CHEMICAL FRACTIONATION AND SOLUBILITY OF PHOSPHORUS IN DAIRY MANURE - AMENDED SOILS AS A PREDICTOR OF PHOSPHORUS CONCENTRATION IN RUNOFF

A Thesis

by

LAURA ELIZABETH HARSTAD

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2005

Major Subject: Soil Science

CHEMICAL FRACTIONATION AND SOLUBILITY OF PHOSPHORUS IN DAIRY MANURE - AMENDED SOILS AS A PREDICTOR OF PHOSPHORUS CONCENTRATION IN RUNOFF

A Thesis

by

LAURA ELIZABETH HARSTAD

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Sam Feagley
Committee Members,	Charles T. Hallmark
	Frank Hons
	Robert Knight
Head of Department,	C. Wayne Smith

December 2005

Major Subject: Soil Science

ABSTRACT

Chemical Fractionation and Solubility of Phosphorus in Dairy Manure-Amended Soils
as a Predictor of Phosphorus Concentration in Runoff. (December 2005)
Laura Elizabeth Harstad, B.S., Texas A&M University
Chair of Advisory Committee: Dr. S. E. Feagley

Nutrient over-loading in many dairy manure-amended soils in the dairy producing areas of Texas has led to environmental problems as such eutrophication of local surface water bodies. One of the nutrients contributing to eutrophication problems is phosphorus (P). This project focused on fractionation and solubility of selected P forms in an effort to determine a relationship with P found in runoff from dairy manure-amend soils. Ten soils (5 calcareous, 5 noncalcareous) were collected from the dairy producing areas of Texas. Triplicate soil samples were analyzed for 0-5 cm and 5-15 cm depths. An acid-base extraction method was used to determine total P (TP), inorganic P, and organic P. Sequential extractions were used to determine the loosely-bound P, iron (Fe) phosphates, aluminum (Al) phosphates, reductant soluble P, occluded apatite P, and calcium (Ca) phosphates for calcareous and noncalcareous samples. The ammonium oxalate method was used to determine extractable Fe, Al, and silicon (Si). Potassium chloride extraction was used to determine soluble Ca, Al, Fe, Mg, and P. A weak NaOH extract was used to determined the amount of bioavalible P. Dissolved P in runoff events and soil pH were collected in a previous study.

Calcareous and noncalcareous soils displayed varying concentrations of P indifferent fractions and with separate comparisons, stronger relationships could be achieved. It was also determined that KCl soluble Mg could be used as a predictor for dissolved and total P in runoff for calcareous soils (r^2's ranging from 0.865 to 0.928 and 0.801 to 0.886, respectively). Ammonium oxalate extractable Al also yielded high correlations in calcareous soils for dissolved and total P in runoff (r^2 ranging from 0.798 to 0.991 and 0.766 to 0.973, respectively). In noncalareous soils, pH resulted in a less correlated relationship with dissolved P ($r^2 = 0.600$). This study shows that there are simple and effective ways of predicting dissolved and total P in runoff to improve best management practice recommendations for manure-amended soils.

ACKNOWLEDGEMENTS

I would like to thank Dr. Feagley for his support and encouragement throughout my graduate career. He always put a positive spin on slow-moving research. I would also like to thank my other committee members Dr. Hallmark, Dr. Hons, and Dr. Knight for their knowledge and time invested in my education.

I would like to recognize the efforts of the TCE Soil, Water, and Forage Testing Laboratory and the Soil Characterization Laboratory for their continued work and knowledge put forth to further this project along. I would particularly like to recognize Donna, John, and Jeff for their help and encouragement.

I could not have written this thesis without the encouragement, support, and liveliness of those that fill the space around me. Debbie, Todd, Scott, Mark, Jim, Fred and Dr. Blumenthal always added life to a what would otherwise be a very boring place to sit and work. Their company will be missed.

I thank my parents, Tim and Bev for their support and encouragement, even though they may not always understand what I am studying. My sisters, Brittany and Brooke, brother-in-law, Bo, and my dog, Blaze always provided needed momentary escapes from the grad school life, and for that I am ever grateful.

I could not have made it through these past two years without the love and support of my husband, Paul. Thank you for making me laugh, being my sounding board, and learning about soil science just so you could try to understand what I am studying. I am indebted to you.

TABLE OF CONTENTS

LIST OF TABLES

TABLE Page

LIST OF FIGURES

INTRODUCTION

In the past years, land application was a simple and efficient method of recycling dairy waste. However, this method, along with over fertilization of agricultural fields has led to problems of phosphorus (P) overloading and eutrophication in local surface waters. Soil retention and reduction of fertilizer have helped decrease the runoff of P bound in particulate form, yet eutrophication still remains a problem. The problem of runoff is more complicated than initial thought. Schindler (1977) has found that it is better to attempt the control of P in eutrophication situations because this increases the nitrogen (N):P ratio encouraging the development of algae that are less objectionable from a water quality perspective than those found in situations where N is the controlled element. Unknown factors such as fractionation and solubility of P create variables in the P loss equation making it difficult to control losses into ground and surface water. No real characterization of the types of P released from manure has been complete (Sims, 2000).

This project addresses the fractionation of P in soils treated with dairy manure in the Central Texas dairy areas. Fractionation into organic and inorganic constituents allows for estimated solubility to be assigned to P forms playing key roles in losses through water transport. With this knowledge, best management practices (BMPs) can be recommended in reference to loading rates, frequency of application, and loss control methods.

This thesis conforms to the style of the Soil Science Society of America Journal.

The objectives of this study are two-fold. First, this project was to determine relationships between P and other parameters in the soils to further the understanding of P interactions in the soil. Second, this project was to discover, if and what, relationships may exist between the amount and type of P contributing to P concentrations in runoff. This information could be further used to predict the effect of runoff imposed on surrounding waterways.

LITERATURE REVIEW

Over the past years, land application was a widely used method of recycling of dairy waste. However, this method, along with over fertilization of agricultural fields has led to problems of P overloading and eutrophication in local surface waters. Soil retention and reduction of fertilizer inputs have helped decrease the runoff of P bound in particulate form, yet eutrophication remains a problem, and has proved to be more complicated than initially thought. Factors such as the different chemical fractions and associated solubility of P create unknown variables contributing to P loses, making it difficult to control P movement into ground and surface waters. No real characterization of the types of P released from manure has been completed (Sims, 2000).

This project addresses the forms of P in soils treated with dairy manure in the Central Texas dairy areas. Fractionation into organic and inorganic constituents allows for estimated solubilities to be assigned to P forms playing key roles in losses through water transport. With this knowledge, BMPs may be recommended in reference to loading rates, frequency of application, and loss control methods.

Eutrophication

Eutrophication is the increase of nutrients, particularly N and P, that exceeds the nutrient load absorbed by the benthic zone sediments of surface waters such as streams and ponds and creates an environment suitable for excess algal growth (McDowell and Sharpley, 2003). Once these increasingly larger populations of algae die, their decomposition reduces oxygen (O_2) in the system, thus diminishing populations of other inhabitants of the aquatic system. This process is even more dramatic in deep, cooler waters, creating a selection process for fish that can either tolerate low O_2 levels or higher temperatures found in upper levels of the water body (EPA, 2003). Anaerobic conditions, particularly in the bottom sediments, create environments through which organic matter over time can begin to release dissolved P and other nutrients causing delayed eutrophication.

Elevated algal populations not only reduce O_2 levels, but algae may also increase turbidity and color the water, blocking light for submerged aquatic vegetation. This vegetation plays host to many young fish, and its destruction weakens the food chain. Also, waters with high turbidity do not meet drinking water standards (EPA, 1999). In estuaries and coastal waters, excess N and P promote fish kills through encouraging the presence of toxic dinoflagellates (EPA, 2003) and creating hypoxic zones such as that found in the Gulf of Mexico (Justice et al., 1995).

Eutrophication affects surface water bodies across the United States (EPA 2003). Sharpley et al. (1984) defines areas particularly sensitive to P levels as locations where the “potential for P loss in runoff exceeds the crop production concerns”, also known as threshold levels. Most conclude that one of the major contributors to this pollution problem is the fertilization of agricultural fields, particularly those that over-fertilize or use a fertilizer with a higher solubility. One report estimates that “during the period of 1950-1995, an average P surplus of 26 kg $ha^{-1}yr^{-1}$ accumulated on agricultural soils in the United States” (Tabbara, 2003). According to the EPA (2002) agriculture is the most wide-spread source of pollution in observed surface waters, affecting 18% of observed river miles and 14% of observed lake acres. Agriculture is also said to have impacted 48% of impaired river miles and 41% of impaired lake acres.

The loss of P is hard to control because there are many different sources (fertilizers, manures, industrial inputs, plant inputs, and natural inputs from vegetation and native P bearing minerals in the soil) and many loss mechanisms through transportation of particulate bound, soluble, and organic forms. Manure applications are commonly practiced in areas where animals and farming go hand-in-hand. Since N is normally the element in highest demand by a crop, manure is normally applied to a field based on the N crop requirement, thus resulting in an excess of applied P (Sharpley et al., 1996). Schindler (1977) found that it is better to attempt the control of P in eutrophic situations because this increases the N:P ratio, encouraging the development of algae that are less objectionable from a water quality perspective than those found in situations where N is the controlling element.

Forms of Phosphorus

Phosphorus is a required element of living organisms. It is essential for the creation of adenosine triphosphates (ATP) which are key in energy production (Havlin et al., 1999). Phosphorus is also required in the bonding of nucleic acids through phosphodiester linkages to create DNA and RNA. “The processes that control P uptake and release in soils and fluvial sediments include a combination of physiochemical processes such as sorption and desorption and compounds and biological processes such as assimilation by bacteria and [terrestrial and] aquatic plants” (McDowell and Sharpley, 2003).

Natural levels of P in soils range from 0.01 to 0.25% by weight and despite the over loading of P into soils through agricultural practices, toxic levels in soils are rarely reached (EPA, 2003). As previously stated, additions of P in aquatic systems are closely linked with eutrophication, which both diminishes the inhabitants of the water and the water quality itself (EPA, 2003). Agriculture is considered one of the leading sources for P pollution as was noted in a study of Lake Champlain where 55-66% of the P pollution in the lake was from agricultural practices (Meals and Budd, 1998; Hegman et al., 1999). Again, areas with excess P are mostly associated with animal-based agriculture (Sims, 2000).

Phosphorus loss mechanisms include water transport such as runoff, leaching, and erosion (Sharpley et al., 1993; Daniel et al., 1998). Phosphorus losses are dependent on several factors. Higher intensity agricultural systems tend to be more susceptible to P losses vs. low intensity areas (Sharpley et al., 1993; Daniel et al., 1998). Coarser-textured soils exhibit greater P loss than finer-textured soils. Water movement is required to transport P from soils to water systems (Lennox et al., 1997). Phosphorus losses can be summarized into two general categories, soluble and insoluble. Soluble P occurs when dissolved P in solution moves through the soil system with the flow of water making it susceptible to runoff and leaching losses (Tabbara, 2003). Dissolved inorganic phosphate (orthophosphate P) is the only form of P that is directly available to algae, making it all the more dangerous for sudden development of algal blooms (Sharpley, 1985). Runoff is the main path through which losses of dissolved or soluble P occur (EPA, 2003). The amount of soluble P to leave an agricultural system is dependent on the level of saturation of the soil sorption sites (Aase et al., 2001). Most P accumulates in the top 5 cm of the soil (EPA, 2003). These losses are also controlled by dissolution and extractability of P from soils and plant materials. With larger levels of saturation, there is less potential P sorption, allowing for more dissolved P to remain in solution with the possible threat of runoff. Leaching losses may also cause problems in ground water (Beauchemin et al., 1998; Schoumans and Groenendijk, 2000; Simard et al., 2000). Soluble P losses are harder to control and measure and therefore provide a greater threat to those areas that might be particularly sensitive to nutrient loading increases (Sharpley et al., 1984). It has been shown that there is a linear relationship between surface soil test P and runoff dissolved P (EPA, 2003).

Particulate P, adsorbed P, or insoluble P occurs when P bonds to soil particles at sorption sites or creates insoluble precipitates with Fe, Al, or Ca. Most insoluble P losses depend on the amount of sediment or soil removed from the field system (Aase et al., 2001). The erosion of particulate P is affected by rainfall, irrigation, runoff, and soil management of the system (EPA, 2003). The chemically dictated equilibrium of P sorption and desorption onto soil particles is one of the most important processes that influence P losses (Lennox et al., 1997). Phosphorus sorption is thought to occur in two phases. The first stage is a rapid initial phase followed by a longer, slower step (Munns and Fox, 1976). The second step is thought to consider P fixation in a crystal phase (Munns and Fox, 1976), P diffusion into the interior of particles (Barrow, 1983), and different populations of sorption sites that control sorption (Syers et al., 1973). Fang et al. (2002) also suggested that there is an increase of P sorption when there is an increase of sorption sites with lower binding energies. It is these binding energies, along with the amount of sorption sites that determine a soils ability to retain P (Fang et al., 2002).

Phosphorous can also be categorized into organic and inorganic forms. The organic form of P has three subgroups, the inositols phosphates, phospholipids, and nucleic acids. Concentration of organic P is dependent on environmental factors such as soil temperature and moisture (Sharpley et al., 1984). Organic P can be classified using terms of susceptibility to microbial activity. Four fractions have been determined: labile, moderately labile, moderately resistant, and resistant, with labile being the most susceptible to microbial activity and resistant being the least suceptible (Sharpley et al., 1984).

Inorganic forms appear in two different pH-dependent forms. Calcium phosphates (Ca P) dominate in areas with high pH values ($pH > 7$), and Fe and Al hydroxy phosphates (Fe/Al P) dominate in low pH systems ($pH < 6.5$). Calcium Ps are stable in alkaline solutions and are soluble at low pHs, creating a potential for loss through water transport. However, Ca Ps are found to exist in all soils of all pH values (Beauchemin et al., 2003). Apatite ($Ca_5(PO_4)_3(F^-, OH^-, Cl^-)$) is a common Ca P mineral (Brady and Weil, 1999).

Iron and Al Ps can develop through three different pathways. Phosphorus can react with Fe, Al or manganese (Mn) to create Al to oxygen (Al-O) single or double bonds or Fe-O bonds (Halvin et al., 1999). Phosphorus can also react with the surface of an amorphous Fe and/or Al hydroxyl polymer that may exist as a coating on soil particles. Lastly, P can react with Al that is a tightly adsorbed on clay surfaces, again creating Al-O single or double bonds (Halvin et al., 1999). Adsorption is thought to be the mechanism that controls the amount of dissolved phosphates at low concentrations (Beauchemin et al., 2003). Strengite ($FePO_4 \cdot 2H_2O$) and variscite ($AlPO_4 \cdot 2H_2O$) are two common Fe/Al P minerals (Brady and Weil, 1999). These two minerals, along with apatite and many others are thought to control P solubility at high concentrations of P, yet the solubility of these minerals is essentially independent of the concentration of P (Beauchemin et al., 2003). The Fe/Al Ps are found to be in higher concentration at lower pH values ($pH < 6.5$), yet they can exist in alkaline solutions, allowing for potential losses through water transport (Beauchemin et al., 2003).

Phosphorous is considered to be fairly insoluble. However, there are a few interactions that occur in soils that increase the solubility of P. Organic matter added through manure can create a coating on the surface of soil particles and prevents or delays the adsorption of P onto the soil surface, therefore increasing the P concentration in solution.

As with most compounds, P compounds exhibit the ability to be reduced and oxidized. The change in Eh of a soil system essentially alters the solubility of certain compounds. At certain Eh's, different elements and minerals dictate the solubility of P. One of the more important forms of P that is affected by changes in Eh is Fe phosphate. Iron is easily reduced to Fe^{2+} from Fe^{3+}. The most noted example of this is in flooded agricultural fields such as with rice production. These fields are often tested for fertilizer recommendations on a yearly basis, making information about reduced conditions plentiful. Normally during a flooding event, particularly in acid soils, the pH of the soil becomes more neutral and there is an increase in the solubility of Fe phosphates, thereby increasing the amount of available P in the system. Also the p*e* + pH can drop below 8.34 which allow the formation of vivianite. Normally the formation of a mineral would seem to be counter intuitive to increasing the amount of available P in the soil. However, in this instance, the root zone of plants provide enough O_2 in the system that the mineral, vivianite is solubilized in the immediate rooting area. This allows for P uptake by the plant in the root zone while in the bulk soil volume P solubility is suppressed by vivianite (Lindsay, 1979).

History of P Fractionations

Methods for fractionation of inorganic P in soils began with Chang and Jackson (1957). They proposed an extraction method with NH_4F at a neutral pH. This was later altered to pH 8.2 by Peterson and Corey (1966). Williams et al. (1976) added a second NaOH extraction for the testing of calcareous soils. Williams et al. (1971b) again altered the procedure by adding sodium citrate-sodium bicarbonate to minimize the re-sorption of P by $CaCO_3$ in the 0.1M NaOH extract. It was also found that bicarbonate was necessary to buffer against a decrease in pH during the extraction of reductant-soluble P. A second HCl extraction for 4 hr was also added to increase the amount of occluded apatite extracted. Loosely-bound P composes a very small fraction of total P, while Ca P comprises a large part of P in calcareous soils (Sharpley and Smith, 1985) while Al P and Fe P comprise large portions in both noncalcareous soils and sediments (Williams et al., 1971a).

There are two major methods for total organic P determination. The ignition method is more of a direct method of measurement of organic P where acid/alkali extraction determines organic P through a subtraction method. The ignition method is simple yet it destroys the sample to such an extent that no further fractionation of the organic P can be determined. There are slight errors in the system as Fe Ps and Al Ps are more soluble at the high ignition temperatures (550° C) (William and Walker, 1967) and sometimes ignition of organic P can be incomplete (Dormarr and Webster, 1964). In the acid-alkali extraction method, the H_2SO_4 strength can be altered along with the extraction time. Saunders and Williams (1955) originally chose 0.1 M H_2SO_4 for 16 hrs, whereas Walker and Adams (1958) chose a more convenient 0.5 M H_2SO_4 for 2 hrs. Despite their differences, Condron et al. (1990) reported that both methods produced equivalent results.

Considerations for P Control

There are many considerations that must be made in attempting to control P loss from soils. Sediment transport and P chemistry both play important roles in determining P losses (McDowell and Sharpley, 2003). Most P travels through overland flow instead of leaching to groundwater (Correll et al.,1999). Phosphorus flux is dependent on precipitation, air temperature, intensity of agricultural practices, geological conditions, and climatical conditions (Correll et al., 1999). Residual pools of P should be described prior to any P application or recommendations for BPMs (Leytem et al., 2004). Amount, type and distribution of P in fertilizers also provide keys in determining possible sources of P losses. Organic P in labile forms will be quickly released into forms that are either bioavailable or that soon can be lost to runoff, returning the site back to pre-fertilization background of P in a fairly short period of time (Sharpley et al., 1984). They also stated that through determining P saturation, soils that have high P levels, and vulnerability to erosion and leaching, could be identified in order to prevent P losses. It should also be considered that nutrient loadings have increased with increasing populations in urban areas and intensified agriculture, allowing for a potential loss of both time used to apply unnecessary P and money through the loss of fertilizer P (Peterjohn and Correll, 1984).

Relationships between organic and inorganic P are dependent on the amount of P in soil. Mineralization (conversion of organic P to inorganic P) occurs when the ratio of carbon (C) in the soil to P is less than 200:1. Immobilization, or the process by which inorganic P is taken up by microorganisms and incorporated into tissue as organic P, occurs at a C:P ratio of > 300:1 (Brady and Weil, 1999). The main sources of P in soils are fertilizers and residual P. Residual P, or P which persists from past additions, occurs generally when C:P ratios are > 300:1 (immobilization) and mineralization of present organic matter occurs when C:P ratios are < 200:1 (Sharpley and Moyer, 2000). Between 200:1 and 300:1 both mineralization and immobilization occur.

Phosphorus, although challenging, does have many known reactions in soil. Water-soluble P often gives a good indication of the losses of P that may occur due to runoff (Fang et al., 2002). Organic material that binds to some subsoil reaction sites, creates a higher solubility of P (Robbins et al., 1999). Phosphorus is most available in a narrow pH range (6-7 pH) and outside this range exists in a number of mineral forms dependent on the other minerals present and pH of the environment (Havlin et al., 1999).

Best management practices, or methods of controlling loss, take various forms. Most P losses are “influenced primarily by P source and chemical form, tillage and P placement, rate and timing of application, intensity and timing of rainfall events, and soil P level” (Tabbara, 2003). One of the best methods for controlling P loss from agricultural fields is through sediment control. If soil can be maintained on the field or site of application, particulate P will also remain where desired. The addition of organic matter with wide C:P ratios along with the application of P may help in reducing the amount of loss by creating more sorption sites (Sharpley et al., 1984).

Another method of P loss control is incorporation. Tabbara (2003) found that “Incorporation also reduced flow-weighted concentrations and losses of dissolved, reactive phosphorus and total phosphorus as much as 30 to 60% depending on source and application rate”. Phosphorus is moved further below mixing layers, securing it from great erosional losses. This method is particularly efficient in areas with intense rainfall and little ground cover (Tabbara, 2003).

Perhaps the hardest form of P to control is dissolved P. Not only is this form susceptible to losses through soil particle loss but also losses in the form of runoff for which control measures are limited (Sharpley et al., 1984). Fang et al. (2002) stated “while the loss of particulate P in runoff can be decreased by conservation measures that reduce soil loss, dissolved P losses are more difficult to reduce and control measures are limited largely to reducing overland runoff and preventing soil P from accumulating to environmentally sensitive thresholds". Runoff P is often estimated by water-soluble or water-extractable P (Fang et al., 2002; Sharpley and Moyer, 2000; Robbins et al., 1999; Siddique and Robinson, 2003). Loss through dissolved P is mainly affected by rainfall rates, forms of fertilizer, and application rates (Tabbara, 2003). Liquid fertilizer will contain large quantities of dissolved P. Also organic materials have been noted to coat soil surfaces, reducing sorption sites and therefore increasing P solubility (Tabbara, 2003). Dissolved P is one of the products of solubilizing particulate-bound P. The release of dissolved P is controlled by pH and what particulate-bound forms of P exist. If application rates are high, there may be an excess amount of P that will not be bound to sorption sites. Phosphorus that is not sorbed is an ideal candidate for being dissolved and lost through leaching or runoff. If rainfall occurs soon after the application of fertilizer, P may be dissolved at high rates and lost through runoff, particularly in areas with little ground cover.

Application of fertilizers is a common method to increase the available P content of a soil. Fertilizers are applied in many forms, both inorganic and organic. Application rates vary depending on the desired nutrient. Most applications of fertilizer are applied based on the desired amount of N for a particular crop. When using inorganic fertilizers, the other nutrients are added closer to recommended amounts. It is when the other elements, such as P, are added to inorganic fertilizer in improper amounts that major problems with runoff occur. Other losses may occur when nutrients supplied through inorganic sources are adsorbed to soil particles and lost through erosion or when nutrients fail to adsorb and are dissolved in runoff water.

Organic sources, such as manures, increase P and other necessary nutrients as well as elevate the problem of livestock waste. Manure or animal waste is “the fecal and urinary waste of livestock and poultry; process water (from milking parlors); and the feed, bedding, litter, and soil with which they become intermixed” (EPA, 2003). Problems with the application rate of manure arise because the chemical content of manure cannot be adjusted drastically. The total P concentration in dairy manure is approximately 9g kg^{-1}, yet varies with diet of the animal (Sharpley and Moyer, 2000). Other factors affecting the P content of manures are diet, animal age, amount of space, amount and type of bedding, and method of storage (Siddique and Robbins, 2003). Also dependent on these factors are the amounts and solubilities of the inorganic and organic forms of P (Tabbara, 2003). Inorganic P is known to account for 12 – 44 % of total P in manure, while organic P only accounts for 2 to 23 % of total P (He et al., 2004). Nitrogen to P ratios are often very narrow, ranging from 8:1 to 2:1 depending on the animal species (Eck and Stewart, 1995). Because manure is often applied to meet N crop requirement, exceedingly high amounts of P are also applied (Sharpley et al., 1996). After long-term applications at high rates, the soil solution may reach equilibrium with CaP in the soil and will exhibit low P sorption capacities and increased risk of P leaching from saturated horizons (Beauchemin et al., 2003). Factors such as time of the year, rainfall, soil type, crop, desired yield, crop uptake, rate of application and incorporation should all be considered to help lessen the losses of P (EPA, 2003). These factors, along with soil physical properties such as pH, organic matter, clay content, mineral composition, and amount of previous P sorption can determine the type of P with a potential for leaching, particularly in the case of bioavailable P (Beek et al., 1980 and Ryan et al., 1985). Calcium is said to play a key role in controlling P availability (Siddique and Robinson, 2003). Organic compounds in manures can create organic acids during decomposition which bond with Al and Fe, lowering the sorption sites for P with Al and Fe molecules, but perhaps increasing the sorption sites with soil particles (Siddique and Robinson, 2003).

Phosphorus' interactions in the soil are complex and not completely understood. However, the role of P in soils is crucial to plant and animal development and life in the soil. The problems associated with P over use are great and must be controlled. Phosphorus application must be monitored to ensure the safety of the surrounding environment.

MATERIALS AND METHODS

Ten soils were selected for this study from previously collected samples. The selected soil samples were collected by Texas Cooperative Extension (TCE), as a part of a dissertation project by Fred Jacoby (2005). These soils had been collected as 0-5 cm, 5-15 cm, and 0-15 cm samples. Each of these soils had been oven dried and ground during the previous study. These soils were selected after consideration of their classes of calcareous vs. noncalcareous (5 calcareous and 5 noncalcareous) and amount of soil remaining from the previous study. It was crucial to the following experiments to have enough soil to complete all procedures. All soils had a history of land application of dairy manure.

Previously Collected Information

Information such as pH, C_aCO_3 concentration, Mehlich-3 P, TAMU extractable P, total carbon, dissolved P in runoff, total P in runoff, vegetative cover, manure applications, inorganic and organic fertilizer application rates and methods were determined during previous study of the areas (Jacoby, 2005). This information is listed in Appendix A.

Particle Size Distribution

The particle size distribution of each soil was quantified with the hydrometer method (Day, 1965). Fifty grams of oven-dried soil were dispersed with 4 g of sodium hexametaphosphate ($NaPO_3$) and 500 mL of deionized water (DI water) in a 1 L graduated cylinder. Hydrometer readings were taken in triplicate 40 seconds after settling had begun to determine the amount of silt and clay in suspension. Readings were taken again at a settling time of 2 hr to determine the amount of clay remaining dispersed in the system. Readings were corrected for temperature.

Inorganic Phosphorus

Inorganic phosphorus (IP) was determined using an extraction with concentrated sulfuric acid (H_2SO_4) to quantify the acid component of the IP (IPA) and dilute sodium hydroxide (NaOH) to quantify the base-extractable fraction of the IP (IPB) (Kuo, 1996). Each measurement was completed in triplicate. Two grams of oven dried soil were added to a 50-mL volumetric flask along with 3 mL of concentrated (18 M) H_2SO_4 if the soil was noncalcareous or 4 mL of concentrated H_2SO_4 if the soil was calcareous. After mixing, the extract was diluted with approximately 35 mL of DI water and filtered through Whatman no. 1 filter paper. The leachate was collected in a 50-mL volumetric flask and brought to volume with DI water. This extract was sent to the Texas Cooperative Extension Soil, Water, and Forage Testing Lab (TCE SWFTL) where the inductively coupled plasma quantometer (ICP) was used to determine the IPA of the solution.

The filter paper and soil was transferred to a plastic container with a lid. Ninety-eight mL of 0.5 M NaOH were added to the container, which was then sealed and shaken for 2 hours. The solution was filtered through Whatman no. 1 filter paper into a 100-mL volumetric flask and brought to volume with DI water. This extract was analyzed through the ascorbic acid colorimetric method (Murphy et al., 1982) for IPB.

Total Phosphorus

Total phosphorus (TP) was determined as a continuation of the IP method described above and was also completed in triplicate. Total P was determined in the acid fraction (TPA) and in the basic fraction (TPB) (Kuo, 1996). A 5 mL aliquot of the IPA solution in a 50-mL volumetric flask was digested with 1 g of $K_2S_2O_8$ and 2 mL of 5.5 M H_2SO_4 at approximately 150° C until vigorous boiling subsided. This extract was then cooled and brought to volume with DI water. The ascorbic acid colorimetric method (Murphy et al., 1982) was used to determine the amount of TPA in the extract.

A 5 mL aliquot of the IPB was used to determine the amount of TPB in the soil following the method listed above for the determination of TPA. The extract was also quantified through the ascorbic acid colorimetric technique (Murphy et al., 1982) to determine the TPB concentration.

Total Organic Phosphorus

Organic P was determined based on a subtraction of P in the acid fraction (OPA), basic fraction (OPB), and total organic P (OP) (Kuo, 1996). The difference between TP, TPA, TPB, and their respective IP counterparts were used to determine the amount of each OP fraction.

Fractionation of Inorganic Phosphorus for Noncalcareous Soils

Inorganic P fractions of noncalcareous soils were segregated into soluble or loosely bound P ($H_2PO_4^-$ and $HPO_4^{=}$), NH_4F-extractable P ($AlPO_4$), NaOH-extractable P ($FePO_4$), reductant-soluble P and occluded apatite P through a sequential procedure (Kuo, 1996). Each step of this procedure was completed in triplicate.

Soluble and Loosely Bound Phosphorus

One gram of oven dried soil was shaken (250 rpm) for 30 minutes in a 100-mL polyethylene centrifuge tube with 50 mL of 1 M NH_4Cl. This extract was then centrifuged (10 min at 1000 rpm), decanted into a 50-mL volumetric flask and brought to volume with DI water. It was analyzed through the TCE SWFTL for P by ICP.

Ammonium Fluoride-Extractable P

The soil residue was shaken for 1 hour with 50 mL of 0.5 M NH_4F (pH 8.2), centrifuged (10 min at 1000 rpm), and decanted into a 100-mL volumetric flask. The soil residue was rinsed twice with 25 mL portions of saturated NaCl. The rinses were combined with the extract in the 100-mL volumetric flask and brought to volume with DI water. The ascorbic acid colorimetric technique (Murphy et al., 1982) was used to estimate the amount of $AlPO_4$ in the solution.

NaOH-Extractable P

The soil residue was shaken for 17 hours with 50 mL of 0.1 M NaOH, centrifuged (10 min at 1000 rpm) and the solution decanted into a 100-mL volumetric flask. The soil residue was rinsed twice with 25 mL of saturated NaCl. The rinses were added to the 100-mL volumetric flask and brought to volume with DI water. The solution was analyzed with the ascorbic acid colorimetric technique (Murphy et al., 1982) for an estimation of the amount of $FePO_4$ in the solution.

Reductant-Soluble Phosphorus

Forty milliliters of 0.3 M $Na_3C_6H_5O_7$ and 5 mL of 1 M $NaHCO_3$ were added to the soil residue and the solution was heated in a water bath at 85° C. One gram of

$Na_2S_2O_4$ was added to the heated mixture, stirred vigorously, and the solution was heated continuously for an additional 15 minutes. The solution was centrifuged (10 min at 1000 rpm) and decanted into a 100-mL volumetric flask. The soil residue was washed twice with 25 mL of saturated NaCl. These washes were combined into the 100-mL volumetric flask and brought to volume with DI water. The solution was then allowed prolonged exposure to the air to oxidize the $Na_2S_2O_4$. The solution was analyzed for reducant-soluble P with the ascorbic acid colorimetric technique (Murphy et al., 1982).

Occluded Apatite Phosphorus

The soil residue was shaken for 1 hour with 50 mL of 0.25 M H_2SO_4. The solution was centrifuged for 10 min (1000 rpm) and decanted into a 100-mL volumetric flask. The soil residue was washed twice with 25 mL aliquots of saturated NaCl. These washings were then combined into the 100-mL volumetric flask and brought to volume with DI water. The extract was analyzed for the amount of occluded apatite P through the ascorbic acid colorimetric method (Murphy et al., 1982).

Fractionation of Inorganic Phosphorus for Calcareous Soils

Inorganic P was segmented into NaOH-extractable P ($CaPO_4$), reductant-soluble P, and occluded apatite P in a sequential extraction (Kuo, 1996). Each step of the procedure was completed in triplicate.

NaOH-Extractable P

One gram of oven dried soil was shaken with an oscillating shaker (250 rpm) in a 100-mL polyethylene centrifuge tube for 17 hours with 50 mL of 0.1 M NaOH + 1 M NaCl. The solution was centrifuged (10 min at 1000 rpm) and decanted into a 100-mL volumetric flask. The soil residue was washed twice with 25 mL of 1 M NaCl. These washings were added to the 100-mL volumetric flask and brought to volume with DI water. The extract was analyzed for an estimate of $CaPO_4$ with the ICP at the TCE SWFTL.

Reductant-Soluble Phosphorus

Forty milliliters of 0.3 M $Na_3C_6H_5O_7$ and 5 mL of 1 M $NaHCO_3$ were added to the soil residue. The mixture was heated in a water bath at 85° C. One gram of $Na_2S_2O_4$ was added to the heated mixture, stirred vigorously, and the solution was heated continuously for an additional 15 minutes. The solution was centrifuged (10 min at 1000 rpm) and decanted into a 100-mL volumetric flask. The soil residue was washed twice with 25 mL of saturated NaCl. These washes were combined into the 100-mL volumetric flask and brought to volume with DI water. The solution was then allowed prolong exposure to the air to oxidize the $Na_2S_2O_4$. The solution was analyzed for reducant-soluble phosphorus with the ascorbic acid colorimetric technique (Murphy et al., 1982).

Occluded Apatite Phosphorus

The soil residue was shaken with an oscillating shaker (250 rpm) for 1 hour with 50 mL of 0.5 M HCl. The mixture was centrifuged (10 min at 1000 rpm) and the supernatant decanted into a 100-mL volumetric flask. The soil residue was washed twice with 25 mL of saturated NaCl. The washings were added to the 100-mL volumetric flask and brought to volume with DI water. The extract was analyzed for the amount of occluded apatite P through the ascorbic acid colorimetric method (Murphy et al., 1982).

Potassium Chloride Extractable Estimates

Extractable Ca, Al, Fe, Mg, and P were determined with extraction by potassium chloride (KCl) solution (Kuo, 1996, Soltanpour et al., 1974, Tan, 1996). Oven dry soil and 0.1 M KCl were mixed in a 1:5 ratio (5 g of soil to 25 mL of 0.1 M KCl). The mixture was shaken with an oscillating shaker (250 rpm) for 15 min and filtered (Whatman no. 1 filter paper). The extract was analyzed for Ca, Al, Fe, and P through the ICP at the TCE SWFTL.

Bioavailable Phosphorus

Bioavailable P (BAP) was determined through an extraction with weak NaOH. The procedure used was a modified version of the Sharpley et al. (1991) method for determining BAP in unfiltered runoff. Sharpley's method required 20 mL of sample with 180 mL of 0.11 M NaOH to be shaken in an end over end shaker (298 k) for 17 h. The samples were then centrifuged (266 x g km s^{-1} for 5 min), filtered (0.45 μm), the ascorbic acid colorimetric method (Murphy et al., 1982) was used to determine the P concentration. For this study, the BAP content of soil samples was desired, not the BAP in runoff, therefore a few modifications were used to adapt this method to dry soil samples. One gram of soil was shaken on an oscillating shaker (250 rpm) for 17 hr with 40 mL of 0.1M NaOH. The mixture was filtered (Whatman's no. 1 filter paper) and the resulting leachate P concentration was determined through the colorimetric ascorbic acid method (Murphy et al., 1982).

Extractable Aluminum, Iron, and Silica

Extactable Al, Fe, and Si were determined through the acid ammonium oxalate extraction procedure (Soil Survey Laboratory Methods Manual, 1996) by the Texas A&M University Soil Characterization Laboratory. Two grams of soil sample were placed in a 250-mL polypropylene bottle with 200 mL of 0.2 M $(NH_4)_2C_2O_4$. While capped, the bottle was shaken in the dark for 4 h. Five to 10 drops of 0.4 % Superfloc were added and the solution was shaken and then centrifuged (2000 rpm). The supernatant liquid was removed and analyses for Fe, Si, and Al concentrations were conducted through atomic absorption methods.

Ascorbic Acid Colorimetric Method

Solutions with too great a concentration of Na or acid were not suitable for measurement through the ICP and were therefore quantified through the ascorbic acid colorimetric method (Murphy et al., 1982). Solutions were created by tenth dilutions. Depending on the amount of extract available, 5 mL of extract were added to a 50-mL volumetric flask, or 10 mL of extract were added to a 100-mL volumetric flask. All TP's and IPB were tested in the former method and all remaining extractions were tested in the latter described manner. Approximately 5 to 10 drops of 0.25% (wt/vol) p-nitrophenol (depending on the amount of extract, respectively) were added to the extract aliquot to determine the pH of the extract (yellow = basic, clear = acidic). Since the ascorbic acid method works best on pH values between 5.6 and 7.6, a clear or colorless solution, free of precipitate was desired. Therefore, 5 N HCl was added drop-by-drop to all solutions that appeared yellowish after the addition of the p-nitrophenol. Enough

HCl was added to just change the color from yellow to clear. Five normal NaOH was added on a drop-by-drop basis to any extract that might have had a precipitate due to a low pH. Each sample was diluted with approximately 30 mL of DI water (approximately 60 mL if in the 100-mL volumetric flask). Eight mL of the ascorbic acid solution (16 mL if in the 100-mL volumetric flask) were added and the solution brought to volume with DI water. The solution was shaken and allowed to sit for 10 minutes. After ten minutes, each solution was transferred into a 1-cm cuvette and transmittance was determined using a Spec-20 (absorbance filter set at 840 to 880 nm and wavelength set at 660 nm).

A standard curve was created using 0, 1, 2, 4, 5, 10, and 15 mg L^{-1} P created in DI water. The results of these standards were compared to the standards made in the other extracts. The line of best fit for the standard curve was then used to determine the amount of P corresponding to the transmittance in the unknown soil samples.

A standard curve using 0, 1, 2, 4, and 5 mg L^{-1} P was created in 0.1M NaOH for use with the results from the BAP assay.

Solubility Determination

The solubility of each selected phosphate compound was determined through the use of solubility diagrams and equations produced by Lindsay (1979). The amount and solubility of each selected form of P were compared to total P and dissolved P in runoff from these sites as determined in previous research (Jacoby, 2005).

Data Analysis

Particle Size Determination

Data gathered from the particle size analyses were utilized to determine the fraction of sand, silt, and clay of each soil. Clay was determined in Equation [1], silt and clay determined in Equation [2], silt determined in Equation [3], and sand determined in Equation [4].

% clay = [1]

(corrected 2 hour reading – corrected blank)/(dry weight of soil) x100

% silt + % clay = [2]

(corrected 40 second reading – corrected blank)/(dry weight of soil)x100

% silt = % silt + % clay - % clay [3]

% sand = 100 - % silt - % clay [4]

Corrected values were achieved by adding 0.36 g/L for every 1° C higher than 20° C and subtracting 0.36 g/L for every 1° C lower than 20° C. All results for particle size analysis are presented in Tables 1 and 2. The ten soils ranged in clay content from 12 to 260 g kg^{-1}, silt ranged from 45.2 to 620 g kg^{-1}, and sand ranged from 120 to 943 g kg^{-1}. The texture ranged from sand to sandy loam and silt loam to loam.

Data from Ascorbic Acid Colorimetric Method

A standard curve was created using 0, 1, 2, 4, 10, and 15 mg kg^{-1} P (Table 3, Fig. 1). The estimated best fit of this line was determined by Statistical Packaging for Social Sciences (SPSS, 2004) (see equation [5]).

$$y = -4E\text{-}5x^3 + 0.0123x^2 - 1.2381x + 44.615 \quad R^2 = 0.9997 \qquad [5]$$

Table 1. Hydrometer and temperature readings at the 40 second and 2 hour settling time for the particle size distribution analysis.

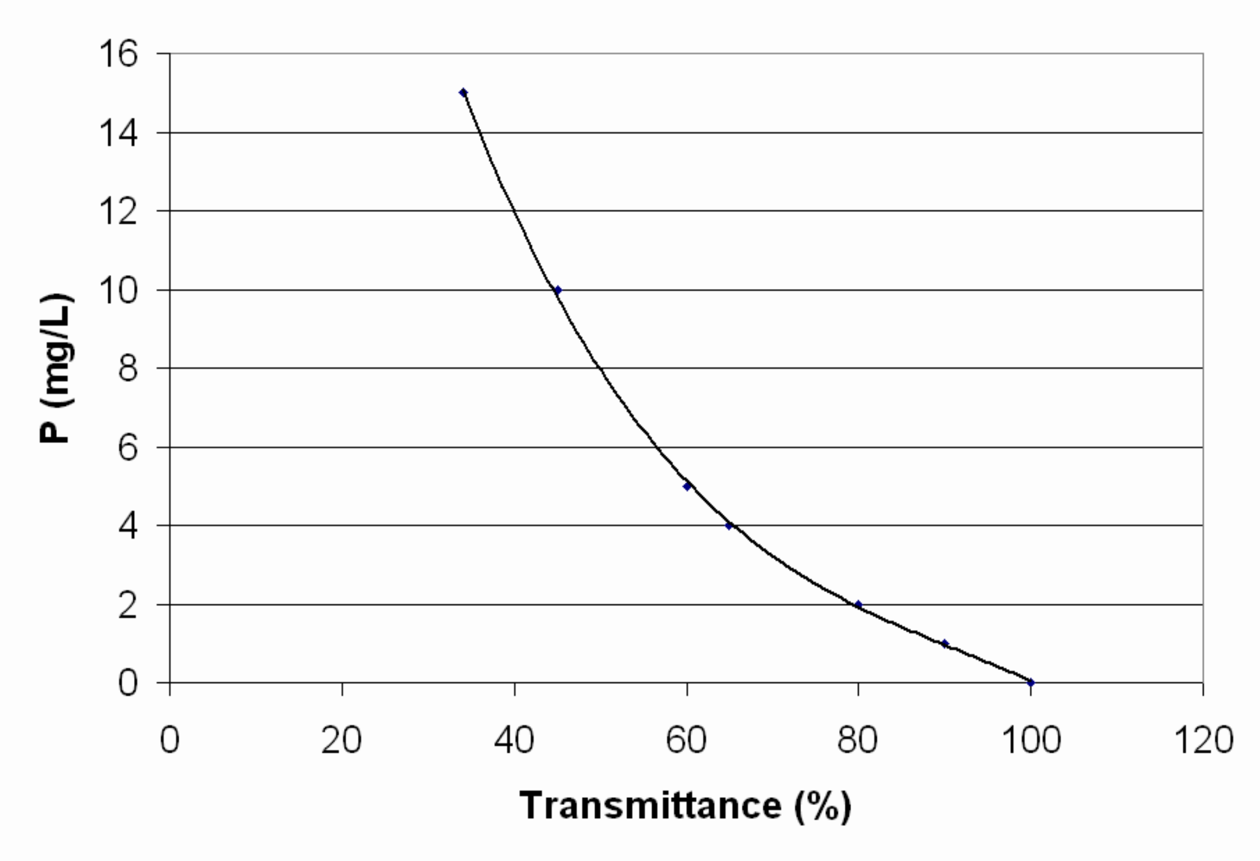
SITE	PLOT	40 SEC (1)	40 SEC (2)	40 SEC (3)	40 SEC TEMP C	2HOUR	2 HOUR TEMP C
BLANK		6.5	7	7	21	6	21.5
L	1	29	29.5	29.5	21	13	21.5
M	1	22	22	21.5	22	10	23.25
N	3	26	25	25	22	11.5	23.25
W	1	38	38	37.5	20.75	19	21.5
V	1	21.5	21.5	22	20.75	9	22
S	1	24.5	24	23.5	20	12.5	22
P	3	8.5	9	9.5	21	6.5	21.75
Q	3	24.5	23.5	23.5	20	13	22
T	2	19	19.5	19	20.75	13	22
O	3	10	9	9.5	21	7	21.75

Table 2. Particle size distribution and textural class for each soil.

SITE	Clay	Silt	Sand	Texture
		G kg^{-1}		
BLANK				
L	140	450	410	Loam
M	93	313	595	Sandy Loam
N	123	383	495	Loam
W	260	620	120	Silt Loam
V	56	293	650	Sandy Loam
S	126	340	534	Sandy Loam
P	12	45	943	Sand
Q	136	336	527	Sandy Loam
T	136	243	620	Sandy Loam
O	22	55	923	Sand

Table 3. Phosphorus concentrations and corresponding transmittances for the standard curve.

P Concentration	Transmittance
mg L^{-1}	%
0	100
1	90
2	80
4	65
5	60
10	45
15	34



$y = -4E\text{-}5x^3 + 0.0123x^2 - 1.2381x + 44.615$ $R^2 = 0.9997$

Fig. 1. Standard curve for the ascorbic acid method for all assays except bioavailable P.

This curve was used for all assays except the bioavailable P assay.

A standard curve was created for the bioavailable P method using 0, 1, 2, 4, and 5 mg kg^{-1} P (Table 4, Fig. 2). The estimated best fit of this curve was determined using SPSS (2004) (see equation [6]).

$$y = 0.0944x^3 + 0.4921x^2 - 12.788x + 100.28 \qquad R^2 = 0.9982 \qquad [6]$$

Concentration Equations

Once the amount of P in each sample was determined, the dilution of each extract from the soil sample to final colorimetric analysis had to be considered. Equation [7] was used for the determination of IPB per gram of soil.

$$\text{IPB} = \text{P concentration } (\mu\text{g mL}^{-1}) \cdot 50\ v_1^{-1} \cdot v_2\ \text{g}^{-1} \text{ soil used} \qquad [7]$$

where v_1 = volume of extract used for inorganic P concentration and v_2 = volume of extract. Equation [8] is for the determination of TPA and TPB per gram of soil.

$$\text{TPA or TPB} = \text{P concentration } (\mu\text{g mL}^{-1}) \cdot 50\ v_3^{-1} \cdot v_2\ \text{g}^{-1} \text{ soil used} \qquad [8]$$

where v_3 = volume of extract used in the digest, v_2 = volume of extract. Equations [9] – [13] are for IP, TP, OPA, OPB, and OP determination, respectively.

$$\text{IPA} + \text{IPB} = \text{IP} \qquad [9]$$

$$\text{TPA} + \text{TPB} = \text{TP} \qquad [10]$$

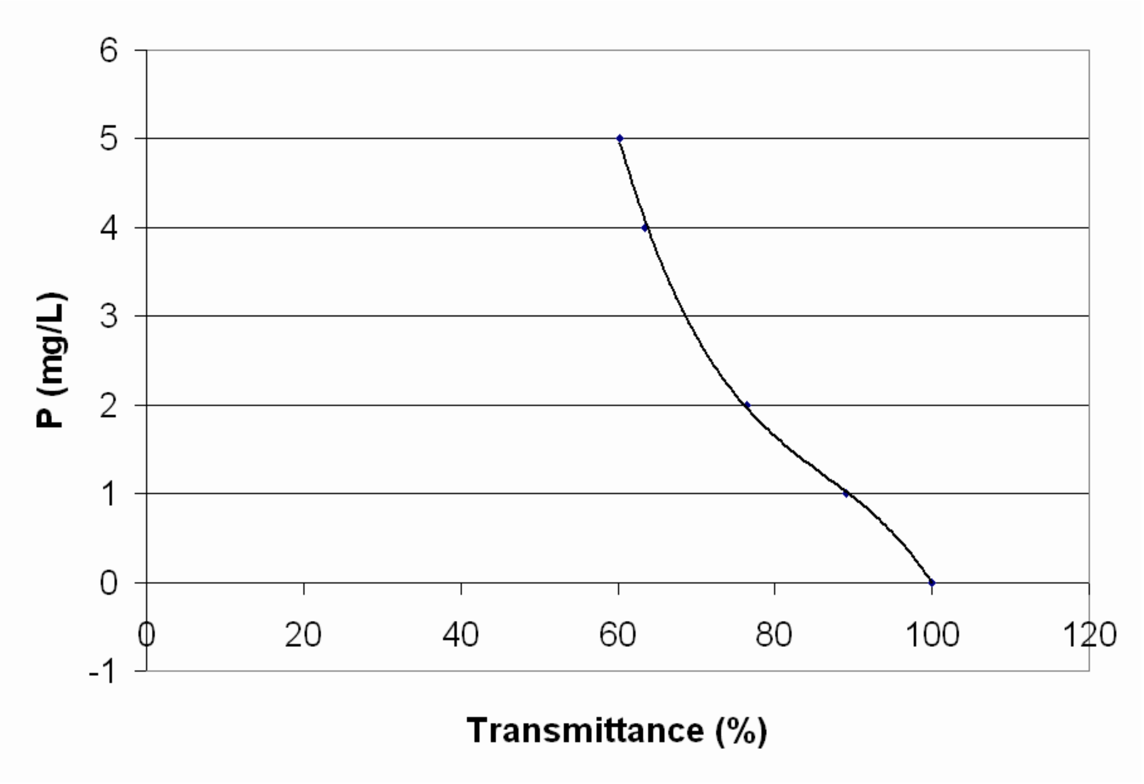
$$\text{OPA} = \text{TPA} - \text{IPA} \qquad [11]$$

$$\text{OPB} = \text{TPB} - \text{IPB} \qquad [12]$$

$$\text{OP} = \text{TP} - \text{IP} \qquad [13]$$

Table 4. Phosphorus concentrations and corresponding transmittance values for the bioavailable P assay.

P Concentration	Transmittance
mg L^{-1}	%
0	100
1	89
2	76.5
4	63.5
5	60.25



$y = 0.0944x^3 + 0.4921x^2 - 12.788x + 100.28$ $R^2 = 0.9982$

Fig. 2. Standard curve for bioavailable P assay.

The results of these equations are presented in Appendix B, Table B-1 through B-4. Equation [14] was used to determine the P content of each inorganic fraction (soluble and loosely bound P, NH_4F-extractable P, NaOH-extractable P from the noncalcareous soil fractionation, reductant-soluble P, and occluded P).

$$P_{extract} = \text{P concentration } (\mu g\ mL^{-1}) \cdot 50\ v_1^{-1} \cdot v_2\ g^{-1} \text{ soil used} \qquad [14]$$

where v_1 = sample volume from the extract for P determination, v_2 = volume of the extract. All data are presented in Appendix B Tables B-5 through B-8.

Equation [15] was used to determine the P concentration in the BAP samples.

$$BAP = \text{P concentration } (\mu g\ mL^{-1}) \cdot 40\ ml \cdot 1g^{-1} \text{ soil} \qquad [15]$$

The results for BAP measurements are presented in Appendix B Table B-9.

Data from ICP

Only IPA, soluble and loosely bound P, $CaPO_4$, and KCl extractable Ca, Al, Fe, and P were determined with the use of the ICP. Equation [16] was used to calculate the amount of IPA per g of soil.

$$IPA = \text{P concentration } (\mu g\ mL^{-1}) \cdot v_1\ g^{-1} \text{ soil used} \qquad [16]$$

where v_1 = the volume of the extract. Results are in Appendix C Table C-1.

Soluble and loosely bound P was calculated using Equation [17].

$$\text{Soluble and loosely bound P} = \text{P concentration } (\mu g\ mL^{-1}) \cdot v_1\ g^{-1} \text{ soil used} \qquad [17]$$

where v_1 = the volume of the extract. Results are in Appendix C Table C-2.

Equation [18] was used to calculate the amount of NaOH-extractable P from the calcareous soil fractionation on a per gram of soil basis.

$$\text{NaOH-P} = \text{P concentration } (\mu\text{g mL}^{-1}) \cdot v_1 \text{ g}^{-1} \text{ soil used} \qquad [18]$$

where v_1 = the volume of the extract. Results are presented in Appendix B Table B-3. Potassium chloride extractable Ca, Al, Fe, and P were calculated using Equation [19].

$$\text{Concentration} = \text{ICP reading} \cdot 25 \text{ mL } 5\text{g}^{-1} \text{ soil} \qquad [19]$$

All results are presented in Appendix C Tables C-4 through C-8.

Ammonium Oxalate Extraction

The ammonium oxalate extractable Fe, Al, and Si were corrected for moisture values. These values are presented in Appendix D, Table D-1. Concentrations were left in percent form in the Results and Discussion section to distinguish these forms from the KCl extractable Fe and Al. Thus, the ammonium oxalate extractable Fe, Al, and Si are referred to as AO_Fe, AO_Al, and AO_Si, respectively, to diminish any confusion with KCl extractable Al and Fe.

Solubility

Some previous work completed on the mineralogy of selected soils indicated that P minerals were not in sufficient quantities to be found by x-ray diffraction. Thus, all minerals whose solubility involved Fe, Ca, Mg, and Al were deemed as potential sources of soluble P that could add to P concentration in runoff. Solubility equations were taken from Lindsay's work (1979). Appendix E Table E-1 contains a list of mineral solubility equations used in this project. The KCl-extractable Fe, Al, Ca, and Mg were used in conjunction with pH and mineral solubility equations to predict the amount of P that could be provided by each mineral type in sample soil conditions. As suggested by Lindsay (1979), double function parameters using the activities of hydrogen (H^+) and Fe, Al, Ca, and Mg were used. Equations [20], [21], and [22] using variscite are given to demonstrate how mineral solubility was used to determine P solubility.

$$\begin{array}{lr} & \underline{\log\ K} \\ AlPO_4{\cdot}2H_2O + 2H^+ \leftrightarrow Al^{3+} + H_2PO_4^- + 2H_2O & -2.50 \\ \qquad\qquad H^+ \leftrightarrow H^+ & 0.00 \\ \hline AlPO_4{\cdot}2H_2O + 3H^+ \leftrightarrow Al^{3+} + H_2PO_4^- + H^+ + 2H_2O & -2.50 \end{array}$$

$$\frac{(Al^{3+})\,(H^+)\,(H_2PO_4^-)}{(H^+)^3} = 10^{-2.50} \qquad [20]$$

$$\log H_2PO_4^- - pH = -2.50 - (\log Al^{3+} + pH) \qquad [21]$$

$$H_2PO_4^- = 10^{(pH - 2.50 - (\log Al + 3pH)} \qquad [22]$$

Each equation was completed for $H_2PO_4^-$ and $HPO_4^{=}$ since these would be the two forms of ortho-P that would be present at the soil pH values found in the selected soils.

Statistical Analysis

One way ANOVA was used to compare means of data groups. Data means were compared based on depth and calcareous class. Significance values were placed at 0.05. In cases where more than 2 groups were compared, Least Square Difference (LSD) was used as a post hoc test to determine if significant differences existed between one or more of the means. Significance values were set at 0.05. Linear regression was used to determine relationships between variables and to check the validity of the TP method. Stepwise linear regression was used to determine relationships between more than 2 variables and to determine prediction equations for dissolved and total P in runoff.

Correlation coefficients and significant values were used to determine precision of equations. All statistical analyses were preformed with SPSS (2004).

RESULTS AND DISCUSSION

This section presents the results of the previously described experiments. Comparisons to published literature as well as conclusions that could be drawn are also included. However, it should be noted that while literature that demonstrated the use of ammonium oxalate extraction and the other fractionation methods in relation to this study were limited, there appeared to be no literature that denoted a study which utilized KCl extractable elements similar to this study. Related literature that could be found is presented in subsequent sections.

Means Comparisons

Total P, Inorganic P, Organic P

The means for total P (acid, basic, and total fractions), inorganic P (acid, basic, and total fractions), and organic P based on depth are presented in Table 5. When all 10 soils were summed together, the result was that IPA, IP, TPA, TPB, and TP demonstrated a significant increase in the upper 0-5 cm compared to deeper depths (Table 5). It was expected that most of the P would be concentrated in the top layer of soil as compared to the lower layers (EPA, 2003). The results followed the expected. The one problem found with the data is that the amount of inorganic P found in the soil was greater than the total P measured and calculated. The explanation of this occurrence is uncertain. However, it is hypothezied that error of working with a low weight of sample and sequential extraction of the low weight of sample, introduces an error that the total P was lower than the inorganic P. Dick and Tabatabai (1977) noted that many methods utilizing molybdate reactive inorganic P, in reality analyze a loosely defined group of molybdate reactive P that can include some labile forms of organic P. Organic P was also found to be below detection limits (Appendix B, Table B-4). Phosphorus in dairy manure is approximately 63 – 92 % inorganic forms (Sharpley and Moyer, 2000). Therefore, it is thought that the little organic P was probably already mineralized in the samples, making it undetectable with the method used to extract the soil. Sharpley et al. (2004) noted that the amount of organic P added with the application of manure is far less than the amount of inorganic P added in the same addition. Therefore, areas with a long-term history of manure application are often characterized as having large concentration of inorganic P in comparison to organic P concentrations (Sharpley et al., 2004).

Results differ slightly when the soils were divided into the calcareous and noncalcareous samples and then compared within the groups. The means for TP and IP are presented in Tables 6 and 7 for calcareous and noncalcareous, respectively. The calcareous soils demonstrated no significant difference with depth in any of the P fractions. The noncalcareous soils followed the same trend as the combined soils. There was a significantly higher amount of IPA, IPB, IP, TPA, TPB, and TP in the 0-5 cm depth that in any of the other depths. Soils dominated by Ca may have more mobile P than systems dominated by Fe and/or Al, allowing for a more equal distribution of P throughout the top 15 cm of the soil.

Table 5. The effect of depth on total P and inorganic P in the soil.

Type	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - -	
IPA	0-5	790a	221	2118	<0.01
	5-15	392b	93	944	
	0-15	518b	138	1132	
IPB	0-5	258a	18	612	0.04
	5-15	153b	18	496	
	0-15	183ab	18	432	
IP	0-5	1049a	386	2423	<0.01
	5-15	545b	16	1130	
	0-15	701b	286	1181	
TPA	0-5	715a	148	1612	<0.01
	5-15	412b	101	945	
	0-15	507b	141	1041	
TPB	0-5	21a	4	40	<0.01
	5-15	12b	4	28	
	0-15	15b	4	28	
TP	0-5	736a	179	1646	<0.01
	5-15	424b	114	949	
	0-15	521b	162	1046	

† Within columns and type of P, means followed by the same letter are not significantly different according to LSD (0.05).

Table 6: The effect of depth in calcareous soils on total and inorganic P in the soil.

Type	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - -	mg kg^{-1}	- - - - - - - - -	
IPA	0-5	649a	331	1508	0.38
	5-15	479a	158	944	
	0-15	535a	205	1132	
IPB	0-5	80a	18	204	0.07
	5-15	43a	18	89	
	0-15	55a	18	96	
IP	0-5	728a	386	1525	0.20
	5-15	522a	186	1009	
	0-15	591a	286	1181	
TPA	0-5	668a	376	1310	0.29
	5-15	505a	189	945	
	0-15	559a	255	1041	
TPB	0-5	12a	4	28	0.14
	5-15	8a	4	13	
	0-15	9a	4	16	
TP	0-5	680a	392	1320	0.27
	5-15	512a	194	949	
	0-15	568a	260	1046	

† Within columns and P types, means followed by the same letter are not significantly different according to LSD (0.05).

Table 7. The effect of depth in noncalcareous soils on total and inorganic P in the soil.

Type	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - -	mg kg^{-1}	- - - - - - -	
IPA	0-5	942a	221	2118	<0.01
	5-15	311b	93	634	
	0-15	500b	138	913	
IPB	0-5	450a	204	612	<0.01
	5-15	256b	135	496	
	0-15	311b	203	432	
IP	0-5	1392a	537	2423	<0.01
	5-15	567b	228	1130	
	0-15	811b	341	1160	
TPA	0-5	766a	148	1612	<0.01
	5-15	326b	101	695	
	0-15	454b	141	744	
TPB	0-5	31a	22	40	<0.01
	5-15	16b	4	28	
	0-15	21b	10	28	
TP	0-5	796a	179	1646	<0.01
	5-15	342b	114	723	
	0-15	475b	162	772	

† Within columns and P types, means followed by the same letter are not significantly different according to LSD (0.05).

When the calcareous soils were compared to the noncalcareous soils for the 0-15 cm depth (Table 8), the noncalcareous soils had significantly more IPB, IP, and TPB than the calcareous soils. This may be due to the selected samples. However, since the TPs are not significantly different, it is theorized that, this may be due to strength of the Ca-P bonds. The Ca phosphates may be less extractable by the NaOH in the calcareous soils than the noncalcareous soils.

Table 8. The effects of the presence or absence of $CaCO_3$ on total and inorganic P present in the soil at the depth of 0-15 cm.

Type	Calcareous Class	Mean*	Minimum	Maximum	Sig
			mgkg^{-1}		
IPA	Calcareous	554*	158	1508	0.85
	Noncalcareous	570*	93	2118	
IBP	Calcareous	59	18	204	<0.01
	Noncalcareous	334	135	612	
IP	Calcareous	614	186	1525	<0.01
	Noncalcareous	905	228	2423	
TPA	Calcareous	577*	189	1310	0.29
	Noncalcareous	506*	101	1612	
TPB	Calcareous	10	4	28	<0.01
	Noncalcareous	22	4	40	
TP	Calcareous	587*	194	1320	0.39
	Noncalcareous	528*	114	1646	

* Means are not significantly different at $p = 0.05$ level.

Inorganic Fractionation of P

The 10 soils were then compared based on depth for the inorganic fractionation of P into reductant soluble P, occluded apatite, and NaOH-extractable P. These were the only fractions found in both the calcareous and noncalcareous soils. The results are presented in Table 9. Occluded apatite was significantly greater in the top 5 cm than at any of the other depths. This increase of occluded apatite may be due to the presence of other elements such as Ca that could quickly bond with P, decreasing the probability of downward movement. The uniformity of reductant soluble P could be attributed to the oxidization of this type of P at the surface, decreasing the amount found in the upper horizons. This uniformity in Fe forms in the soils was continued in the Fe P's, ammonium oxalate extractable Fe, and the KCl extractable Fe. There was no depth difference for calcareous, noncalcareous, and all combined soils for any form related to Fe.

Table 9. The effect of depth on the fractionation of inorganic P for all soils.

Type	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - -	mg kg^{-1}	- - - - - - -	
Occluded P	0-5	1330a	135	3779	0.01
	5-15	723b	18	2227	
	0-15	920b	135	2146	
Reductant P	0-5	66a	18	192	0.70
	5-15	54a	18	210	
	0-15	58a	18	174	
NaOH-P	0-5	78a	31	158	0.86
	5-15	67a	21	207	
	0-15	71a	29	178	

† Within columns and P types, means followed by the same letter are not significantly different according to LSD (0.05).

When the soils were divided into calcareous and noncalcareous groups, the means were again compared based on depth (0-15 cm). In the calcareous soils, occluded apatite, reductant soluble P, and NaOH-extractable P were compared. The results are presented in Table 10. There was a significant increase of NaOH-extractable P in the top 5 cm, which would indicate that P added to the system is reacting with Ca, slowing or preventing downward movement or perhaps that Ca is not located in large concentrations in the lower depths. Sharpley et al. (2004) indicated that both Ca and P concentrations are increased as manure is added to a soil system, and with the addition of these two elements. P is increasingly precipitated, particularly in more soluble precipitate forms.

Table 10. The effect of depth in calcareous soils on the fractionation of inorganic P.

Type	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - -	
Occluded P	0-5	1595a	772	2290	0.25
	5-15	1259a	519	2227	
	0-15	1371a	619	2146	
Reductant P	0-5	108a	30	192	0.74
	5-15	92a	18	210	
	0-15	97a	42	174	
NaOH-P	0-5	60a	30	86	0.01
	5-15	39b	21	71	
	0-15	46b	28	74	

† Within columns and P types, means followed by the same letter are not significantly different according to LSD (0.05).

For the noncalcareous soils, the means of loosely bound and soluble P, NaOH-extractable P, NH_4F-extractable P, reducant soluble P, and occluded P were compared by depth. The results are presented in Table 11. The 0-5 cm depth had significantly more occluded, loosely bound and soluble P. Again, this indicates that the noncalcareous soils follow the same trend as the calcareous soils, in that P binds to Ca in the upper part of the soils. The loosely bound and soluble P indicated that there perhaps was more biotic activity in the top 5 cm of the soil which create large concentrations of these plant available forms of P.

Table 11. The effect of depth in noncalcareous soils on the fractionation of inorganic P.

Type	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - -	mg kg^{-1}	- - - - - - -	
Occluded P	0-5	1045a	135	3779	<0.01
	5-15	220b	18	553	
	0-15	469b	135	1334	
Reductant P	0-5	21a	18	54	0.27
	5-15	18a	18	18	
	0-15	19a	18	30	
Soluble and Loosely Bound P	0-5	449a	25	871	<0.01
	5-15	189b	3	400	
	0-15	266b	10	476	
NaOH-P	0-5	100a	42	181	0.93
	5-15	92a	18	271	
	0-15	95a	26	218	
NH_4F-P	0-5	20a	18	42	1.00
	5-15	19a	18	42	
	0-15	19a	18	42	

† Within columns and P types, means followed by the same letter are not significantly different according to LSD (0.05).

When total depth (0-15 cm) was compared on a calcareous class basis, again only occluded apatite, reductant soluble P, and NaOH-extractable P values could be used. The results are presented in Table 12. Both the occluded and reductant soluble P were found in significantly higher concentrations in the calcareous soils. The larger concentration of occluded apatite P indicates that these systems are dominated by Ca, yet Fe still plays a large role because it is the primary part of the reductant soluble P. The occluded apatite followed logic as there would be more Ca in the calcareous system to allow for more reversion to apatite. As noted for both calcareous, noncalcareous, and combinations of all soils (Table 11), occluded P greatly outweighed all other P forms.

This agrees with the Sharpley et al. (2004) observation that solubility in heavily manured soils is dominated by Ca.

Table 12. The effect of the presence or absence of $CaCO_3$ on inorganic P fractionations at the depth of 0-15 cm.

Type	Calcareous Class	Mean*	Minimum	Maximum	Sig
		- - - - - - - -	mg kg^{-1}	- - - - - - -	
Occluded	Calcareous	1409	519	2290	<0.01
	Noncalcareous	560	18	3779	
Reductant	Calcareous	99	18	210	<0.01
	Noncalcareous	19	18	54	
NaOH-P	Calcareous	46*	29	74	0.07
	Noncalcareous	95*	57	178	

* Means are not significantly different at p = 0.05 level.

KCl-Extractable Elements

The KCl-extractable P, Ca, Fe, Mg, and Al means were compared based on depth for all study soils (Table 13). There was no significant difference between the concentrations at any of the depths for any of the KCl-extractable elements. There appeared to be an even distribution of KCl-extractable elements throughout the sample depth. This equal distribution could be contributed to water movement through the soil or transport of elements due to plant roots creating osmotic potentials that would foster the movement of soluble salt materials.

Table 13. The effect of depth on the amount of KCl-extractable Mg, P, Ca, Fe, and Al.

KCl Soluble	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - - - -	
Mg	0-5	192a	96	324	0.57
	5-15	150a	43	331	
	0-15	167a	63	328	
P	0-5	40a	7	98	0.15
	5-15	15a	1	53	
	0-15	24a	4	68	
Ca	0-5	1229a	723	1701	0.99
	5-15	1200a	423	2108	
	0-15	1209a	534	1972	
Fe	0-5	1.57a	0.27	5.64	0.52
	5-15	0.84a	0.27	3.97	
	0-15	1.08a	0.27	3.55	
Al	0-5	1.79a	0.05	14.81	0.58
	5-15	0.47a	0.05	2.15	
	0-15	0.91a	0.05	5.04	

† Within columns and element, means followed by the same letter are not significantly different according to LSD (0.05).

KCl-extractable elements were also compared separately by depth in the calcareous and noncalcareous soils by depth (Tables 14 and 15, respectively). There again was no significant difference for depth between any of the elements in either the calcareous or noncalcareous soils. But the large concentration of Ca does again support Sharpely's et al. (2004) observation that much of the solubility and extractability of P in soils with long histories of manure application is determined by Ca.

Table 14. Concentrations of KCl-extractable elements in calcareous soils with depth.

KCl Soluble	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - - - -	
Mg	0-5	167a	96	324	0.51
	5-15	113a	43	178	
	0-15	137a	63	207	
P	0-5	65a	9	98.35	0.14
	5-15	24a	1	53.25	
	0-15	38a	4	68.28	
Ca	0-5	1159a	757	1701	0.89
	5-15	987a	423	2108	
	0-15	1044a	534	1972	
Fe	0-5	2.83a	0.52	5.64	0.37
	5-15	1.41a	0.27	3.97	
	0-15	1.86a	0.36	3.55	
Al	0-5	3.53a	0.10	14.81	0.57
	5-15	0.69a	0.05	2.15	
	0-15	1.77a	0.07	5.04	

† Within columns and elements, means followed by the same letter are not significantly different according to LSD (0.05).

Table 15. Concentrations of KCl-extractable elements in noncalcareous soils with depth.

KCl Soluble	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - - - -	
Mg	0-5	215a	120	323	0.90
	5-15	189a	53	331	
	0-15	196a	72	328	
P	0-5	15a	7	26	0.24
	5-15	6a	2	20	
	0-15	10a	7	22	
Ca	0-5	1299a	723	1677	0.91
	5-15	1412a	965	1855	
	0-15	1375a	896	1784	
Fe	0-5	0.30a	0.27	0.37	0.29
	5-15	0.30a	0.27	0.27	
	0-15	0.30a	0.27	0.32	
Al	0-5	0.06a	0.05	0.08	0.52
	5-15	0.05a	0.05	0.05	
	0-15	0.05a	0.05	0.06	

† Within columns and elements, means followed by the same letter are not significantly different according to LSD (0.05).

When the calcareous and noncalcareous KCl-extractable elements were compared for the 0-15 cm depth (Table 16), there were elements that demonstrated significant difference in the means. Both KCl-extractable P and Fe were found to be significantly greater in the calcareous soils that in the noncalcareous soils. It was unexpected that there would be more Fe found in a calcareous system than a calcareous one, however, the more soluble P found in the calcareous soils may be be due to more readily solubilized P forms native to calcareous systems. Again, there was a large concentration of Ca further supporting the observation that Ca is increased with the application of manure (Sharpley et al., 2004). It was noted that there is a larger concentration of Ca and P in the calcareous soil than in the noncalcareous soil. This directly contradicts Torbert's et al. (2002) assumptions that calcareous soils will contain less soluble P at higher total P levels than noncalcareous soils.

Table 16. Concentrations of KCl-extractable elements in calcareous and noncalcareous soils at the depth of 0-15 cm.

KCl Soluble	Calcareous Class	Mean*	Minimum	Maximum	Sig
		-- - - - - -	mg kg^{-1}	- - - - - - - - -	
Mg	Calcareous	137*	63	207	0.28
	Noncalcareous	196*	72	328	
P	Calcareous	38	4	68.28	0.05
	Noncalcareous	10	7	22.15	
Ca	Calcareous	1044*	534	1972	0.34
	Noncalcareous	1375*	896	1784	
Fe	Calcareous	1.88	0.36	3.55	0.02
	Noncalcareous	0.29	0.27	0.32	
Al	Calcareous	1.77*	0.07	5.04	0.09
	Noncalcareous	0.05*	0.05	0.06	

* Means are not significantly different at p = 0.05 level.

Ammonium Oxalate Extractable Elements

Extractable Fe, Al, and Si were compared for all 10 soils based on depth (Table 17). There was no significant change in extractable elements with depth. This is probably due to the even distribution of most Fe, Al, and Si minerals found in the top 15 cm of the soils of the study area.

Table 17. Concentration of ammonium oxalate extractable elements by depth.

Element	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - - - -	
Fe	0-5	762a	413	1470	0.97
	5-15	725a	245	1838	
	0-15	719a	304	1715	
Al	0-5	786a	202	1369	0.98
	5-15	823a	100	1583	
	0-15	811a	134	1511	
Si	0-5	431a	101	818	0.98
	5-15	411a	100	821	
	0-15	418a	100	820	

† Within columns and elements, means followed by the same letter are not significantly different according to LSD (0.05).

The soils were also compared as either calcareous or noncalcareous by depth (Tables 18 and 19, respectively). There again was no difference between depths in either the calcareous or noncalcareous comparisons.

Table 18. Concentrations of ammonium oxalate extractable elements in calcareous soils with depth.

Element	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - -	mg kg^{-1}	- - - - - - - - -	
Fe	0-5	628a	415	870	0.94
	5-15	632a	389	821	
	0-15	594a	353	837	
Al	0-5	955a	608	1228	0.90
	5-15	1036a	607	1334	
	0-15	1009a	607	1299	
Si	0-5	548a	404	818	1.00
	5-15	539a	404	821	
	0-15	542a	404	820	

† Within columns and elements, means followed by the same letter are not significantly different according to LSD (0.05).

Table 19. Concentrations of ammonium oxalate extractable elements in noncalcareous soils with depth.

Element	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - - - -	
Fe	0-5	896a	413	1470	0.98
	5-15	818a	245	1838	
	0-15	844a	304	1715	
Al	0-5	617a	202	1369	1.00
	5-15	609a	100	1583	
	0-15	612a	134	1512	
Si	0-5	314a	101	506	0.96
	5-15	283a	100	507	
	0-15	293a	100	507	

† Within columns and elements, means followed by the same letter are not significantly different according to LSD (0.05)

The soils were then compared as calcareous to noncalcareous at the 0-15 cm depth increment (Table 20). The amount of extractable Si found in the calcareous soil was significantly greater than for the noncalcareous group of soils. This could be explained by the greater amount of opal phytolyths in the calcareous soils as most developed under grasslands while the noncalcareous soils were under oak savannahs. The reasoning for this is uncertain.

Table 20. Concentrations of ammonium oxalate extractable elements in calcareous and noncalcareous soils at the depth of 0-15 cm.

Element	Calcareous Class	Mean*	Minimum	Maximum	Sig
		- - - - - -	mg kg^{-1}	- - - - - - - - -	
Fe	Calcareous	594*	353	837	0.40
	Noncalcareous	844*	304	1715	
Al	Calcareous	1009*	607	1299	0.20
	Noncalcareous	612*	134	1512	
Si	Calcareous	542	404	820	0.04
	Noncalcareous	293	100	507	

* Means are not significantly different at p = 0.05 level.

Bioavailable P

The BAP means were compared by depth using all study soils (Table 21). There was no significant difference between depths. The highest BAP was found in the 5-15 cm depth. The depth should parallel the density and have more favorable microbiological conditions than the 0-5 cm depth. These findings contradict what Sharpley (1995) found in comparing 10 Oklahoma soils. He stated that the concentration of BAP is related to the amount of soil test P (Mehlich-3 P) in the surface layer of the soil (0-1 cm). Sharpley (1995) also determined that soils treated with the equivalent of 150 lb/A of P from chicken manure, yielded between 50 and 125 mg kg^{-1} P as measured by the Fe impregnated paper strip method. It appears that the NaOH extraction method may overestimate BAP, but it is uncertain because of the lack of accurate site history for this study.

Table 21. Bioavailable P (BAP) concentrations with depth for all soils.

	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - - - - -	
BAP	0-5	400a	338	585	0.07
	5-15	507a	338	667	
	0-15	471a	340	599	

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

The BAP mean were also compared by depth separately for the calcareous and noncalcareous soils (Tables 22 and 23, respectively). Separating the soils by calcareous class, we found there was no significant difference in depth.

Table 22. Bioavailable P (BAP) concentrations in calcareous soils with depth.

	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - - - - -	
BAP	0-5	364a	338	425	0.22
	5-15	444a	338	574	
	0-15	418a	340	495	

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 23. Bioavailable P concentrations in noncalcareous soils with depth.

	Depth	Mean†	Minimum	Maximum	Sig
	cm	- - - - - - -	mg kg^{-1}	- - - - - - - - - -	
BAP	0-5	436a	359	585	0.17
	5-15	570a	354	667	
	0-15	525a	356	599	

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Also, when BAP means were compared by calcareous class based on the 0-15 cm, again no significant difference between the two groups of soils were found in any of the depths (Table 24).

Table 24. Bioavailable P (BAP) concentrations in calcareous and noncalcareous soils.

Depth	Calcareousness	Mean*	Minimum	Maximum	Sig
		- - - - - -	mg kg^{-1}	- - - - - - - - -	
0-15	Calcareous	418*	340	495	0.08
	Noncalareous	525*	356	599	

* Means are not significantly different at p = 0.05 level.

Solubility Equations

The only mineral that yielded sufficient amounts of P to be noted was monocalcium phosphate (MCP). The equations for determining the MCP potential of the soil are in presented in equations [23] and [24]. The results for this mineral are presented in Table 25. However, there were no differences between soils and the amount of P released from MCP. Minerals, while they can play a large part in P release and sorption in a soil system, appear not to be as important in systems dominated by manure applications.

	log K	
$Ca(H_2PO_4)_2{\cdot}H_2O \leftrightarrow Ca^{2+} + 2H_2PO_4^- + H_2O$	-1.15	[23]
$Ca(H_2PO_4)_2{\cdot}H_2O \leftrightarrow Ca^{2+} + 2HPO_4^{=} + 2H^+ + H_2O$	-15.55	[24]

Table 25. Phosphorus concentration solubilized from monocalcium phosphate.

Soil	Depth	pH	KCl-extractable Ca	P
	cm		mg kg^{-1}	mg kg^{-1}
O	0-5	6.36	757	0.01
P	0-5	6.33	423	0.01
Q	0-5	4.86	534	0.01
S	0-5	6.87	1016	0.01
T	0-5	6.83	551	0.01
O	5-15	6.36	706	0.01
P	5-15	6.33	1701	0.01
Q	5-15	4.86	2108	0.01
S	5-15	6.87	1972	0.01
T	5-15	6.83	1209	0.01
O	0-15	6.36	1306	0.01
P	0-15	6.33	1274	0.01
Q	0-15	4.86	1115	0.01
S	0-15	6.87	546	0.01
T	0-15	6.83	736	0.01
L	0-5	7.80	998	0.01
M	0-5	7.51	965	0.01
N	0-5	7.51	976	0.01
W	0-5	8.10	1677	0.01
V	0-5	8.57	1407	0.01
L	5-15	7.80	1497	0.01
M	5-15	7.51	1642	0.01
N	5-15	7.51	1855	0.01
W	5-15	8.10	1784	0.01
V	5-15	8.57	1458	0.01
L	0-15	7.80	1854	0.01
M	0-15	7.51	1722	0.01
N	0-15	7.51	723	0.01
W	0-15	8.10	982	0.01
V	0-15	8.57	896	0.01

Linear Regression

Acid-Base Extractable P Relationships with Other P Test Values

The total P determination in this thesis was called acid-base total P for clarification. The acid-base total P results were plotted against the P determinations from Melich-3, TAMU extract, and a nitric acid digest (Jacoby, 2005) for P for each of the 10 soils (Fig. 3). All three of the previous P testing methods produced good correlations with the acid-base total P. The correlation values were high for the nitric digest P, TAMU P, and Mehlich-3 P at 0.80, 0.78, and 0.80 respectively. The highest correlation was with Mehlich-3 which proved to be useful since this is the soil test being used in many Land Grant Universities soil testing laboratories in the region. These high correlations confirm the precision of the acid-base extraction method for determining total P in a soil.

Comparisons to Mehlich-3 P Values

Because Mehlich-3 P is a widely used and accepted soil testing P method, it was chosen as a standard for comparison for all testing results in this study. The IPA, IP, TPA, TP, and occluded P all presented acceptable correlating trends. The relationships are presented in Figures 4 though 8, respectively. With further study, an interesting relationship was determined. When the 5 P values listed were compared with Mehlich-3 values on a total (use of all 10 soils) at the 0-15 cm depth, the correlation values were acceptable in most cases. However, when the calcareous soils and noncalareous soils were examined separately, the correlation always increased for the calcareous soils and some of the time in the noncalcareous soils. This demonstrated that these soils should be examined separately based upon calcareous class. Comparing the two together may not present an accurate representation of the soil system in question. It was also shown that while these soils are similar, the difference in calcareous classes also indicates that there are different species that dictate the P reactions. Therefore for accurate results, soils should be studied in groups based on whether or not they are calcareous.

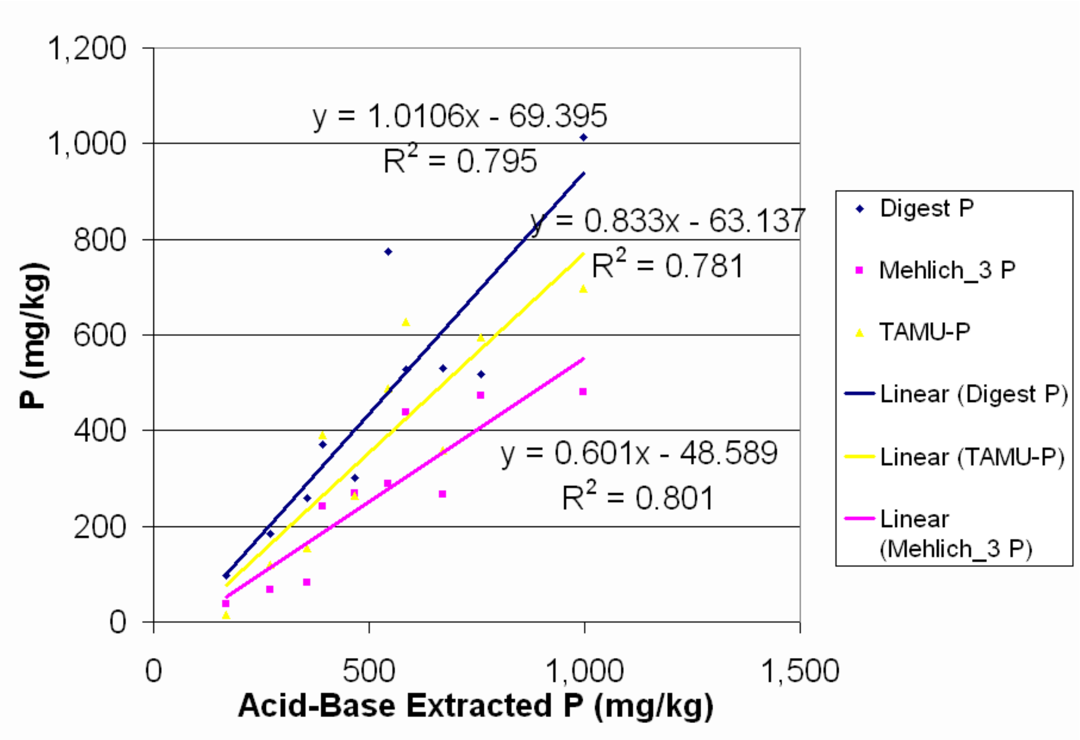


Fig. 3. Linear regressions between acid-base total and other P extraction/digestion methods.

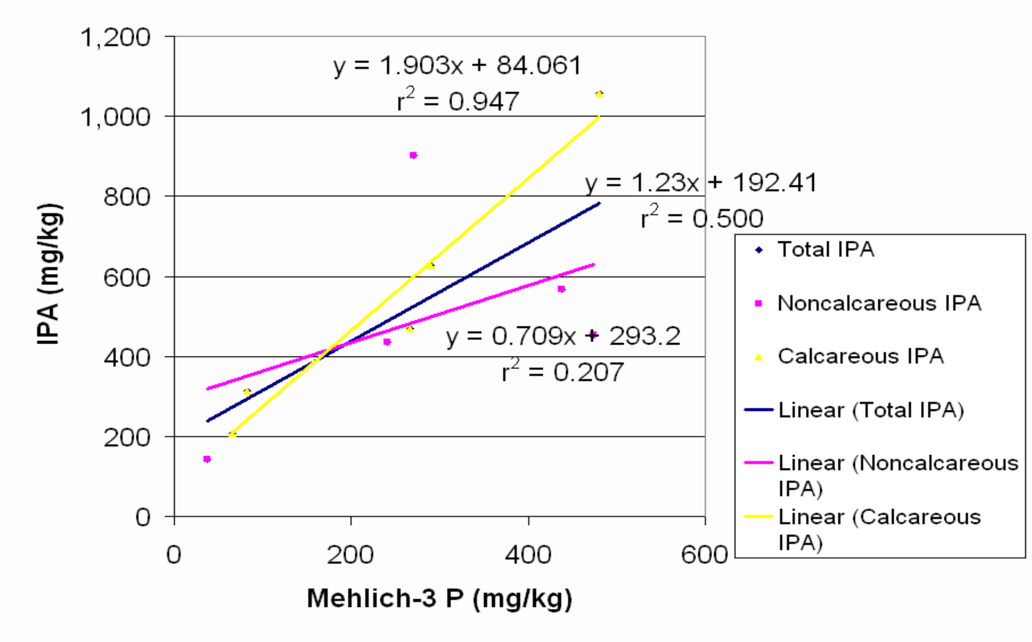


Fig. 4. Relationships between Mehlich-3 P, inorganic P acid fraction (IPA), IPA calcareous, and IPA noncalcareous.

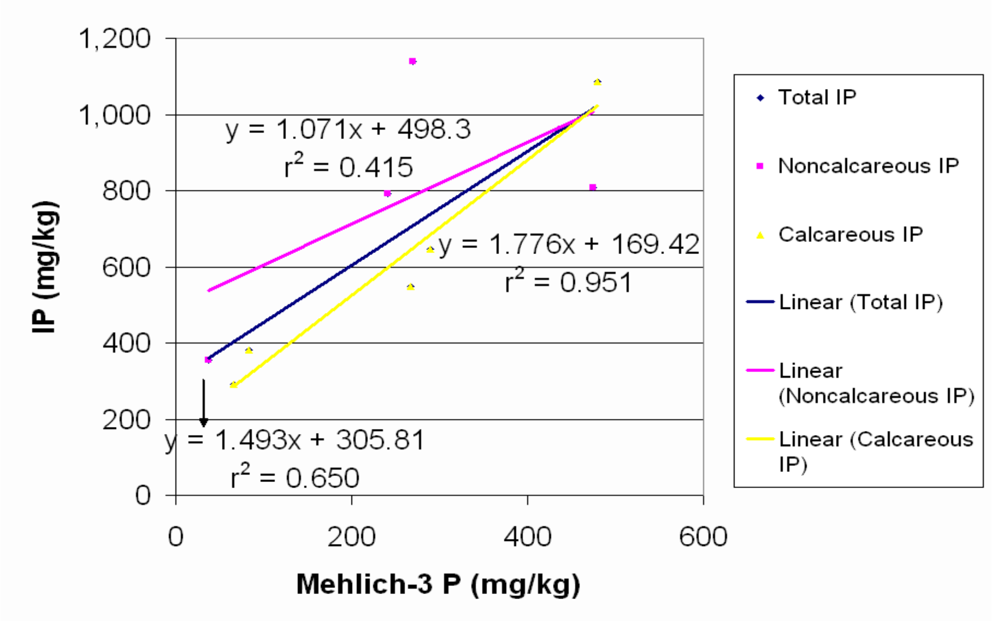


Fig. 5. Relationships between Mehlich-3 P, inorganic P (IP), IP calcareous, and IP noncalcareous.

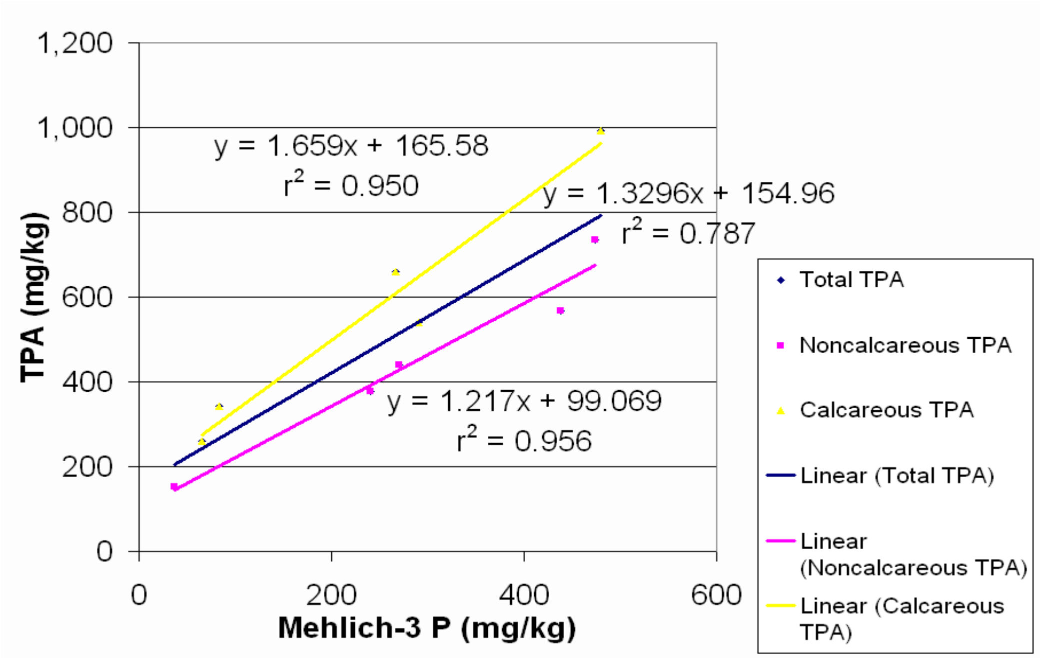


Fig. 6. Relationships between Mehlich-3 P, total P acid fraction (TPA), TPA calcareous, and TPA noncalcareous.

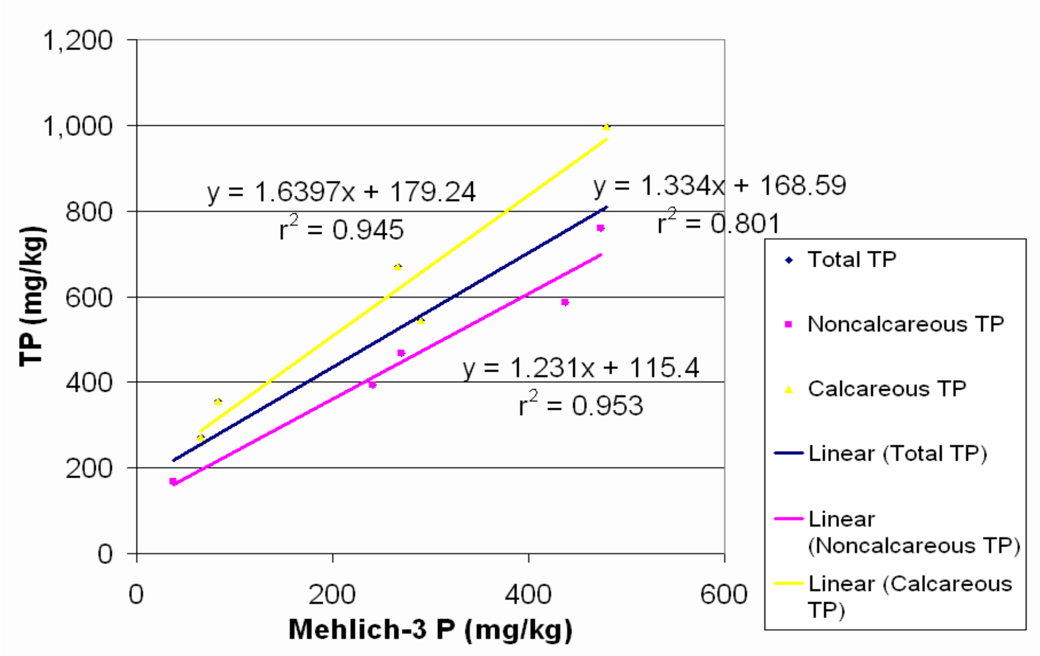


Fig. 7. Relationships between Mehlich-3 P, total P (TP), TP calcareous, and TP noncalcareous.

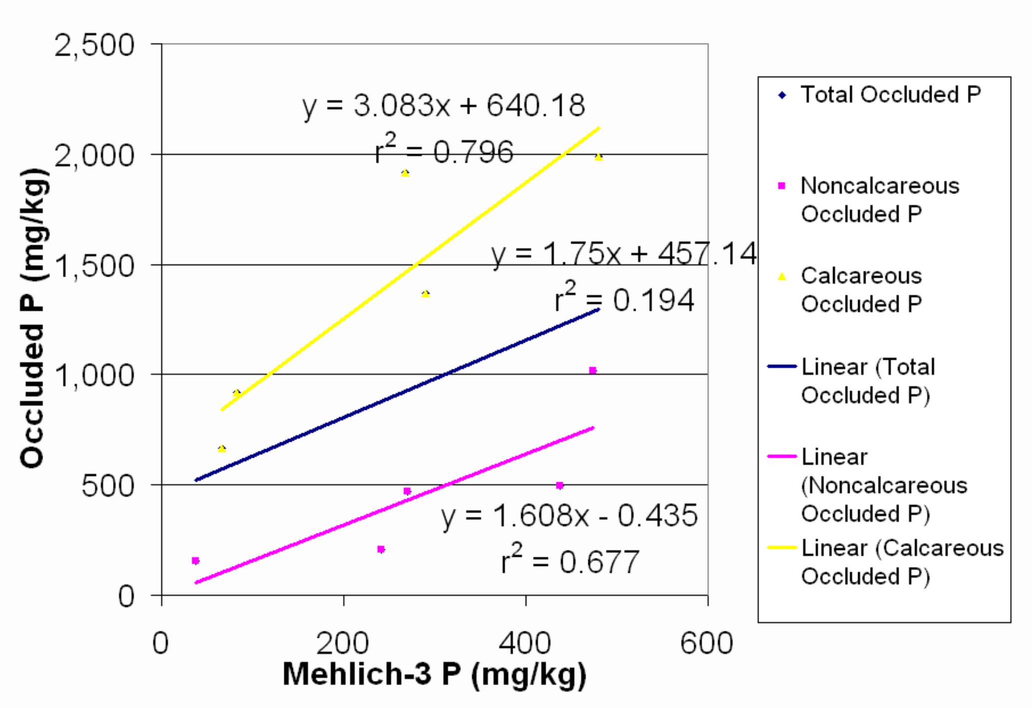


Fig. 8. Relationships between Mehlich-3 P, occluded phosphorus, occluded phosphorus calcareous, and occluded phosphorus noncalcareous.

Prediction Relationships

The second objective for this project was to determine a method of predicting P concentration in runoff from soil characteristics. Each of the measurements made in this study along with measurements from a previous study (Jacoby, 2005) listed in Table 26 were utilized in a stepwise linear regression to determine if dissolved P (DP) and total P in runoff (TP_R) can be predicted. First, scatter plots were used to determine if there was any relationship between the variable and either dissolved P or total P in runoff. Variables that exhibited no relationship were not considered further because their use would only decrease the correlation value of the equation. Table 26 provides a list of variables used. Variables were utilized first, in groups according to assays to determine if there would be a relationship determined through one assay instead of multiple assays. Second, all variables in Table 26 were entered to determine if multiple comparisions could improve the relationship of the predication equations. Because of the determination that calcareous soils and noncalcareous soils should be studied as separate groups, this section will analyze soils based on calcareous classes. These results are further supported by the determination by Torbert et al. (2002) that grouping soils by chemical characteristics such as whether $CaCO_3$ is present allows for the development of prediction equations which are more accurate. Therefore, each grouping of calcareous and noncalcareous soils were analyzed at depths of 0-5 cm, 5-15 cm, 0-15 cm and a weighted combination of 0-5 cm and 5-15 cm.

Table 26. Variables included in equations for predicting total and dissolved P in runoff.

Variables	Abbreviations
Occluded Apatite	Occ_ P
Reductant P	Red_P
Soluble P	Sol_P
Acid Fraction of Total P	TPA
Total P	TP
Inorganic P	IP
Bioavailable P	BAP
Mehlich-3 P	Meh_P
Total Carbon	TC
KCl Soluble Mg	KCl_Mg
KCl Soluble Ca	KCl_Ca
KCl Soluble Al	KCl_Al
KCl Soluble Fe	KCl_Fe
KCl Soluble P	KCl_P
Ammonium Oxalate Al	AO_Al
Ammonium Oxalate Fe	AO_Fe
Ammonium Oxalate Si	AO_Si
pH	pH
Amount of Clay	clay

Calcareous Soils

In the calcareous soils, several strong relationships were determined through the stepwise analysis. In the 0-5 cm depth, only one prediction relationship was determined and is presented in equation [25].

$$DP = -4.527 + 0.008(AO\_Al) \qquad [25]$$

$r^2 = 0.821 \qquad Sig = <0.01$

Ammonium oxalate extractable Al provided the only prediction relationship for dissolved P (DP) in runoff. There was no other variable that provided a relationship with either the dissolved or total P in runoff (TP_R). Sharpley (1995) stated that oxalate extractable Al could be used to determine extractable soil P and P sorption maximums in noncalcareous soils. However, no further published work could be located to extend this type observation to either calcareous soils or dissolved P in runoff.

In the 5-15 cm depth, several other prediction equations were found for both dissolved and total P in runoff. These relationships are presented in equations [26] through [29].

$$DP = -0.352 + 0.018(KCl\_Mg) \qquad [26]$$

$r^2 = 0.928$ Sig = 0.01

$$DP = -3.749 + 0.007(AO\_Al) \qquad [27]$$

$r^2 = 0.991$ Sig = <0.01

$$TP\_R = -0.587 + 0.026\ (KCl\_Mg) \qquad [28]$$

$r^2 = 0.886$ Sig = 0.02

$$TP\_R = -5.573 + 0.009(AO\_Al) \qquad [29]$$

$r^2 = 0.973$ Sig = <0.01

As can be seen in these relationships, both KCl-extractable Mg and ammonium oxalate-extractable Al provided highly correlated relationships with dissolved and total P in runoff. Since the KCl extractable method is far simpler and less expensive, it is advisable to use the KCl method to determine both dissolved and total P in runoff when analyzing the 5-15 cm depth of calcareous soils. These results are further supported by Jacoby's (2005) determination that extractable Mg had significant relationships to soil test P (TAMU). Booram et al. (1975), Ferguson et al. (1973), and Hansen et al. (2004)

found that Mg compounds were formed as manure was stockpiled, therefore creating higher concentrations in the soil.

In the 0-15 cm depth, there were again several relationships determined as predictors for dissolved and total P in runoff. These relationships are presented in equations [30] through [33].

$$DP = -0.824 + 0.020(KCl\_Mg) \tag{30}$$

$r^2 = 0.865$ Sig = 0.02

$$DP = -4.218 + 0.007(AO\_Al) \tag{31}$$

$r^2 = 0.987$ Sig = <0.01

$$TP\_R = -1.177 + 0.028(KCl\_Mg) \tag{32}$$

$r^2 = 0.801$ Sig = 0.04

$$TP\_R = -6.096 + 0.010(AO\_Al) \tag{33}$$

$r^2 = 0.941$ Sig = 0.01

Again, both the KCl-extractable Mg and ammonium oxalate-extractable Al provided excellent surrogates for predicting dissolved and total P in runoff. These results also confirm the importance of Mg in the soil as a predictor. Again, KCl would be a more desirable extraction method due to time and cost efficiency.

When the 0-5 and 5-15 cm variables were weighted as demonstrated in equations [34] and [35] to estimate KCl-extractable Mg and ammonium oxalate-extractable Al, the relationships further confirmed the results in the previous depths already discussed.

$$\text{0-5 cm values} = (1/3)*\text{variable} \tag{34}$$

$$\text{5-15 cm variable} = (2/3)*\text{variable} \tag{35}$$

The prediction equations are presented in equations [36] through [39].

$$DP = -0.296 + 0.019(KCl\_Mg) \qquad [36]$$

$r^2 = 0.885$ Sig = <0.01

$$DP = 0.419 + 7.652(AO\_Al) \qquad [37]$$

$r^2 = 0.798$ Sig = <0.01

$$TP\_R = -0.436 +0.026(KCl\_Mg) \qquad [38]$$

$r^2 = 0.841$ Sig = <0.01

$$TP\_R = -0.900 + 60.993(AO\_Al) \qquad [39]$$

$r^2 = 0.766$ Sig = <0.01

Again, it is shown here that the KCl-extractable Mg and ammonium oxalate-extractable Al provided a method for determining dissolved and total P in runoff. These results support the previous findings.

Noncalcareous Soils

The noncalcareous soils provided fewer highly correlated prediction relationships with dissolved and total P in runoff. When the 0-5 cm depth was analyzed, there was no correlation determined between any variable and either the dissolved P or total P in runoff. The same lack of correlation was found at the 5-15 cm and 0-15 depths.

However, when the 0-5 and 5-15 depths were weighted and entered, several relationships were found. These relationships were only noted when all variables were entered into the stepwise analysis. These relationships are presented in equations [40] and [41].

$$DP = -0.057 + 0.253(pH) \quad [40]$$

$r^2 = 0.600$ Sig = 0.01

$$TP\_R = 0.294 + 0.003(BAP) \quad [41]$$

$r^2 = 0.558$ Sig = 0.01

These relationships demonstrate that pH and BAP can be used as weak indicators of dissolved and total P in runoff. Mehlich-3 P and pH in combination provide a strong relationship for determining total P in runoff. The addition of ammonium oxalate Fe only increases the correlation of this relationship. The pH of a soil provides an indication of the type of P found in the soil. Iron phosphates are more soluble in acid soils and therefore in the range of the noncalcareous soils provide a large portion of the P to the soil (Brady and Weil, 1999). Bioavailable P could be considered an indicator of extractable Mg because Mg is found to increase enzyme activity, therefore increasing dissolved P and, in turn, total P in runoff (Jackson et al., 1967). Total P in runoff was significantly correlated to dissolved P (R^2 =0.814, Sig <0.01). With the doubling of data points, statistical relationships should increase.

All Soils

When all soils were compared there again were several useful relationships found. In the 0-5 cm depth, the total of all soils followed the trends of the noncalcareous soils, demonstrating no significant correlations.

For the 5-15 cm depth, there was one relationship that demonstrated stronger correlations. These results are presented in equations [42].

$$TP\_R = -0.262 + 0.022\ (KCl\_Mg) \qquad [42]$$

$r^2 = 0.704$ Sig = <0.01

Again, the KCl-extractable Mg demonstrates a strong relationship with total P in runoff. These results again support Jacoby's (2005) findings.

In the 0-15 cm depth, two weak relationships appeared, and are presented in equations [43] and [44].

$$DP = -0.276 + 0.015(KCl\_Mg) \qquad [43]$$

$r^2 = 0.567$ Sig = 0.01

$$TP\_R = -0.766 + 0.023(KCl\_Mg) \qquad [44]$$

$r^2 = 0.594$ Sig = 0.01

Here again, the KCl-extractable Mg provided a weak estimate of the dissolved and total P in runoff, further reflecting the theory that with the increase of microbial activity through increased Mg from stock piling manure, there is an increase in dissolved P in runoff (Booram et al., 1975, Ferguson et al., 1973, Hansen et al., 2004, and Jackson et al., 1967).

When the 0-5 and 5-15 cm depths were weighted and compared collectively, several stronger relationships emerged. These relationships are presented in equations [45] through [47].

$$DP = -0.056 + 0.014(KCl\_Mg) \qquad [45]$$

$r^2 = 0.609$ Sig = <0.01

$$DP = -0.057 + 0.253(pH) \qquad [46]$$

$r^2 = 0.600$ Sig = 0.01

$$TP\_R = -0.242 + 0.021(KCl\_Mg) \quad [47]$$

$r^2 = 0.642$ Sig = <0.01

Again, KCl-extractable Mg demonstrates a correlation with dissolved and total P in runoff. This further reiterates the importance of Mg in the soil as a factor for releasing P into runoff (Booram et al., 1975, Ferguson et al., 1973, and Hansen et al., 2004, and Jackson et al., 1967). The pH also provided a correlation to dissolved P in runoff. This again could be related to the types of P that are soluble at given pH ranges (Brady and Weil, 1999). There was a strong relationship determined between dissolved and total P in runoff ($r^2 = 0.950$). The use of the 0-5 and 5-15 cm depths contradicts the findings in previous studies where the 0-5 cm depth alone provided the best prospects for determining a prediction equation for varied soil types (Torbert et al., 2002). It is uncertain why this difference should exist since the projects took place in the same region of Texas. However, the testing methods for P in this study differed from the Torbert study, along with the consideration of elements other than P, which were not considered in the Torbert study. It may be that with the inclusion of other elements, the 0-15 cm depth provided prediction equations for a wider variety of soils.

CONCLUSIONS

Throughout this study, it was evident that soils need to be grouped based on whether or not they are calcareous in order to ensure the most accurate interpretation. Mean comparisons showed the different P fractions gave different concentrations. Regression analysis demonstrated that relationships were strengthened through the separate consideration of calcareous and noncalcareous soils, particularly in the calcareous groups.

Acid-base extractable P was found to have a highly significant relationship with Mehlich-3 P, allowing the prediction of total P from the more rapid Mehlich-3 procedure.

The KCl-extractable Mg proved to be an excellent predictor of both dissolved and total P in runoff water for calcareous soils at all depths, except 0-5 cm (r^2 values ranging from 0.865 to 0.928 and 0.801 to 0.886, respectively). However, KCl-extractable Mg proved to be nonsignificant in the noncalcareous soils. When the soils were combined, KCl-extractable Mg showed several weak correlations at the 5-15, 0-15 depths and combination of 0-5 and 5-15 cm depths (r^2 ranging from 0.567 to 0.609 for dissolved P and 0.594 to 0.704 for total P in runoff). No relationships were found for all combined soils at the 0-5 cm depth. This demonstrates that KCl-extractable Mg plays large parts in contributing to dissolved and total P in runoff.

Ammonium oxalate-extractable Al provided a useful surrogate for determining dissolved and total P in runoff in calcareous soils at all depths (r^2 ranging from 0.798 to

0.991 and 0.766 to 0.973, respectively). Both lower r^2 values were found in the weighted combination of 0-5 and 5-15 depths, indicating that this assay was not significant a measure of P runoff at these depth combinations as the depths taken individually. No relationships of dissolved or total P in runoff were found with ammonium oxalate-extractable elements in the noncalcareous or across all soils at any depths.

Combinations of variables proved to be beneficial in the weighted combined depth of 0-5 and 5-15 cm in the noncalcareous and across all soils. In the noncalareous soils, pH created a weak relationship with dissolved P ($r^2 = 0.600$).

Following these results, it is recommended to test soil samples at the 5-15 cm depth or a weighted depth combined to make up 0-15 cm. It is also suggested that soils be compared based on the chemical characteristic of calcareous classes. As calcareous and noncalcareous soils exhibited different P relationships. Potassium chloride-extractable Mg would be recommended as a predictor for both dissolved and total runoff P from calcareous soils, as the KCl-extract provides a simple and inexpensive procedure with accurate results. For noncalcareous soils, pH provides a simple prediction of dissolved P. However, more research is needed to determine if a simplified and more accurate relationship can be determined to predict dissolved and total P in runoff for noncalcareous soils.

REFERENCES

Aase, J.K., D.L. Bjorneberg, and D.T. Westermann. 2001. Phosphorus runoff from two water sources on a calcareous soil. J. Environ. Qual. 30:1315-1323.

Barrow, N.J. 1983. A mechanistic model for describing the sorption and desorption of phosphate by soil. J. Soil Sci. 34:733-750.

Beauchemin, S., D. Hesterberg, J. Chou, M. Beauchemin, R.R. Simard, and D.E. Sayers. 2003. Speciation of phosphorus in phosphorus-enriched agricultural soils using x-ray absorption near-edge structure spectroscopy and chemical fractionation. J. Environ. Qual. 32:1809-1819.

Beauchemin, S., R.R. Simard, and D. Cluis. 1998. Forms and concentration of phosphorus in drainage water of twenty-seven tile-drained soils. J. Environ. Qual. 27:721-728.

Beek, J., W.H. Van Riemsdijk, and K. Koenders. 1980. Aluminum and iron fractions affecting phosphate bonding in sandy soil treated with sewage water. p. 369-379. *In* A. Banin and U. Kafkafi (ed.) Agrochemicals in soils. Pergamon Press, Oxford.

Booram, C.V., T.E. Hazen, and R. J. Smith. 1975. Trends and variations in an anaerobic lagoon with recycling. p. 573-540. *In* Managing livestock waste. Proceedings of the International Symposium on Livestock Waste. American Society of Agricultural Engineers, St. Joseph, MI.

Brady, N.C., and R.R. Weil. 1999. The Nature and Property of Soils, 12th Ed. Prentice Hall, New Jersey.

Chang, S.C., and M.L. Jackson. 1957. Fractionation of soil phosphorus. Soil Sci. 84:133-144.

Condron, L.M., J.O. Moir, H. Tiessen, R.H. Newman, and J. W. B. Stewart. 1990. Chemical nature of organic phosphorus in cultivated and uncultivated soils under different environmental conditions. J. Soil Sci. 41:41-50.

Correll, D.L., T.E. Jordan, and D.E. Weller. 1999. Effects of precipitation and air temperature on phosphorus fluxes from Rhode River watersheds. J. Environ. Qual. 28:144-154.

Daniel, T.C., A.N. Sharpley, and J.L. Lemunyon. 1998. Agricultural phosphorus and eutrification: A symposium overview. J. Environ. Qual. 27:251-257.

Day, P.R. 1965. Particle fractionation and particle-size analysis. p. 545-567. *In* C. A. Black (ed.) Methods of soil analysis. Part I. Agron. Monogr. 9. ASA and SSA, Madison, WI.

Dick, W.A., and M.A. Tabatabai. 1977. Determination of orthophosphate in aqueous solutions containing labile organic and inorganic phosphorus compounds. J. Environ. Qual. 6:82-85.

Dormarr, J.F., and G.R. Webster. 1964. Losses inherent in ignition procedures for determing total organic phosphorus. Can. J. Soil Sci. 44:1-6.

Eck,. H., and B.A. Stewart. 1995. Manure. p. 169-198 *In* J. E. Rechcigl (ed.) Environmental aspects of soil amendments. Lewis Publ., Boca Raton, FL.

EPA. 1999. Uncovered Fished Water Reservoirs Guidance Manual. United States Environmental Protection Agency, Office of Water, Washington, DC.

EPA. 2002. National water quality inventory – 2000 report to Congress. EPA 841-F-02-003. Office of Water (4503-T). U.S. Environmental Protection Agency, Washington, DC.

EPA. 2003. National management measures for the control of nonpoint pollution from agriculture. U. S. Environmental Protection Agency. Office of Water, Washington, DC.

Fang, F., P.L. Brezonik, D. J. Mulla, and L. K. Hatch. 2002. Estimating runoff phosphorus losses from calcareous soils in the Minnesota River Basin. J. Environ. Qual. 31:1918-1929.

Ferguson, J.F., D. Jenkins, and J. Eastman. 1973. Calcium phosphate precipitation at slightly alkaline pH values. J. Water Pollution Control Fed. 44:620-631.

Hansen, J.C., B.J. Cade-Menum, and D.G. Straum. 2004. Phosphorus speciation in manure-amended alkaline soils. J. Environ. Qual. 33:1521-1527.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 1999. Soil fertility and fertilizers: An introduction to nutrient management. 6th ed. Prentice Hall, Upper Saddle River, NJ.

He, Z., T.S. Griffin, and C.W. Honeycutt. 2004. Phosphorus distribution in dairy manures. J. Environ. Qual. 33:1528-1534.

Hegman, W., D. Wang, and C. Borer. 1999. Estimation of Lake Champlain Basin nonpoint source phosphorus export. Tech. Rep. No. 31, Lake Champlain Basin Program, Grand Isle, VT.

Jackson, T.L., J. Hay, and D.P. Moore. 1967. The effect of Zn on yield and chemical composition of sweet corn in the Willamette valley. Proc. Am. Soc. Hortic. Sci. 91:462-471.

Jacoby, F.J. 2005. Extractable soil phosphorus, correlated with P forms in soil runoff, and relationships with the Texas P index as a nutrient management tool for CAFOs. Ph.D. Dissertation. Texas A&M University.

Justice, D., N.N. Rabalais, and R.E. Turner. 1995. Stoichiometric nutrient balance and origin of coastal eutrophication. Marine Pollution Bull. 30:41-46.

Kuo, S. 1996. Phosphorus. p. 869-917. *In* J. M. Bigham (ed.) Methods of soil analysis Part 3. Chemical methods. Book series 5. ASA and SSA, Madison, WI.

Lennox, S.D., R.H. Foy, R.V. Smith, and C. Johnson. 1997. Estimating the contribution from agriculture to the phosphorus load in surface water. p. 55-57. *In* H. Tunney (ed.) Phosphorus loss from soil to water. CAB International. Cambridge, MA.

Leytem, A.B., J.T. Sims, and F.J. Coale. 2004. Determination of phosphorus source coefficients for organic phosphorus sources: Laboratory studies. J. Environ. Qual. 33:380-388.

Lindsay, W.L. 1979. Chemical equilibria in soils. John Wiley and Sons Inc. New York. p. 163-205.

McDowell, R.W., and A.N. Sharpley. 2003. Uptake and release of phosphorus from overland flow in a stream environment. J. Environ. Qual. 32:937-948.

Meals, D.W., and L.F. Budd. 1998. Lake Champlain Basin nonpoint source phosphorus assessment. J. Amer. Water Res. Assoc. 34:251-265.

Munns, D.N., and R.L. Fox. 1976. The slow reaction which continues after phosphate adsorption: Kinetics and equilibrium in some tropical soils. Soil Sci. Soc. Am. J. 40:46-51.

Murphy, J., H.P. Riley, F.S. Wantanabe, and S. R. Olsen. 1982. Phosphorus analysis procedure. p. 413-414. *In* A. L. Page (ed.) Methods of soil analysis, Part 2. Chemical and microbial properties. 2^{nd} Ed. ASA and SSA, Madison, WI.

Peterjohn, W.T., and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology. 65:1466-1475.

Peterson, G.W., and R.B. Corey. 1966. A modified Chang and Jackson prodedure for routine fractionation of inorganic soil phosphates. Soil Sci. Soc. Am. Proc. 30:563-565.

Robbins, C.W., D.T. Westermann, and L.L. Freeborn. 1999. Phosphorus forms and extractability from three sources in a recently exposed calcareous subsoil. Soil. Sci. Soc. Am. J. 63:1717-1724.

Ryan, J., D. Curtin, and M.A. Cheema. 1985. Significance of iron oxides and calcium carbonate particle size in phosphate sorption by calcareous soils. Soil Sci. Soc. Am. J. 49:74-76.

Saunders, W. M.H., and E.G. Williams. 1955. Observations on the determination of total organic phosphorus in soils. J. Soil Sci. 6:254-267.

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. Science. 195:260-262.

Schoumans, O.F., and P. Groenendijk. 2000. Modeling soil phosphorus levels and phosphorus leaching from agricultural lands in the Netherlands. J. Environ. Qual. 29:111-116.

Sharpley, A.N. 1985. Depth of surface soil-runoff interaction as affected by rainfall, soil slope and management. Soil Sci. Soc. Am. J. 49:1010-1015.

Sharpley, A.N. 1995. Dependence of runoff on extractable soil phosphorus. J. Environ. Qual. 24:920-926.

Sharpley, A.N., T.C. Daniel, J. T. Sims, and D. H. Pote. 1996. Determining environmentally sound phosphorus levels. J. Soil Water Conserv. 51:160-166.

Sharpley, A.N., T.C. Daniel, and D. R. Edwards. 1993. Phosphorus movement in the landscape. J. Prod. Agric. 6:492-500.

Sharpley, A.N., R.W. McDowell, and J. A. Kleinman. 2004. Amounts, forms, and solubility of phosphorus in soils receiving manure. Soil Sci. Soc. Am. J. 68:2048-2057.

Sharpley, A., and B. Moyer. 2000. Phosphorus forms in manure and compost and their release during simulated rainfall. J. Environ. Qual. 29:1462-1469.

Sharpley, A.N., and S.J. Smith. 1985. Fractionation of inorganic and organic phosphorus in virgin and cultivated soils. Soil Sci. Soc. Am. J. 49:127-130.

Sharpley, A.N., S.J. Smith, B. A. Stewart, and A. C. Mathers. 1984. Forms of phosphorus in soil receiving cattle feedlot waste. J. Environ. Qual. 13:211-215

Sharpley, A.N., W.W. Troeger, and S. J. Smith. 1991. Water quality: The measurement of bioavailable phosphorus in agricultural runoff. J. Environ. Qual. 20:235-238.

Siddique, M.T., and J.S. Robinson. 2003. Phosphorus sorption and availability in soils amended with animal manures and sewage sludge. J. Environ. Qual. 32:1114-1121.

Simard, R.R., S. Beauchemin, and P.M. Haygarth. 2000. Potential for preferential pathways of phosphorus transport. J. Environ. Qual. 29:97-105.

Sims, J.T. 2000. The role of soil testing in environmental risk assessment for phosphorus. p. 57-81 *In* A. N. Sharpley (ed.) Agriculture and phosphorus management. Lewis Publishers, Boca Raton, FL.

Soil Survey Laboratory Methods Manual. Januray, 1996. Soil Survey Investigations Reports No. 42 Version 3.0. National Soil Survey Center NRCS. Lincoln, NE.

Soltanpour, P.N., F. Adams, and A.C. Bennett. 1974. Soil phosphorus availability as measured by displaced soil solutions, calcium-chloride extracts, dilute-acid extracts, and labile phosphorus. Soil. Sci. Soc. Am. J. 51:255-256.

Statistical Packaging for Social Science. 2004. SPSS for Windows. Version 11.0. SPSS Inc., Chicago, IL.

Syers, J.K., M.G. Browman, G.W. Smillie, and R.B. Corey. 1973. Phosphate sorption by soils evaluated by the Langmuir adsorption equation. Soil Sci. Soc. Am. J. 37:358-363.

Tabbara, H. 2003. Phosphorus loss to runoff water twenty-four hours after application of liquid swine manure or fertilizer. J. Environ. Qual. 32:1044-1052.

Tan, K.H. 1996. Soil sampling, preparation and analysis: Determination of available P. p. 157-167. Mercel Dekker Inc. New York.

Torbert, H.A., T.C. Daniel, J.L. Lemunyon, and R.M. Jones. 2002. Relationship of soil test phosphorus and sampling depth to runoff phosphorus in calcareous and noncalareous soils. J. Environ. Qual. 31:1380-1387.

Walker, T.W., and A.F.R. Adams. 1958. Studies on soil organic matter: 1. Influence of phosphorus content of parent materials on accumulations of carbon, nitrogen, sulfur, and organic phosphorus in grassland soils. Soil Sci. 85:307-318.

Williams, J.D.H., J.K. Syers, and R.F. Harris. 1971a. Characterization of inorganic phosphate in non-calcareous lake sediments. Soil Sci. Soc. Am. Proc. 35:556-561.

Williams, J.D.H., J.K. Syers, R.F. Harris, and D.E. Armostrong. 1971b. Fraction of inorganic phosphate in calcareous lake sediments. Soil Sci. Soc. Am. Proc. 35:250-255.

Williams, J.D.H., J.K. Syers, and T.W. Walker. 1976. Fractionation of soil inorganic phosphate by a modification of Chang and Jackson's procedure. Soil Sci. Soc. Am. Proc. 31:736-739.

Williams, J.D.H., and T.W. Walker. 1967. Comaprison of 'ignition' and 'extraction' methods for the determination of organic phosphates in rocks and soils. Plant Soil. 27:457-459.

APPENDIX A

Table A-1. Previously gathered information on soil sites.

Plot	County	Soil Series	pH	Calcareous Class	Crop Management	% cover	SLOPE
L	Erath	Maloterre	7.8	Calcareous	Mulch/ Sorghum	25%	2.2
M	Hamilton	Bosque clay loam occassionally flooded	7.51	Calcareous	Bermuda	100%	7.6
N	Hamilton	Bosque clay loam occassionally flooded	7.51	Calcareous	Bermuda	100%	6.7
O	Erath	Nimrod fine sand, 0-5%	6.36	Noncalcareous	Bermuda	75%	5.9
P	Erath	Nimrod-Arenosa-Patilo fine sands, 3 to 8 %	6.33	Noncalcareous	Bermuda	100%	8.1
Q	Erath	Windthorst soil, 3 to 5%	4.86	Noncalcareous	Bare, Grazed rotational	20%	10.3
S	Erath	Windthorst soil, 3 to 5%	6.87	Noncalcareous	Fallow/ bare	50%	2.1
T	Erath	Windthorst soil, 1 to 8%	6.83	Noncalcareous	Bermuda	100%	3.0
V	Comanche	Sunev clay loam 3-5%	8.1	Calcareous	Corn/ tilled	10%	4.3
W	Comanche	Purves-Bolar association	8.57	Calcareous	Corn/ tilled	10%	2.5

Table A-2. Runoff, proximity to stream, and RUSEL2 values for soils.

Soil	Proximity to Stream	Runoff Class	RUSLE2
L	>2000ft	High	Medium 3-5 t/ac
M	<100 ft	Negligible	Very Low <1 t/ac
N	<100 ft	Negligible	Very Low <1 t/ac
W	1000-1999 ft	High	Very High >10 t/ac
V	1000-1999 ft	Very High	Very High >10 t/ac
O	100-499 ft	High	Very Low <1 t/ac
P	500-999 ft	High	Very Low <1 t/ac
Q	500-999 ft	Very High	Low 1-3 t/ac
S	100-499 ft	Moderate	Low 1-3 t/ac
T	100-499 ft	Moderate	Very Low <1 t/ac

Table A-3. Inorganic fertilizer rates for each soil.

Soil	Inorganic Fertilizer P Application Rate	Inorganic Fertilizer P Application Rate
L	None Applied	None Applied
M	None Applied	None Applied
N	None Applied	None Applied
W	None Applied	None Applied
V	None Applied	None Applied
O	41-90 lb/ac P2O5	41-90 lb/ac P2O5
P	41-90 lb/ac P2O5	41-90 lb/ac P2O5
Q	None Applied	None Applied
S	None Applied	None Applied
T	None Applied	None Applied

Table A-4. Organic fertilizer rates for each soil.

Soil	Organic P Application Rate	Organic P application Method and Timing
L	>150 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours
M	>150 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours
N	>150 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours
W	>150 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours
V	>150 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours
O	>150 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours
P	>150 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours
Q	>150 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours
S	None Applied	None Applied
T	1-40 lbs/ac P2O5	Placed deeper than 2 in. or broadcast and incorporated within 48 hours

Table A-5. Phosphorus test values from previous study (Jacoby, 2005). Extracts used Melich-3 for the Meh-3, and Texas A&M University Extract for TAMU-P.

Plot #	Depth	Meh 3-P	TAMU-P
	cm	mg kg^{-1} soil	mg kg^{-1} soil
L1	0-15	471	665
L1	0-15	526	721
L1	0-15	443	709
M1	0-15	57	122
M1	0-15	83	115
M1	0-15	57	120
N3	0-15	77	155
N3	0-15	79	152
N3	0-15	94	159
O3	0-15	310	402
O3	0-15	310	427
O3	0-15	414	342
P3	0-15	437	588
P3	0-15	408	671
P3	0-15	467	621
Q3	0-15	39	17
Q3	0-15	38	16
Q3	0-15	34	16
S1	0-15	278	283
S1	0-15	270	253
S1	0-15	262	258
T2	0-15	477	607
T2	0-15	463	565
T2	0-15	482	612
V1	0-15	262	367
V1	0-15	270	352
V1	0-15	268	359
W1	0-15	279	488
W1	0-15	297	476
W1	0-15	294	497

Table A-6. Soil organic matter and carbon measurements.

Soil	Depth	Total Organic Carbon	Soil Organic Matter	Soil Inorganic Carbon	Total Carbon
	cm	- - - - - - - - - - - - -	- - - - - mg kg^{-1}	- - - - - - - - - - - - -	- - - - - -
O	0-5	28.7	50.0	1.2	51.2
P	0-5	17.7	31.0	1.9	32.9
Q	0-5	11.1	19.0	0.0	19.0
S	0-5	13.4	23.0	0.1	23.1
T	0-5	23.1	40.0	1.2	41.2
O	5-15	28.7	50.0	1.2	51.2
P	5-15	17.7	31.0	1.9	32.9
Q	5-15	11.1	19.0	0.0	19.0
S	5-15	13.4	23.0	0.1	23.1
T	5-15	23.1	40.0	1.2	41.2
O	0-15	28.7	50.0	1.2	51.2
P	0-15	17.7	31.0	1.9	32.9
Q	0-15	11.1	19.0	0.0	19.0
S	0-15	13.4	23.0	0.1	23.1
T	0-15	23.1	40.0	1.2	41.2
L	0-5	25.2	44.0	48.0	92.0
M	0-5	13.7	24.0	0.0	31.3
N	0-5	16.9	29.0	9.1	38.1
W	0-5	16.4	28.0	8.3	36.3
V	0-5	12.3	21.0	20.4	41.4
L	5-15	25.2	44.0	48.0	92.0
M	5-15	13.7	24.0	0.0	31.3
N	5-15	16.9	29.0	9.1	38.1
W	5-15	16.4	28.0	8.3	36.3
V	5-15	12.3	21.0	20.4	41.4
L	0-15	25.2	44.0	48.0	92.0
M	0-15	13.7	24.0	0.0	31.3
N	0-15	16.9	29.0	9.1	38.1
W	0-15	16.4	28.0	8.3	36.3
V	0-15	12.3	21.0	20.4	41.4

Table A-7. Soil calcite and dolomite data.

Soil	Depth	Calcite	Dolomite
	cm	- - - - - - - - mg kg^{-1}	- - - - - - - - - - - - - - -
O	0-5	10.00	0.00
P	0-5	15.00	1.00
Q	0-5	0.00	0.00
S	0-5	0.00	1.00
T	0-5	9.00	1.00
O	5-15	10.00	0.00
P	5-15	15.00	1.00
Q	5-15	0.00	0.00
S	5-15	0.00	1.00
T	5-15	9.00	1.00
O	0-15	10.00	0.00
P	0-15	15.00	1.00
Q	0-15	0.00	0.00
S	0-15	0.00	1.00
T	0-15	9.00	1.00
L	0-5	408.00	1.00
M	0-5	0.00	0.00
N	0-5	71.00	5.00
W	0-5	56.00	12.00
V	0-5	150.00	18.00
L	5-15	408.00	1.00
M	5-15	0.00	0.00
N	5-15	71.00	5.00
W	5-15	56.00	12.00
V	5-15	150.00	18.00
L	0-15	408.00	1.00
M	0-15	0.00	0.00
N	0-15	71.00	5.00
W	0-15	56.00	12.00
V	0-15	150.00	18.00

Table A-8. Dissolved and total P in runoff from rainfall simulations on each soil site.

Soil	Depth	Total P in Runoff	Dissolved P in Runoff
	cm	- - - - - - - - - - mg kg^{-1}	- -
O	0-5	2.29	2.22
P	0-5	1.56	1.42
Q	0-5	1.62	0.78
S	0-5	2.24	1.81
T	0-5	1.21	1.10
O	5-15	2.29	2.22
P	5-15	1.56	1.42
Q	5-15	1.62	0.78
S	5-15	2.24	1.81
T	5-15	1.21	1.10
O	0-15	2.29	2.22
P	0-15	1.56	1.42
Q	0-15	1.62	0.78
S	0-15	2.24	1.81
T	0-15	1.21	1.10
L	0-5	4.16	3.72
M	0-5	0.54	0.38
N	0-5	1.98	1.29
W	0-5	7.48	5.07
V	0-5	7.13	4.75
L	5-15	4.16	3.72
M	5-15	0.54	0.38
N	5-15	1.98	1.29
W	5-15	7.48	5.07
V	5-15	7.13	4.75
L	0-15	4.16	3.72
M	0-15	0.54	0.38
N	0-15	1.98	1.29
W	0-15	7.48	5.07
V	0-15	7.13	4.75

APPENDIX B

Table B-1. Inorganic basic P (IPB) colorimetric data

			Inorganic Basic P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - - - -
L	0-5	100.00	0.04	0
L	0-5	100.00	0.04	0
L	0-5	100.00	0.04	0
L	5-15	100.00	0.04	0
L	5-15	99.00	0.13	65
L	5-15	100.00	0.04	0
M	0-5	98.00	0.22	112
M	0-5	96.00	0.41	204
M	0-5	96.50	0.36	181
M	5-15	99.00	0.13	65
M	5-15	99.50	0.08	42
M	5-15	100.00	0.04	0
N	0-5	97.50	0.27	135
N	0-5	97.75	0.25	124
N	0-5	98.00	0.22	112
N	5-15	99.50	0.08	42
N	5-15	99.50	0.08	42
N	5-15	99.50	0.08	42
V	0-5	100.00	0.04	0
V	0-5	100.00	0.04	0
V	0-5	100.00	0.04	0
V	5-15	100.00	0.04	0
V	5-15	100.00	0.04	0
V	5-15	100.00	0.04	0
W	0-5	99.00	0.13	65
W	0-5	99.00	0.13	65
W	0-5	98.50	0.18	89
W	5-15	98.50	0.18	89
W	5-15	98.50	0.18	89
W	5-15	99.00	0.13	65

Table B-1 Continued.

			Inorganic Basic P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - - - -
O	0-5	89.50	0.99	496
O	0-5	89.50	0.99	496
O	0-5	88.00	1.13	565
O	5-15	94.00	0.59	294
O	5-15	95.00	0.50	249
O	5-15	94.25	0.56	282
P	0-5	88.75	1.06	530
P	0-5	88.75	1.06	530
P	0-5	88.50	1.08	542
P	5-15	92.00	0.77	383
P	5-15	94.25	0.56	282
P	5-15	93.75	0.61	305
Q	0-5	93.00	0.68	338
Q	0-5	93.50	0.63	316
Q	0-5	91.75	0.79	394
Q	5-15	97.50	0.27	135
Q	5-15	97.25	0.29	147
Q	5-15	97.25	0.29	147
S	0-5	91.00	0.86	428
S	0-5	94.00	0.59	294
S	0-5	96.00	0.41	204
S	5-15	96.00	0.41	204
S	5-15	97.00	0.32	158
S	5-15	95.00	0.50	249
T	0-5	90.00	0.95	473
T	0-5	87.00	1.22	612
T	0-5	87.75	1.15	577
T	5-15	94.00	0.59	294
T	5-15	95.75	0.43	215
T	5-15	95.00	0.50	249

Table B-2. Total basic P (TPB) colorimetric data.

			Total Basic P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - - -
L	0-5	99.50	0.08	11
L	0-5	100.00	0	0
L	0-5	100.00	0	0
L	5-15	100.00	0	0
L	5-15	100.00	0	0
L	5-15	100.00	0	0
M	0-5	98.50	0.18	22
M	0-5	100.00	0	0
M	0-5	98.25	0.20	25
M	5-15	100.00	0	0
M	5-15	100.00	0	0
M	5-15	99.50	0.08	11
N	0-5	98.00	0.22	28
N	0-5	99.00	0.13	16
N	0-5	99.00	0.13	16
N	5-15	99.50	0.08	11
N	5-15	99.25	0.11	13
N	5-15	99.25	0.11	13
V	0-5	100.00	0	0
V	0-5	100.00	0	0
V	0-5	100.00	0	0
V	5-15	100.00	0	0
V	5-15	100.00	0	0
V	5-15	100.00	0	0
W	0-5	99.75	0.06	7
W	0-5	99.00	0.13	16
W	0-5	99.50	0.08	10
W	5-15	99.50	0.08	10
W	5-15	99.25	0.11	13
W	5-15	99.75	0.06	7

Table B-2 Continued.

			Total Basic P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - - -
O	0-5	98.00	0.22	28
O	0-5	97.75	0.25	31
O	0-5	97.50	0.27	34
O	5-15	100.00	0	0
O	5-15	99.00	0.13	16
O	5-15	100.00	0.04	4
P	0-5	97.50	0.27	34
P	0-5	98.50	0.18	22
P	0-5	97.50	0.27	34
P	5-15	99.00	0.13	16
P	5-15	99.50	0.08	10
P	5-15	99.00	0.13	16
Q	0-5	98.50	0.18	22
Q	0-5	98.00	0.22	28
Q	0-5	98.50	0.18	22
Q	5-15	99.00	0.13	16
Q	5-15	99.00	0.13	16
Q	5-15	100.00	0	0
S	0-5	97.50	0.27	34
S	0-5	97.50	0.27	34
S	0-5	98.00	0.22	28
S	5-15	98.50	0.18	22
S	5-15	98.25	0.20	25
S	5-15	98.50	0.18	22
T	0-5	97.50	0.27	34
T	0-5	97.00	0.32	40
T	0-5	97.50	0.27	34
T	5-15	99.00	0.13	16
T	5-15	99.25	0.11	13
T	5-15	98.25	0.20	25

Table B-3. Total Acidic P (TPA) colorimetric data.

			Total Acidic P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - -
L	0-5	43.50	10.48	1310
L	0-5	45.00	9.87	1234
L	0-5	46.50	9.29	1162
L	5-15	54.50	6.65	831
L	5-15	51.50	7.56	945
L	5-15	54.25	6.72	840
M	0-5	71.10	3.10	388
M	0-5	71.10	3.10	388
M	0-5	70.00	3.27	409
M	5-15	83.25	1.59	199
M	5-15	84.00	1.51	189
M	5-15	83.65	1.55	194
N	0-5	66.10	3.95	493
N	0-5	66.00	3.97	496
N	0-5	66.35	3.90	488
N	5-15	78.40	2.12	265
N	5-15	78.35	2.13	266
N	5-15	78.25	2.14	267
V	0-5	62.35	4.70	587
V	0-5	62.00	4.77	596
V	0-5	61.90	4.79	599
V	5-15	65.10	4.14	517
V	5-15	65.75	4.01	502
V	5-15	65.00	4.16	519
W	0-5	58.60	5.56	695
W	0-5	71.75	3.00	376
W	0-5	55.50	6.37	796
W	5-15	59.25	5.40	675
W	5-15	61.00	4.99	624
W	5-15	57.25	5.90	738

Table B-3 Continued.

			Total Acidic P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - mg kg^{-1}	- - - - - - - - - - - - -
O	0-5	58.60	5.56	695
O	0-5	87.40	1.19	148
O	0-5	59.15	5.43	678
O	5-15	75.00	2.55	318
O	5-15	77.25	2.26	282
O	5-15	74.00	2.68	335
P	0-5	53.75	6.87	859
P	0-5	54.20	6.74	842
P	0-5	53.65	6.90	862
P	5-15	70.50	3.20	399
P	5-15	69.25	3.40	425
P	5-15	68.25	3.56	445
Q	0-5	79.00	2.05	256
Q	0-5	81.50	1.77	222
Q	0-5	79.25	2.02	253
Q	5-15	91.15	0.84	105
Q	5-15	91.50	0.81	101
Q	5-15	90.75	0.88	110
S	0-5	61.40	4.90	613
S	0-5	61.25	4.94	617
S	0-5	59.90	5.25	656
S	5-15	72.25	2.93	366
S	5-15	72.50	2.89	362
S	5-15	75.35	2.50	314
T	0-5	39.35	12.32	1540
T	0-5	39.00	12.48	1561
T	0-5	38.15	12.90	1612
T	5-15	73.50	2.75	344
T	5-15	76.00	2.42	302
T	5-15	75.50	2.48	310

Table B-4. Total P (TP), inorganic P (IP), organic basic P (OPB), organic acid P (OPA), and organic P (OP) determined through subtraction method.

Soil	Depth	TP	IP	OPB	OPA	OP
	cm	- - - - - - - -	- - - - - - - -	mg kg^{-1}	- - - - - -	- - - - - -
O	0-5	538	1170	<0.1	<0.1	<0.1
P	0-5	884	1432	<0.1	<0.1	<0.1
Q	0-5	268	592	<0.1	0.9	<0.1
S	0-5	660	2382	<0.1	<0.1	<0.1
T	0-5	1606	1295	<0.1	830.0	311.9
O	5-15	320	601	<0.1	<0.1	<0.1
P	5-15	438	726	<0.1	20.5	<0.1
Q	5-15	118	237	<0.1	11.2	<0.1
S	5-15	370	518	<0.1	32.0	<0.1
T	5-15	337	564	<0.1	7.5	<0.1
O	0-15	393	791	<0.1	<0.1	<0.1
P	0-15	586	961	<0.1	<0.1	<0.1
Q	0-15	168	356	<0.1	7.8	<0.1
S	0-15	467	1140	<0.1	<0.1	<0.1
T	0-15	760	807	<0.1	281.7	<0.1
L	0-5	1242	1378	<0.1	<0.1	<0.1
M	0-5	412	468	<0.1	92.3	<0.1
N	0-5	512	573	<0.1	42.5	<0.1
W	0-5	599	616	<0.1	<0.1	<0.1
V	0-5	634	605	<0.1	90.1	28.4
L	5-15	877	940	<0.1	<0.1	<0.1
M	5-15	200	203	<0.1	32.7	<0.1
N	5-15	279	285	<0.1	22.5	<0.1
W	5-15	517	661	<0.1	<0.1	<0.1
V	5-15	689	520	<0.1	239.4	168.9
L	0-15	998	1086	<0.1	<0.1	<0.1
M	0-15	271	291	<0.1	52.6	<0.1
N	0-15	357	381	<0.1	29.2	<0.1
W	0-15	544	646	<0.1	<0.1	<0.1
V	0-15	671	549	<0.1	189.7	122.1

Table B-5. Colorimetric data for NH_4F-extractable P.

			NH_4F-extractable P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - - - - - - - -
O	0-5	100.00	0	0
O	0-5	100.00	0	0
O	0-5	100.00	0	0
O	5-15	100.00	0	0
O	5-15	100.00	0	0
O	5-15	100.00	0	0
P	0-5	100.00	0	0
P	0-5	100.00	0	0
P	0-5	100.00	0	0
P	5-15	100.00	0	0
P	5-15	100.00	0	0
P	5-15	100.00	0	0
Q	0-5	100.00	0	0
Q	0-5	100.00	0	0
Q	0-5	100.00	0	0
Q	5-15	100.00	0	0
Q	5-15	100.00	0	0
Q	5-15	100.00	0	0
S	0-5	99.50	0.08	42
S	0-5	100.00	0	0
S	0-5	100.00	0	0
S	5-15	99.50	0.08	42
S	5-15	100.00	0	0
S	5-15	100.00	0	0
T	0-5	100.00	0	0
T	0-5	100.00	0	0
T	0-5	100.00	0	0
T	5-15	100.00	0	0
T	5-15	100.00	0	0
T	5-15	100.00	0	0

Table B-6. Colorimetric data of NaOH-extractable P from noncalcareous soil.

			NaOH-extractable P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - - - - - - -
O	0-5	99.50	0.08	42
O	0-5	98.50	0.18	89
O	0-5	99.50	0.08	42
O	5-15	98.50	0.18	89
O	5-15	99.50	0.08	42
O	5-15	100.00	0	0
P	0-5	98.00	0.22	112
P	0-5	97.50	0.27	135
P	0-5	98.00	0.22	112
P	5-15	94.50	0.54	271
P	5-15	95.25	0.48	238
P	5-15	98.00	0.22	112
Q	0-5	96.50	0.36	181
Q	0-5	96.50	0.36	181
Q	0-5	98.00	0.22	112
Q	5-15	99.00	0.13	65
Q	5-15	98.50	0.18	89
Q	5-15	99.00	0.13	65
S	0-5	99.50	0.08	42
S	0-5	99.00	0.13	65
S	0-5	98.25	0.20	100
S	5-15	100.00	0	0
S	5-15	98.50	0.18	89
S	5-15	99.50	0.08	42
T	0-5	98.00	0.22	112
T	0-5	99.25	0.11	54
T	0-5	99.00	0.13	65
T	5-15	98.50	0.18	89
T	5-15	98.00	0.22	112
T	5-15	98.50	0.18	89

Table B-7. Reductant-soluble P colorimetric data.

			Reudctant-Soluble P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - - - - - - - -
L	0-5	96.50	0.36	181
L	0-5	97.00	0.32	158
L	0-5	96.25	0.38	192
L	5-15	97.25	0.29	147
L	5-15	98.75	0.15	77
L	5-15	97.75	0.25	124
M	0-5	99.75	0.06	30
M	0-5	99.00	0.13	65
M	0-5	99.00	0.13	65
M	5-15	98.50	0.18	89
M	5-15	98.00	0.22	112
M	5-15	99.25	0.11	54
N	0-5	98.00	0.22	112
N	0-5	97.00	0.32	158
N	0-5	96.50	0.36	181
N	5-15	100.00	0	0
N	5-15	99.00	0.13	65
N	5-15	98.50	0.18	89
V	0-5	99.25	0.11	54
V	0-5	99.50	0.08	42
V	0-5	99.50	0.08	42
V	5-15	99.60	0.07	37
V	5-15	99.25	0.11	54
V	5-15	99.50	0.08	42
W	0-5	96.25	0.38	192
W	0-5	98.25	0.20	100
W	0-5	99.50	0.08	42
W	5-15	97.25	0.29	147
W	5-15	95.85	0.42	210
W	5-15	97.75	0.25	124

Table B-7 Continued.

			Reductant-Soluble P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - $\mathrm{mg\ kg^{-1}}$	- - - - - - - - - - - - - - - -
O	0-5	100.00	0	0
O	0-5	100.00	0	0
O	0-5	100.00	0	0
O	5-15	100.00	0	0
O	5-15	100.00	0	0
O	5-15	100.00	0	0
P	0-5	100.00	0	0
P	0-5	100.00	0	0
P	0-5	**100.00**	0	0
P	5-15	100.00	0	0
P	5-15	100.00	0	0
P	5-15	100.00	0	0
Q	0-5	100.00	0	0
Q	0-5	100.00	0	0
Q	0-5	100.00	0	0
Q	5-15	100.00	0	0
Q	5-15	100.00	0	0
Q	5-15	100.00	0	0
S	0-5	99.25	0.11	54
S	0-5	100.00	0	0
S	0-5	99.75	0.06	30
S	5-15	100.00	0	0
S	5-15	100.00	0	0
S	5-15	100.00	0	0
T	0-5	100.00	0	0
T	0-5	100.00	0	0
T	0-5	100.00	0	0
T	5-15	100.00	0	0
T	5-15	100.00	0	0
T	5-15	100.00	0	0

Table B-8. Occluded apatite colorimetric data.

			Occluded P	
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	------------ mg kg^{-1}	----------------
L	0-5	64.00	4.35	2177
L	0-5	66.00	3.97	1983
L	0-5	66.00	3.97	1983
L	5-15	68.50	3.52	1761
L	5-15	67.00	3.78	1891
L	5-15	63.50	4.45	2227
M	0-5	79.50	1.99	997
M	0-5	83.70	1.54	772
M	0-5	81.50	1.77	887
M	5-15	89.00	1.04	519
M	5-15	88.50	1.08	542
M	5-15	87.25	1.20	600
N	0-5	77.50	2.23	1115
N	0-5	77.00	2.29	1145
N	0-5	74.40	2.63	1313
N	5-15	81.25	1.80	900
N	5-15	85.50	1.37	683
N	5-15	83.75	1.54	770
V	0-5	70.25	3.23	1617
V	0-5	73.10	2.81	1404
V	0-5	67.25	3.74	1869
V	5-15	75.90	2.43	1214
V	5-15	75.75	2.45	1224
V	5-15	75.00	2.55	1273
W	0-5	64.75	4.20	2102
W	0-5	62.90	4.58	2290
W	0-5	63.00	4.56	2279
W	5-15	65.50	4.06	2030
W	5-15	70.25	3.23	1617
W	5-15	70.00	3.27	1637

Table B-8 Continued.

		Occluded P		
Soil	Depth	Transmittance	P concentration from standard curve	P concentration of soil
	cm	%	- - - - - - - - - - - - - mg kg^{-1}	- - - - - - - - - - - - - - - - -
O	0-5	88.25	1.11	553
O	0-5	87.00	1.22	612
O	0-5	91.50	0.81	402
O	5-15	99.25	0.11	54
O	5-15	99.00	0.13	65
O	5-15	100.00	0	0
P	0-5	81.50	1.77	887
P	0-5	77.25	2.26	1130
P	0-5	84.25	1.49	745
P	5-15	93.00	0.68	338
P	5-15	94.50	0.54	271
P	5-15	95.00	0.50	249
Q	0-5	97.00	0.32	158
Q	0-5	97.50	0.27	135
Q	0-5	97.50	0.27	135
Q	5-15	96.50	0.36	181
Q	5-15	96.75	0.34	170
Q	5-15	97.50	0.27	135
S	0-5	86.50	1.27	635
S	0-5	85.00	1.42	708
S	0-5	81.00	1.83	914
S	5-15	96.00	0.41	204
S	5-15	93.50	0.63	316
S	5-15	90.00	0.95	473
T	0-5	62.00	4.77	2386
T	0-5	51.50	7.56	3779
T	0-5	65.75	4.01	2006
T	5-15	96.75	0.34	170
T	5-15	98.00	0.22	112
T	5-15	96.00	0.41	204

Table B-9. Bioavailable P (BAP) colorimetric data.

Soil	Depth	Transmittance	P Concentration in Solution	P Concentration in Soil*
	cm	%	- - - - - - - - mg kg^{-1}	- - - - - - - - - - - - -
L	0-5	58.5	9.0	359
L	5-15	59.25	8.9	354
L	0-15			356
M	0-5	83	11.3	452
M	5-15	98.5	16.7	667
M	0-15			596
N	0-5	76.5	9.7	388
N	5-15	96.5	15.9	637
N	0-15			554
O	0-5	72	8.9	357
O	5-15	73.5	9.1	366
O	0-15			363
P	0-5	80.5	10.6	425
P	5-15	83.5	11.4	458
P	0-15			447
Q	0-5	65	8.5	338
Q	5-15	92.25	14.3	574
Q	0-15			495
S	0-5	58.75	8.9	357
S	5-15	85.75	12.1	485
S	0-15			443
T	0-5	61.75	8.6	344
T	5-15	65.5	8.5	338
T	0-15			340
V	0-5	77.5	9.9	396
V	5-15	93	14.6	585
V	0-15			522
W	0-5	93	14.6	585
W	5-15	94.5	15.2	607
W	0-15			599

*0-15 cm depths were estimated with the following equation:
(1/3)*(Pconcentration 0-5) + (2/3)*(Pconcentration 5-15)

APPENDIX C

Table C-1. Inorganic acid P (IPA) ICP data.

		Inorganic Acid P	
Soil	Depth	P concentration from ICP	P concentration in soil
	cm	mg L^{-1}	mg kg^{-1}
L	0-5	60.0	1500
L	0-5	60.3	1508
L	0-5	43.0	1075
L	5-15	36.4	910
L	5-15	37.8	945
L	5-15	34.7	866
M	0-5	12.0	300
M	0-5	12.1	303
M	0-5	12.2	305
M	5-15	6.3	158
M	5-15	6.3	158
M	5-15	6.7	168
N	0-5	16.5	413
N	0-5	17.7	443
N	0-5	19.7	493
N	5-15	10.0	251
N	5-15	9.8	244
N	5-15	9.4	236
W	0-5	23.8	596
W	0-5	14.7	368
W	0-5	33.2	831
W	5-15	26.2	656
W	5-15	24.0	600
W	5-15	27.0	675
V	0-5	21.2	530
V	0-5	22.0	550
V	0-5	20.7	517
V	5-15	17.8	444
V	5-15	17.1	428
V	5-15	17.9	447

Table C-1 Continued.

Inorganic Acid P			
Soil	Depth	P concentration from ICP	P concentration in soil
	cm	mg L^{-1}	mg kg^{-1}
S	0-5	25.4	634
S	0-5	24.7	617
S	0-5	28.1	703
S	5-15	14.0	351
S	5-15	13.6	341
S	5-15	11.5	287
P	0-5	33.7	843
P	0-5	36.7	918
P	0-5	37.3	933
P	5-15	15.0	376
P	5-15	16.7	417
P	5-15	16.6	415
Q	0-5	10.2	254
Q	0-5	8.8	221
Q	0-5	10.2	254
Q	5-15	3.7	93
Q	5-15	3.8	96
Q	5-15	3.8	94
T	0-5	79.8	1995
T	0-5	84.7	2118
T	0-5	84.3	2108
T	5-15	13.0	325
T	5-15	12.2	304
T	5-15	12.6	315
O	0-5	28.7	718
O	0-5	31.0	774
O	0-5	29.2	730
O	5-15	12.5	312
O	5-15	11.6	290
O	5-15	13.3	333

Table C-2. Soluble and loosely bound P ICP data.

Soluble and Loosely Bound P			
Soil	Depth	P concentration from ICP	P concentration in soil
	cm	mg L^{-1}	mg kg^{-1}
S	0-5	3.6	358
S	0-5	3.6	363
S	0-5	3.6	358
S	5-15	1.4	138
S	5-15	1.4	141
S	5-15	1.4	139
P	0-5	6.3	628
P	0-5	6.6	661
P	0-5	5.7	566
P	5-15	4.0	400
P	5-15	3.5	351
P	5-15	3.8	378
Q	0-5	0.3	25
Q	0-5	0.3	28
Q	0-5	0.3	27
Q	5-15	0.0	3
Q	5-15	0.0	3
Q	5-15	0.0	3
T	0-5	7.8	776
T	0-5	8.7	871
T	0-5	7.9	787
T	5-15	2.1	205
T	5-15	2.1	206
T	5-15	2.1	209
O	0-5	4.0	397
O	0-5	4.2	423
O	0-5	3.8	380
O	5-15	1.7	164
O	5-15	1.7	171
O	5-15	1.5	150

Table C-3. ICP data for NaOH-extractable P from calcareous soil.

		NaOH-extractable P	
Soil	Depth	P concentration from ICP	P concentration in soil
	cm	mg L^{-1}	mg kg^{-1}
L	0-5	0.9	86
L	0-5	0.8	80
L	0-5	0.8	82
L	5-15	0.7	68
L	5-15	0.7	71
L	5-15	0.7	69
M	0-5	0.8	75
M	0-5	0.7	72
M	0-5	0.7	70
M	5-15	0.2	22
M	5-15	0.2	21
M	5-15	0.2	21
N	0-5	0.7	72
N	0-5	0.7	70
N	0-5	0.7	73
N	5-15	0.3	33
N	5-15	0.3	32
N	5-15	0.3	32
W	0-5	0.4	44
W	0-5	0.4	44
W	0-5	0.4	43
W	5-15	0.4	42
W	5-15	0.4	42
W	5-15	0.5	46
V	0-5	0.3	31
V	0-5	0.3	31
V	0-5	0.3	30
V	5-15	0.3	29
V	5-15	0.3	27
V	5-15	0.3	29

Table C-4. Potassium chloride extractable Mg ICP data.

Soil	Depth	Mg concentration from ICP	Mg concentration in soil*
	cm	mg L^{-1}	mg kg^{-1}
O	0-5	20.8	104
O	5-15	8.5	423
O	0-15		63
P	0-5	19.2	96
P	5-15	9.9	49
P	0-15		65
Q	0-5	27.8	139
Q	5-15	28.9	145
Q	0-15		143
S	0-5	35.0	175
S	5-15	35.5	178
S	0-15		177
T	0-5	64.7	324
T	5-15	29.6	148
T	0-15		206
L	0-5	53.8	269
L	5-15	44.0	220
L	0-15		236
M	0-5	22.0	110
M	5-15	10.7	53
M	0-15		72
N	0-5	38.4	192
N	5-15	19.6	98
N	0-15		129
W	0-5	64.6	323
W	5-15	66.2	331
W	0-15		328
V	0-5	36.6	183
V	5-15	46.1	230
V	0-15		215

*0-15 cm depths were estimated with the following equation:
(1/3)*(Pconcentration 0-5) + (2/3)*(Pconcentration 5-15)

Table C-5. Potassium chloride extractable Ca ICP data.

Soil	Depth	Ca Concentration from ICP	Ca Concentration in soil*
	cm	mg L^{-1}	mg kg^{-1}
O	0-5	151.3	757
O	5-15	84.5	423
O	0-15		534
P	0-5	203.2	1016
P	5-15	110.2	551
P	0-15		706
Q	0-5	340.2	1701
Q	5-15	421.6	2108
Q	0-15		1972
S	0-5	241.8	1209
S	5-15	261.2	1306
S	0-15		1274
T	0-5	222.9	1115
T	5-15	109.2	546
T	0-15		736
L	0-5	199.5	998
L	5-15	192.9	965
L	0-15		976
M	0-5	335.4	1677
M	5-15	281.4	1407
M	0-15		1497
N	0-5	328.3	1642
N	5-15	370.9	1855
N	0-15		1784
W	0-5	291.5	1458
W	5-15	370.7	1854
W	0-15		1722
V	0-5	144.5	723
V	5-15	196.4	982
V	0-15		896

*0-15 cm depths were estimated with the following equation:
(1/3)*(Pconcentration 0-5) + (2/3)*(Pconcentration 5-15)

Table C-6. Potassium chloride extractable Al ICP data.

Soil	Depth	Al Concentration from ICP	Al Concentration in soil*
	cm	mg L^{-1}	mg kg^{-1}
O	0-5	0.2	1
O	5-15	0.4	2
O	0-15		2
P	0-5	0.3	1
P	5-15	0.4	2
P	0-15		2
Q	0-5	3.0	15
Q	5-15	0.0	0
Q	0-15		5
S	0-5	0.0	0
S	5-15	0.0	0
S	0-15		0
T	0-5	0.0	0
T	5-15	0.0	0
T	0-15		0
L	0-5	0.0	0
L	5-15	0.0	0
L	0-15		0
M	0-5	0.0	0
M	5-15	0.0	0
M	0-15		0
N	0-5	0.0	0
N	5-15	0.0	0
N	0-15		0
W	0-5	0.0	0
W	5-15	0.0	0
W	0-15		0
V	0-5	0.0	0
V	5-15	0.0	0
V	0-15		0

*0-15 cm depths were estimated with the following equation:
(1/3)*(Pconcentration 0-5) + (2/3)*(Pconcentration 5-15)

Table C-7. Potassium chloride extractable Fe ICP data.

Soil	Depth	Fe Concentration from ICP	Fe Concentration in soil*
	cm	mg L^{-1}	mg kg^{-1}
O	0-5	0.5	3
O	5-15	0.8	4
O	0-15		4
P	0-5	0.6	3
P	5-15	0.4	2
P	0-15		2
Q	0-5	1.1	6
Q	5-15	0.0	0
Q	0-15		2
S	0-5	0.1	1
S	5-15	0.1	0
S	0-15		0
T	0-5	0.5	2
T	5-15	0.1	1
T	0-15		1
L	0-5	0.1	0
L	5-15	0.1	0
L	0-15		0
M	0-5	0.1	0
M	5-15	0.1	0
M	0-15		0
N	0-5	0.1	0
N	5-15	0.1	0
N	0-15		0
W	0-5	0.1	0
W	5-15	0.1	0
W	0-15		0
V	0-5	0.1	0
V	5-15	0.1	0
V	0-15		0

*0-15 cm depths were estimated with the following equation:
(1/3)*(Pconcentration 0-5) + (2/3)*(Pconcentration 5-15)

Table C-8. Potassium chloride extractable P ICP data.

Soil	Depth	P Concentration from ICP	P Concentration in soil*
	cm	mg L^{-1}	mg kg^{-1}
O	0-5	17.2	86
O	5-15	6.0	30
O	0-15		49
P	0-5	19.7	98
P	5-15	10.7	53
P	0-15		68
Q	0-5	1.9	9
Q	5-15	0.2	1
Q	0-15		4
S	0-5	7.5	37
S	5-15	1.8	9
S	0-15		18
T	0-5	18.0	90
T	5-15	5.7	28
T	0-15		49
L	0-5	5.2	26
L	5-15	4.0	20
L	0-15		22
M	0-5	3.2	16
M	5-15	0.5	2
M	0-15		7
N	0-5	2.8	14
N	5-15	0.7	3
N	0-15		7
W	0-5	1.3	7
W	5-15	1.5	8
W	0-15		7
V	0-5	2.2	11
V	5-15	1.0	5
V	0-15		7

*0-15 cm depths were estimated with the following equation:
(1/3)*(Pconcentration 0-5) + (2/3)*(Pconcentration 5-15)

APPENDIX D

Table D-1. Ammonium oxalate raw data.

Soil	Depth*	Fe	Al	Si
	cm	- - - - - - - - - - - -	- - - - mg kg^{-1} - - -	- - - - - - - - - - - -
O	0-5	413	202	101
O	5-15	290	100	100
O	0-15	331	134	100
P	0-5	423	302	202
P	5-15	245	200	200
P	0-15	304	234	201
Q	0-5	1470	1369	254
Q	5-15	1838	1583	306
Q	0-15	1715	1511	289
S	0-5	1012	708	506
S	5-15	1064	810	507
S	0-15	1047	776	507
T	0-5	1164	506	506
T	5-15	653	351	301
T	0-15	823	403	370
L	0-5	709	1114	608
L	5-15	708	1112	404
L	0-15	708	1113	472
M	0-5	415	608	405
M	5-15	389	607	404
M	0-15	398	607	404
N	0-5	539	814	509
N	5-15	533	813	610
N	0-15	535	813	576
W	0-5	870	1228	818
W	5-15	821	1334	821
W	0-15	837	1299	820
V	0-5	607	1011	404
V	5-15	709	1317	456
V	0-15	675	1215	439

* 0-15 cm depth was estimated with the following equations:
(1/3)*(concentration 0-5) + (2/3)*(concentration 5-15)

APPENDIX E

Table E-1. Solubility equations and log K values.

Mineral	Solubility Equation	log K
	Orthophosphoric Acid	
Orthophosphate	$H_2PO_4^- \leftrightarrow H^+ + HPO_4^=$	-7.20
	Aluminum Phosphates	
Berlinite	$AlPO_4 + 2H^+ \leftrightarrow Al^{3+} + H_2PO_4^-$	0.50
	$AlPO_4 + H^+ \leftrightarrow Al^{3+} + HPO_4^=$	-6.70
Variscite	$AlPO_4 \cdot 2H_2O + 2H^+ \leftrightarrow Al^{3+} + H_2PO_4^- + 2H_2O$	-2.50
	$AlPO_4 \cdot 2H_2O + H^+ \leftrightarrow Al^{3+} + HPO_4^= + 2H_2O$	-9.70
	Iron Phosphates	
Iron Phosphate	$FePO_4 + 2H^+ \leftrightarrow Fe^{3+} + H_2PO_4^-$	-5.37
	$FePO_4 + H^+ \leftrightarrow Fe^{3+} + HPO_4^=$	-12.57
Strengite	$FePO_4 \cdot H_2O + 2H^+ \leftrightarrow Fe^{3+} + H_2PO_4^- + 2H_2O$	-6.85
	$FePO_4 \cdot H_2O + H^+ \leftrightarrow Fe^{3+} + HPO_4^= + 2H_2O$	-14.05
Vivianite	$Fe_3(PO_4) \cdot 8H_2O + 4H^+ \leftrightarrow 3Fe^{3+} + 2H_2PO_4^- + 8H_2O$	3.11
	$Fe_3(PO_4) \cdot 8H_2O + 2H^+ \leftrightarrow 3Fe^{3+} + 2HPO_4^= + 8H_2O$	-11.29
	Calcium Phosphates	
Monocalcium Phosphate (MCP)	$Ca(H_2PO_4)_2 \cdot H_2O \leftrightarrow Ca^{2+} + 2H_2PO_4^- + H_2O$	-1.15
	$Ca(H_2PO_4)_2 \cdot H_2O \leftrightarrow Ca^{2+} + 2HPO_4^= + 2H^+ + H_2O$	-15.55
Brushite	$CaHPO_4 \cdot 2H_2O + H^+ \leftrightarrow Ca^{2+} + H_2PO_4^- + 2H_2O$	0.63
	$CaHPO_4 \cdot 2H_2O \leftrightarrow Ca^{2+} + HPO_4^= + 2H_2O$	-6.57
Monetite	$CaHPO_4 + H^+ \leftrightarrow Ca^{2+} + H_2PO_4^-$	0.30
	$CaHPO_4 \leftrightarrow Ca^{2+} + HPO_4^=$	-6.90
Octocalcium Phosphate (OCP)	$Ca_4H(PO_4)_3 \cdot 2.5H_2O + 5H^+ \leftrightarrow 4Ca^{2+} + 3H_2PO_4^- + 2.5H_2O$	11.76
	$Ca_4H(PO_4)_3 \cdot 2.5H_2O + 2H^+ \leftrightarrow 4Ca^{2+} + 3HPO_4^= + 2.5H_2O$	-9.84

Table E-1 Continued.

Mineral	Solubility Equation	log K
Alpha Calcium	$\alpha\text{-}Ca_3(PO_4)_2(c) + 4H^+ \leftrightarrow 3Ca^{2+} + 2H_2PO_4^-$	13.61
Phosphate	$\alpha\text{-}Ca_3(PO_4)_2(c) + 2H^+ \leftrightarrow 3Ca^{2+} + 2HPO_4^{=}$	-0.79
Beta Calcium	$\beta\text{-}Ca_3(PO_4)_2(c) + 4H^+ \leftrightarrow 3Ca^{2+} + 2H_2PO_4^-$	10.18
Phosphate	$\beta\text{-}Ca_3(PO_4)_2(c) + 2H^+ \leftrightarrow 3Ca^{2+} + 2HPO_4^{=}$	-4.22
Hydroxapatite	$Ca_5(PO_4)_3OH + 7H^+ \leftrightarrow 5Ca^{2+} + 3H_2PO_4^- + H_2O$	14.46
	$Ca_5(PO_4)_3OH + 4H^+ \leftrightarrow 5Ca^{2+} + 3HPO_4^{=} + H_2O$	-7.14
	Magnesium Phosphates	
Newberryite	$MgHPO_4 \cdot 3H_2O + H^+ \leftrightarrow Mg^{2+} + H_2PO_4^- + 3H_2O$	1.38
	$MgHPO_4 \cdot 3H_2O \leftrightarrow Mg^{2+} + HPO_4^{=} + 3H_2O$	-5.82
Magnesium	$Mg_3(PO_4)_2(c) + 4H^+ \leftrightarrow 3Mg^{2+} + 2H_2PO_4^-$	24.51
Phosphate	$Mg_3(PO_4)_2(c) + 2H^+ \leftrightarrow 3Mg^{2+} + 2HPO_4^{=}$	-5.82
Bobierrite	$Mg_3(PO_4)_2 \cdot 8H_2O + 4H^+ \leftrightarrow 3Mg^{2+} + 2H_2PO_4^- + 8H_2O$	14.10
	$Mg_3(PO_4)_2 \cdot 8H_2O + 2H^+ \leftrightarrow 3Mg^{2+} + 2HPO_4^{=} + 8H_2O$	-0.30
Hydrated Magnesium	$Mg_3(PO_4)_2 \cdot 22H_2O + 4H^+ \leftrightarrow 3Mg^{2+} + 2H_2PO_4^- + 22H_2O$	16.01
Phosphate	$Mg_3(PO_4)_2 \cdot 22H_2O + 2H^+ \leftrightarrow 3Mg^{2+} + 2HPO_4^{=} + 22H_2O$	1.61

VITA

Name: Laura Elizabeth Harstad

Education:

Texas A&M University, B.S.: Plant and Environmental Soil Science, with an emphasis in Soil Science

Permanent Mailing Address:

2007 Southgate Blvd. #4, Houston, TX, 77030, U.S.A