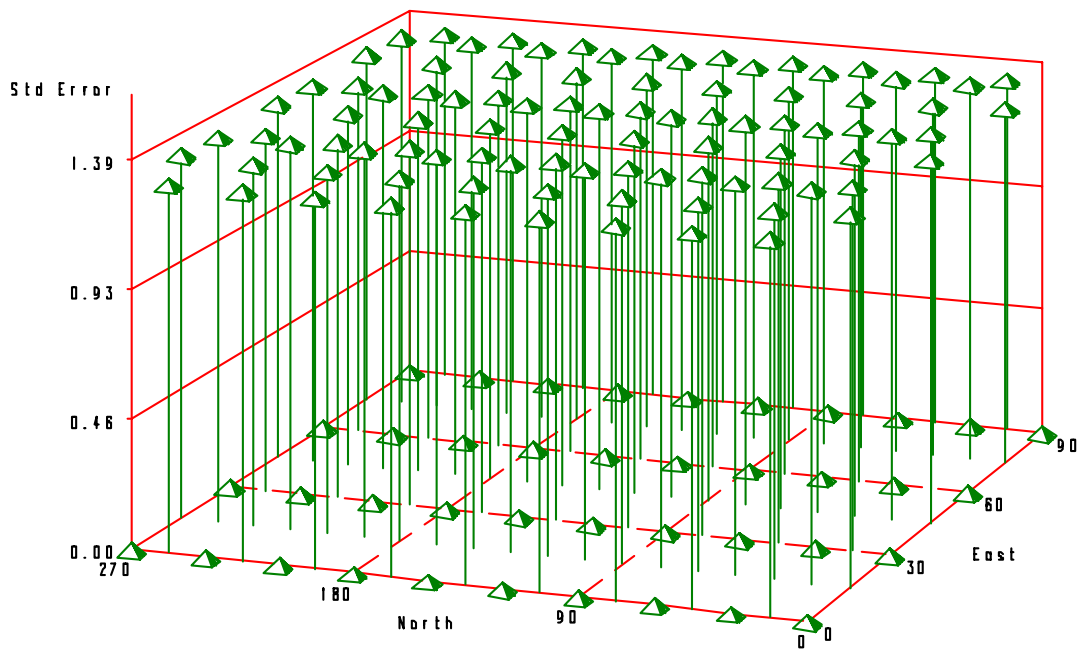
Standard Errors of Kriging Estimates



Kriged Darley 0-5 S (C= 1.0)



Standard Errors of Kriging Estimates



VITA

Greg Waldron was born in Gainesville, Florida. Although he also lived in Virginia, North Carolina, Oklahoma, Orlando and Arcadia, Florida, Greg calls Gainesville his hometown. He graduated from high school in Gainesville in 1986 and then attended Santa Fe Community College and the University of Florida, where he graduated with a Bachelor of Science degree with Honors in agricultural management in 1991.

Greg moved to Baton Rouge in 1998 and took classes at LSU as a post-baccalaureate student in the Spring of 2001. He entered the Master of Science program in agronomy (soils) in the Fall of 2001. He will graduate in December of 2003 with the degree of Master of Science.