SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

INFORMATION/EDUCATIONITRAINING/DEMONSTRATION PROJECT

FINAL REPORT

Manure Management BMPs Based on Soil Phosphorus

by

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This project was conducted in cooperation with the state of South Dakota and the United States Environmental Protection Agency, Region 8.

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EXECUTIVE SUMMARY

PROJECT TITLE: Manure Management BMPs Based on Soil Phosphorus

PROJECT START DATE: April 14, 2002

PROJECT COMPLETION DATE: June 30, 2005

FUNDING:

	Original Budget	Expended
EPA 319	$112,000.00	$112,000.00
Local Match (SDSU Plant Science and WRI)	$ 75,434.00	$ 75,434.00
SDSU CES	$ 12,000.00	$ 12,000.00
USGS 104b		$ 27,936.13
SD Corn Utilization Council		$ 40,000.00
SD Pork Producers Council		$ 10,000.00
SD AES		$ 12,652.00
SDSU Plant Science Dept.		$ 27,438.67
TOTAL:	**$199,434.00**	**$317,460.80**

SUMMARY ACCOMPLISHMENTS:

The goal of the project was to reduce phosphorus (P) loading in South Dakota by characterizing the P loading contributions of South Dakota soils and improving manure management strategies by better understanding the relationships that exist among soil test phosphorus (STP), saturation P, and runoff P for select benchmark soils. Information gained during the project was used to develop improved manure management BMPs based on soil and runoff P relationships. Stakeholder education and communication of effective manure management to livestock producers was a component of the project.

The project determined correlations between STP and runoff P for five soils located across eastern South Dakota. This was two more than the three soil series planned in the original project. Other accomplishments included evaluating the correlations among P saturation and soil test P, and surface runoff P for the five benchmark soils. The data was used to develop manure management BMPs and guidelines to improve manure application strategies and protect water quality. This project was a major step to understanding sources of nonpoint source nutrient loading of South Dakota's water resources. Information collected on South Dakota soils was essential for producer acceptance of phosphorus-based manure management.

The Cooperative Extension Service (CES) was an important component of this project. The SDSU CES has developed extensive statewide contacts with livestock and other producers.

This project used these CES programs and contacts to the fullest extent possible to conduct information transfer about the improved manure management BMPs developed.

A total of three field day demonstration events were conducted during summer 2003 and 2004 at the NE research farm and at Dakota Fest in Mitchell SD for a total of three field day events and nine demonstrations. The field day demonstrations were conducted at different field sites and required separate simulator setups, whereas the nine rainfall demonstrations were associated solely with Dakota Fest and were conducted periodically throughout the day. Demonstrations and seminars at SDSU were also conducted for the P group agency personnel.

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INTRODUCTION

At the inception of this project, South Dakota based land applications of manure on nitrogen needs of the crop with no consideration given to crop P requirements. This practice can result in excessive phosphorus additions since the P/N ratio in most manure is usually much higher than the P/N ratio required by plants (Pote et al., 1996). For instance, Pote et al. (1996) discussed that when manure was applied to satisfy N needs for fescue (*festuca arundiacea*) production in northwest Arkansas, an excess of 40, 37, and 17 kg ha^{-1} of P was applied annually using poultry, swine or dairy manure, respectively. The result of over-application of P is increased soil test P (STP) levels (Gelderman et al., 1999; Kingery et al., 1994; Sharpley, 1995; Vivekanandan and Fixen, 1990; Meek et al., 1982). This is particularly evident where beef feedlot manure is used since almost all the N is in organic forms. Only about one third of the N in organic form is available to the crop during the year of application. Therefore, to supply enough available N for the crop, three times the amount required by the crop must be applied, dramatically increasing the over-application of P (Gerwing and Gelderman, 1985).

South Dakota data (SDSU – Soil Testing Laboratory) shows a STP increase from 18 mg P Kg^{-1} in 1985 to 40 mg P Kg^{-1} in 2000 (Table 1) on fields that receive repeated manure applications. Moreover, nearly 60% of the soil samples taken from fields that received manure applications were considered to have very high agronomic STP levels (Fig. 1). The SD Cattlemen's Association, Corn Utilization Council, and the SD Pork Producers Council were sufficiently concerned about the phosphorus issue that they supported a literature review to gather information and identify data gaps so that needed information may be clearly defined (German et al., 2000). Much of the information reviewed supported the hypothesis that a direct correlation exists between STP and runoff P (Hooda et al., 1999; Pote et al., 1996; Sharpley, 1995; Schreiber, 1988). It has been found however, that depending on soil type, various management systems and site hydrology, STP alone may not be a reliable estimator of runoff P (Cruse et al., 2001; Pote et al., 1999; Daniel et al., 1993). Consequently, studying the relationship that exists among P saturation, STP, and runoff P (sediment and dissolved P) of select benchmark (extensive or dominant) soils of South Dakota is a critical first step in understanding soil P contributions to P loading in surface water resources of South Dakota.

Table 1. Average change in soil test P from fields with manure, Soil Testing Lab, SDSU.

Years	No. of Samples	Olson P
		----ppm----
1985-1992	302	18*
1993-1995	21	32*
1996-2000	135	40

*Equivalent Olsen test (Bray P x 0.67).

Much of the information available concerning STP and runoff P relationships was gained from data collected on the more weathered soils in the eastern and southeastern United States, and on soils that had received poultry manure applications (German et al., 2000). Soil test phosphorus and runoff P correlations have not been evaluated for upper mid-western soils receiving manure from the major livestock enterprises of the region (i.e., beef, dairy and swine). This project was a major step to understanding nutrient loading to water resources of South Dakota. Information collected on South Dakota soils was essential for producer acceptance of phosphorus-based manure management.

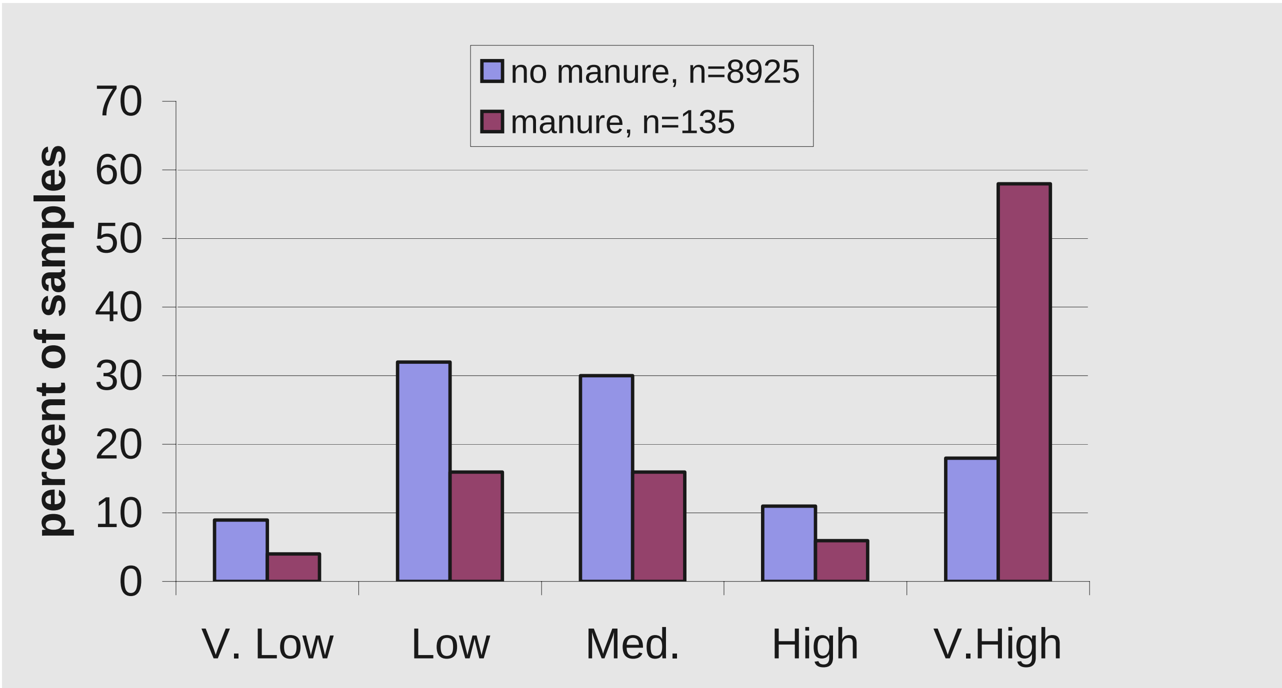


Figure 1. Phosphorus soil test distribution from manure application. (Based on data from the South Dakota Soil Testing Laboratory; crop year 2000)

The extent to which manure application affects P loading of surface water was unknown for the benchmark soils of South Dakota. Certain soils in South Dakota have the capacity to retain higher levels of added P in “fixed” forms, and with proper erosion control, may be much less subject to P loss. Conversely, soils with a low capacity to retain P against the forces of dissolution or erosion would be major solution and sediment sources of P. These soil types have not been identified in South Dakota. This project began characterizing the relationships between STP, P sorption saturation, and runoff P (total and dissolved reactive P) for five South Dakota benchmark soils. The information gathered from this project not only benefits the major lakes of the upper Big Sioux watershed, but helps environmental stakeholders and soil fertility managers make improved manure management decisions for other priority watersheds and their associated sub-basins for the entire state of South Dakota. This project was a vital first step in reducing P loading to South Dakota’s surface water resources by providing effective best management practices (BMPs) for improved manure application strategies.

The project has statewide application. The data collected is being used to improve manure management BMPs in South Dakota, and was the basis for P-index development. An index will help assess the risk of P delivery to surface waters and assist landowners/users in making informed management decisions regarding manure application. An index is also necessary in anticipation of revised state and federal waste management requirements. Since the project maintained strict adherence to the National Phosphorus Project Protocol (Appendix 1), data generated during the project has national significance and could be incorporated as part of the national P runoff database. The database is used to establish national pollution control regulations concerning P application to land resources.

A 319 Nonpoint Source Watershed Project (Big Sioux Project) was initiated in 1994 by the City of Watertown, SD and the South Dakota Department of Environment and Natural Resources to restore the full beneficial uses of Lake Kampeska. The project, subsequently expanded to include much of the upper Big Sioux watershed area, is designed to reduce nutrient and sediment loads entering Lake Kampeska, Pelican Lake, and their associated sub-basins. In order for the Upper Big Sioux Watershed Project to reach its objectives, information concerning the soils capacity to retain P from manure applications was needed.

There are several benchmark (dominant) soils in the Upper Big Sioux watershed. Each of these soils may have a different capacity to adsorb and retain P against dissolution, aggregate destruction, and loading to surface water resources. The efforts of the Upper Big Sioux Project and the Manure Management Information and Education project were complementary and vital to the support of Lakes Kampeska and Pelican. The information generated is transferable to other natural water resources of South Dakota by developing improved manure management BMPs that can be used in all watersheds in South Dakota.

The goal of the project was to reduce P loading in South Dakota by characterizing the P loading contributions of South Dakota soils and improving manure management strategies by better understanding the relationships that exist among soil test phosphorus (STP), saturation P, and runoff P for select benchmark soils. The uncertainty associated with the P loss potential of South Dakota soils has generated considerable interest from both industry and extension educators alike (Appendix 2). Stakeholder education and communication of effective manure management have made livestock producers more cognizant of strategies needed to reduce P loading to surface water resources and eutrophication of lakes statewide.

The project, in cooperation with the Upper Big Sioux 319 watershed project, was committed to reducing long-term P loading of South Dakota waters from animal manure application. This was accomplished by evaluating the correlations among P saturation, soil test P, and surface runoff P. These data provided information concerning the maximum P sorption capacity of five soils located across eastern South Dakota. In addition, the project provided correlations between STP and runoff P, which are needed to develop improved manure application strategies and guidelines.

The activities included in this project were performed on the Poinsett (Fine-silty, mixed, superactive, frigid Calcic Hapludolls), Kranzburg (fine-silty, mixed, superactive, frigid Calcic Hapludolls), and Barnes (fine-loamy, mixed, superactive, frigid Calcic Hapludolls) soil series located in the Upper Big Sioux watershed (Hydrologic Unit Codes: 10170202010, 10170302020, 10170202030, 07020001180, 02020001160, and 10160010020) and on the Vienna (fine-loamy, mixed, superactive, frigid Calcic Hapludolls) and Moody (fine-silty, mixed, superactive, mesic Udic Haplustollssoils) located in the Brookings and Del Rapids areas of east central South Dakota.

PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

The goal of the project was to reduce P loading to surface waters in South Dakota by characterizing the P loading contributions of South Dakota soils and improving manure management strategies. This goal was attained by evaluating the correlations among P saturation, soil test P, and surface runoff P for three soils in the Upper Big Sioux watershed, and two other dominant glacial till soils of eastern South Dakota (i.e., Moody and Vienna soil series). This information was limited for South Dakota soils and was vital for educating area producers and extension educators on proper manure management. In addition, this database will serve as a foundation to future P-indexing and manure management system development for the state of South Dakota.

The Upper Big Sioux area was chosen because the soils represent major agricultural soils of the state and is a critical risk area for P loss. This information will increase the level of technical assistance available to improve manure application strategies statewide. The information gathered concerning BMPs for improved manure management has been transferred to state livestock producers, extension educators, commodity groups, and environmental stakeholders via the Cooperative Extensive Service and the South Dakota Soil Extension Specialist. This will alleviate environmental degradation of surface water resources in South Dakota and lake eutrophication.

The project, in cooperation with the Upper Big Sioux 319 project, was designed to reduce long-term P loading from animal manure applications. This project was a major step to understanding sources of nonpoint source nutrient loading of South Dakota's water resources. Information collected on South Dakota soils is essential for producer acceptance of phosphorus-based manure management.

The goal was attained by reaching the following three objectives:

1. Establish laboratory correlations among STP, runoff P, and P saturation for soils collected from areas within the upper Big Sioux watershed that range in STP levels from low to high.

2. Validate correlations established in the laboratory by conducting *in situ* rainfall simulation in the field.

3. Provide manure management education to extension educators and livestock producers.

Activities completed to reach objective are described below. A milestone comparison table appears at the end of this section.

Objective 1: Establish laboratory correlations among STP, runoff P, and P saturation for soils collected from areas within the upper Big Sioux watershed that range in STP levels from low to high.

According to the National Resources Conservation Service (NRCS), the state of South Dakota contains approximately 33 benchmark (dominant or extensive soil types) soils. Of these 33 soils, three dominate the upper Big Sioux watershed area: Barnes, Kransburg, and Poinsett. Ten conventionally tilled, cropland areas were identified for each of the three benchmark soils for a total of 30 evaluation sites. These sites had similar slope and topography and varied from low to high agronomic soil test phosphorus (STP). An average of 40 surface soil samples (0-15 cm) were collected and prepared for a routine analysis by the Soils Testing Laboratory at South Dakota State University. The routine analyses established baseline chemical characteristics and were used to identify the 30 evaluation sites. The identified field sites consisted of areas that have had long-term manure applications (manure disposal) or were directly adjacent to an animal feeding lot.

Soil associations SD111, SD126, SD129, and SD130 contain predominantly the Barnes, Kranzburg, and Poinsett soil series (USDA-NRCS, 2000) and thus served as the primary site locations. All field evaluation sites were identified and established within the tilled, cropland areas of the watershed and within those areas containing the benchmark soils of interest.

The protocol for the National Research Project for Simulated Rainfall-Surface Runoff Studies was followed to complete Objective 1 (Appendix 1). A rainfall simulator, constructed according to the National protocol (Appendix 1) by Joern Inc., Purdue University, was tested and calibrated prior to the start of this study. Runoff boxes were constructed according to the National protocol (Appendix 1) and used to conduct indoor rainfall simulation to establish STP, runoff P (dissolved and sediment P), and saturation P correlations. Composite surface soil samples (7.5 cm) were collected from the 10 field sites established for each of the benchmark soils for a total of 30 samples. Soil test phosphorus was determined on each of the 30 samples prior to laboratory simulation using the standard Olsen P procedure (Olsen et al., 1954; Soil Testing Procedures, 1995). Each of the 30 samples were packed into three different runoff boxes. The runoff events were evaluated in triplicate. All soil was packed to approximate field bulk density in accordance with National Protocol (Appendix 1). Rainfall simulation, runoff collection, and chemical analyses were also performed according to the National protocol (Appendix 1).

Ninety runoff water samples (30 soils x 3 replicates) were analyzed for total and dissolved P fractions according to the National Protocol. All runoff samples were analyzed by sulfuric acid/persulfate digestion and ascorbic acid reduction as described in section 4500-P of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1998) by South Dakota State University (SDSU) Analytical Services. Soil test phosphorus (STP) and soil P saturation correlations were evaluated to ascertain how an environmental indicator such as soil P saturation may affect the risk of P loss to surface water.

Soil P sorption capacity and the extent of P saturation were determined and correlated to runoff P. Because of the calcareous nature of most South Dakota soils, saturation P may be best defined as initial STP content (mg kg^{-1}) divided by P_{MAX} (mg kg^{-1}) and multiplied by 100 (Pote et al., 1999). The P_{MAX} is the maximum amount of P that could be adsorbed by the soil and is defined as

$$P_{MAX} = (PSI + 52.9)/0.5 \quad (1)$$

where PSI is a single-point P sorption index described by Pierzynski (2000). The PSI is calculated as

$$PSI = X(\log PF)^{-1} \quad (2)$$

where X is P sorbed (mg kg^{-1}) = [(PI)(V) – (PF)(V)] (kg of soil)$^{-1}$, PI is initial P concentration in sorption solution (mg L^{-1}), V is the volume of P sorption solution (L), and PF is the final P concentration in solution (mg L^{-1}). The PSI method, as opposed to the oxalate extraction procedure, which is the most widely reported P saturation index (Kleinman et al., 1999), may yield better relationships between STP and saturation P. The oxalate procedure is used to extract P in acidic soils that contain large amounts of noncrystalline Fe and Al minerals. Iron and Al oxides are the primary mechanism controlling P adsorption-precipitation in acidic soils (Kleinman et al., 1999). South Dakota soils are calcareous in nature and do not contain significant amounts of these acidifying minerals. Therefore, P adsorption-precipitation and release to soil solution may be more a function of inner-sphere complexation with surface functional groups and calcium phosphate precipitation.

Relationships among STP, runoff P, and saturation P were determined by the method of least squares through standard SAS regression analysis (SAS Institute, 1999). Regressions and correlation coefficients were determined for each benchmark soil. Relationships were determined between STP and runoff P, and P saturation and runoff P within and between each of the benchmark soils (Appendix 1).

Based on previous research, positive correlations were expected to exist between STP and runoff P and between STP and saturation P. However, because of the calcareous nature of South Dakota soils, occluded P, and differences in soil chemistry, relationships needed to be verified. Objective 1 was a vital first step in understanding the effects that manure application and STP have on P loss to surface water resources in South Dakota soils.

As a consequence of additional funding by the SD Corn Utilization Council, United States Geological Survey-State Water Resources Institute Program (USGS-SWRIP), and the SD Pork Producers Council, this project was able to evaluate two additional soils. These soils were the Vienna (fine-loamy, mixed, superactive, frigid Calcic Hapludolls) and Moody (fine-silty, mixed, superactive, mesic Udic Haplustollssoils) series located around the Brookings and Del Rapids areas of South Dakota, respectively. These soils will be addressed in this section and Section 2.1 Planned and Actual Milestones, Products, and Completion Dates. All results related to these additional soils will be discussed henceforth. Products and milestones will be discussed in terms of what was planned and what was actually produced or completed (i.e., planned and actual products and milestones).

Task 1: Identify 10 evaluation field sites for each of three benchmark soils that have similar slope and topography and vary from low to high agronomic STP.

Figure 2. Soil Scientist with the NRCS taking soil cores to verify soil type.

Product 1: *Planned* – Thirty (30) evaluation sites (10 sites/benchmark soil x 3 benchmark soils).

Actual – Fifty (50) evaluation sites (10 sites/benchmark soil x 5 benchmark soils). The identification of field evaluation sites was accomplished by collecting approximately 90 surface soil samples (0-15 cm) from cropland soils (Barnes, Kranzburg, Poinsett, Moody and Vienna series) in the Upper Big Sioux Watershed and around the Brookings and Dell Rapids areas of South Dakota. Natural Resources Conservation Service (NRCS) personnel helped verify the soil types (Fig 2). The sites were located in areas that have had long-term manure applications (manure disposal) or were directly adjacent to an animal feeding lot. These sites were used for field rainfall simulation. Soils collected from the sites, with the exception of the Moody soil, were also used for laboratory simulation studies. Funding was not sufficient to complete the moody soil lab simulation. A Global Positioning System with a Hand-held Geographical Information Software was used to locate and record field positions (Fig. 3).

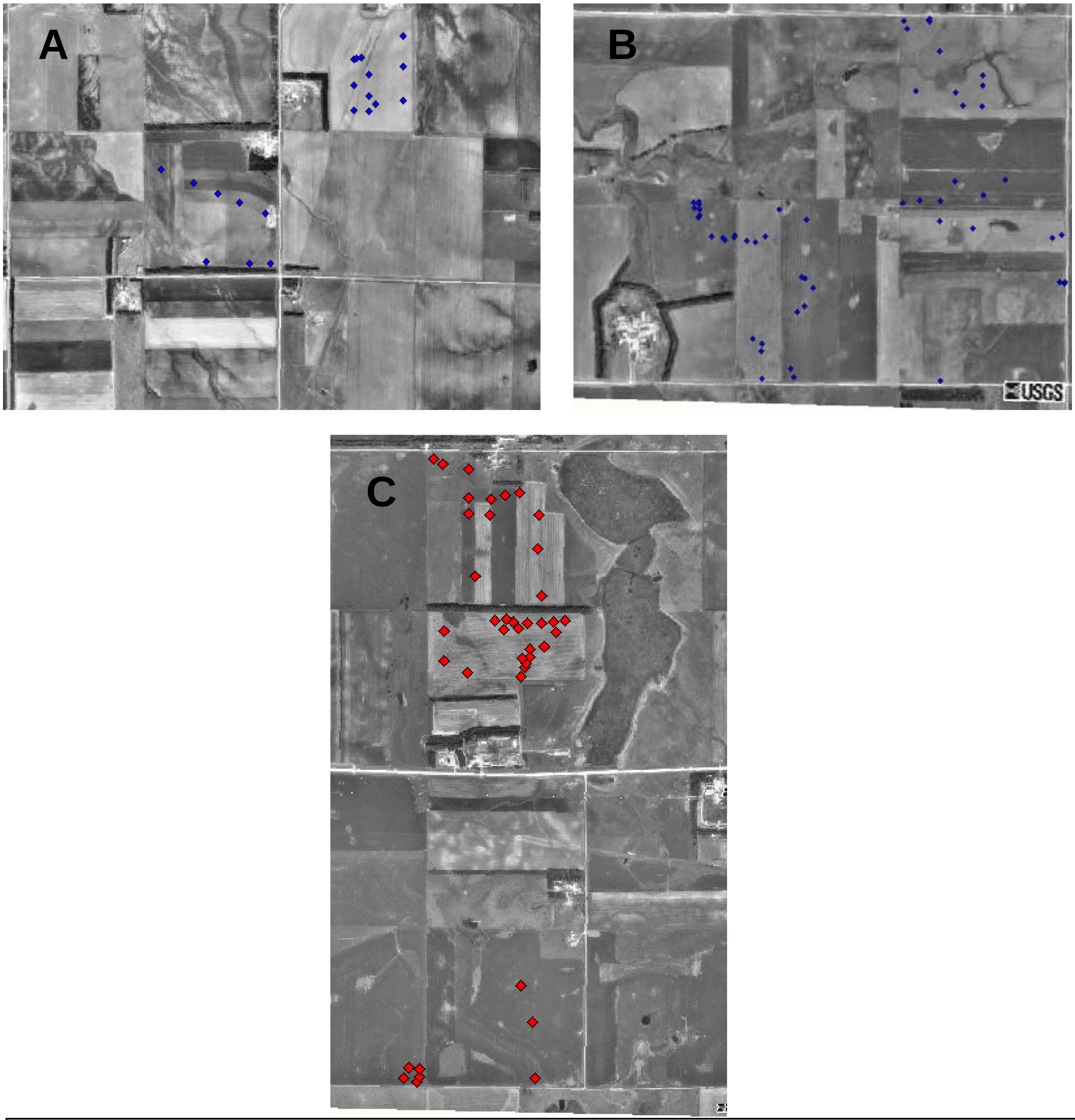


Figure 3. HGIS depiction of field sites for the Kranzburg (A), Barnes (B), and Poinsett (C) soil series.

Milestones: *Planned* – Identify ten evaluation sites per each of three benchmark soils (total evaluation sites = 30) by October, 2002.

Actual – Ten evaluation sites per each of five benchmark soils (total evaluation sites = 50) was completed by April 2005.

Task 2: Conduct indoor (laboratory) rainfall simulation and analyze soil and runoff water samples.

Product 2: *Planned* – P-sorption capacity and P-saturation percentages of bulk composite surface soil samples (7.5 cm) from the 10 field sites established for each of the benchmark soils (total of 30 samples).

Actual – P-sorption capacity and P-saturation percentages of bulk composite surface soil samples (7.5 cm) from the ten field sites established for each of five benchmark soils (total of 50 samples). Composite surface soil samples (7.5 cm) from the ten field sites established for each of the benchmark soils were collected to pack into soil boxes. Fifty soil samples representing five benchmark soils were collected. The rainfall simulator was tested and calibrated. The rest included an evaluation of both rainfall intensity and distribution. Nine runoff boxes were constructed from 3/8 inch PVC sheets. Soils collected, with the exception of the Moody soil, were used for laboratory simulation.

Milestones: *Planned* – Samples collected by October 2002. Laboratory P sorption and saturation percentages for the first benchmark soil would be completed by September 2003. The second and third benchmark soils will be completed by March 2004.

Actual – All samples for P saturation determination and indoor rain simulation were collected by May 2005 (5 soils x 10 sites per soil = 50 samples).

Product 3: *Planned* – Soil test phosphorous, P-saturation, and runoff P correlations for laboratory simulations.

Figure 4. Runoff boxes used for indoor rainfall simulation.

Actual – Soil test phosphorous, P-saturation, and runoff P correlations based on laboratory simulations for the Vienna, Kranzburg, Poinsett, and Barnes soil series. Ten field sites per soil series, with the exception of the Kranzburg soil which consisted of 9 evaluations sites (i.e., the farmer cooperator inadvertently spread manure on one site rendering it unusable). Samples were collected from the field immediately following field simulations, packed into runoff boxes (Fig. 4), and subjected to indoor rain simulation according to the National Protocol (Fig. 5 and Appendix 1). Four soil series x 10 sites per series (except Kranzburg at 9 sites) = forty sites and four correlations for each of STP/runoff P and P saturation/runoff P (Fig. 6 A & B). Funding was not available to conduct indoor evaluations for the Moody soil.

Milestones: *Planned* – Correlations for the first benchmark soil will be completed by September 2003. The second and third benchmark soils will be completed by March 2004.

Actual – Laboratory correlations for the Vienna soil was completed by April, 2003. Laboratory correlations for the Kranzburg and Poinsett soils and for the Barnes soil were completed by September 2004, and October 2005, respectively.

Figure 6 depicts the relationships between STP and surface runoff TDP (A) and P sorption saturation percentage and surface runoff TDP (B) for the Vienna, Kranzburg, Poinsett, and Barnes soil series as determined by indoor rainfall simulation. A strong linear relationship between STP and TDP exists among all soil types (significant at the 0.001 probability level).

The relationship found indicates that continued additions of either manure or fertilizer P will result in increased P loss to surface water resources, and that the soils are not infinite sinks for added P.

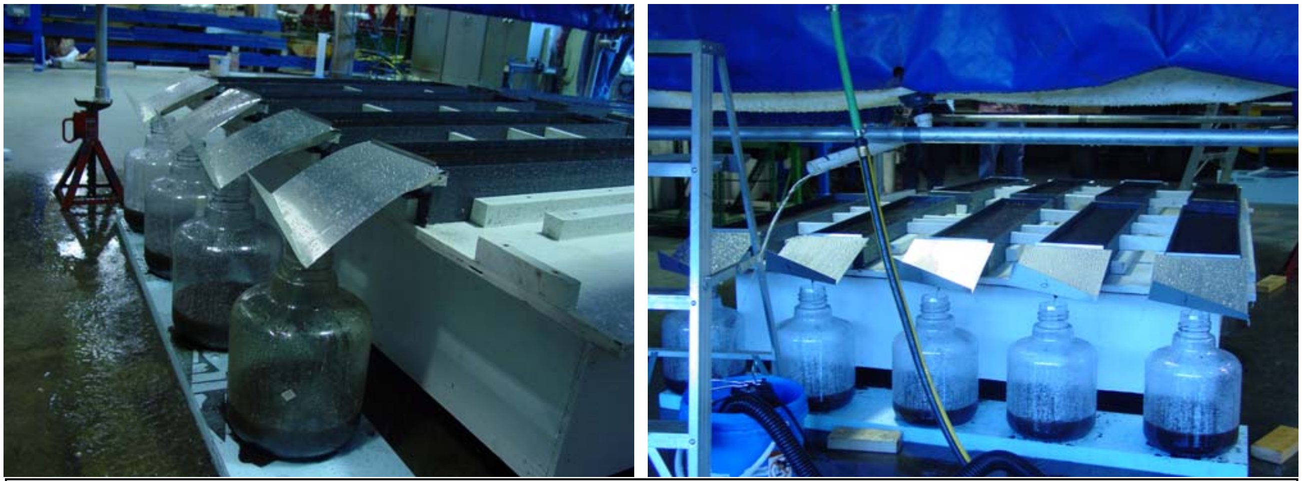


Figure 5. Surface runoff collection during indoor rainfall simulation.

In addition, all soils shown in Fig 6A are below the 1.0 ppm level established by the EPA (US EPA, 1986) as the limit required of sewage treatment output and advocated by some as a critical concentration for agricultural runoff (Sharpley et al., 1996).Consequently, these five soils show that the current manure application guidelines used by SDDENR for the state of South Dakota (SDDENR, 2003) (i.e., at Olsen-P levels of >100 ppm, manure cannot be applied) are within reasonable limits when compared relative to the “accepted” critical levels.

The relationships between P saturation percentage and TDP in surface runoff also exhibits strong linearity (Fig. 6B). At the 25 percent P sorption saturation level established by Dutch Scientists, which is generally accepted by researchers and environmentalists as the level at which greater P loss to water resources can be expected, all soils maintain TDP concentrations in surface runoff below the 1.0 ppm critical level. This further illustrates that the current manure application guidelines provide a seemingly effective strategy for environmental preservation relative to the national standards.

Objective 2: Validate correlations established in the laboratory by conducting *in situ* rainfall simulation in the field.

As with Objective number 1, the protocol for the National Research Project for Simulated Rainfall-Surface Runoff Studies was followed to complete Objective 2 (Appendix 1). The rainfall simulator was used to establish STP, runoff P (dissolved and sediment P), and saturation P relationships for each of the 10 locations per benchmark soil. All chemical and statistical analyses were performed as outlined for Objective 1. Comparisons of the P concentrations in surface runoff generated in the field were compared to the P concentrations in surface runoff generated under laboratory conditions. These comparisons were made to assess the efficacy of using indoor simulation to predict P concentrations in field surface runoff. Being able to use indoor rain simulation to predict P concentrations in field surface runoff is a cost effective means of evaluating the soil P/runoff P relationships for other dominant South Dakota soils. The field simulations also provided an excellent opportunity to educate area livestock producers and other environmental stakeholders about how STP and P saturation can affect runoff P levels.

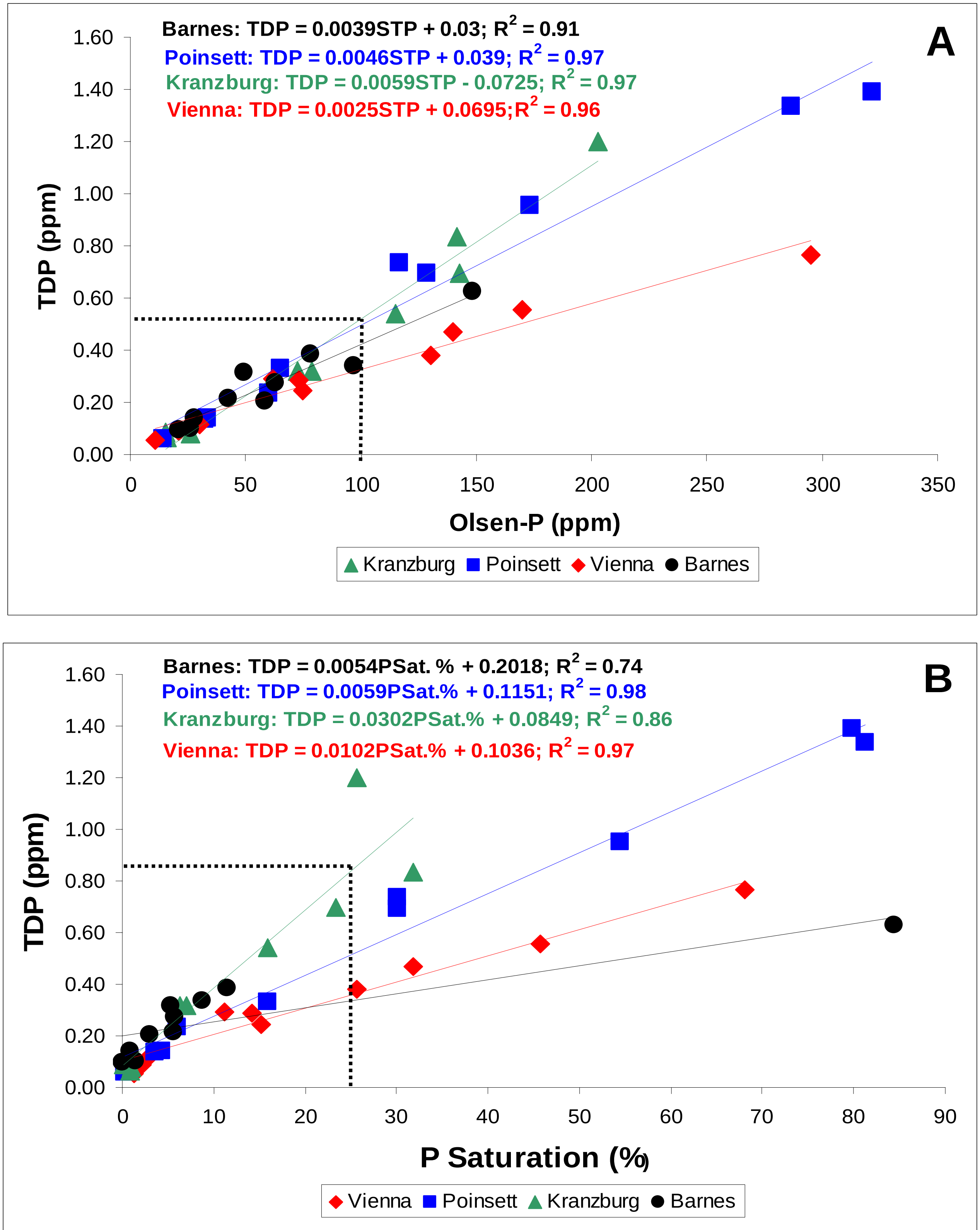


Figure 6. (A) Relationship between Olsen-P and (B) P saturation percentage and total dissolved P concentrations in surface runoff as determined by indoor rainfall simulation for the Vienna, Poinsett, Kranzburg, and Barnes soil series.

A composite of ten soil cores (0-5 and 0-15 cm soil depth, 2.54 cm diameter core) were collected randomly within each plot area immediately following the simulation event. The samples were analyzed for STP, particle size, and other select chemical parameters. The number of runoff water samples for this objective and related activities totals 294 (49 evaluation sites x 3 simulation events per site x 2 replicates per site = 294). All water samples were analyzed for total P (TP) and total dissolved P (TDP).

Task 3: Complete field rainfall simulations according to protocol for the National Research Project (Appendix 1) for Simulated Rainfall-Surface Runoff Studies.

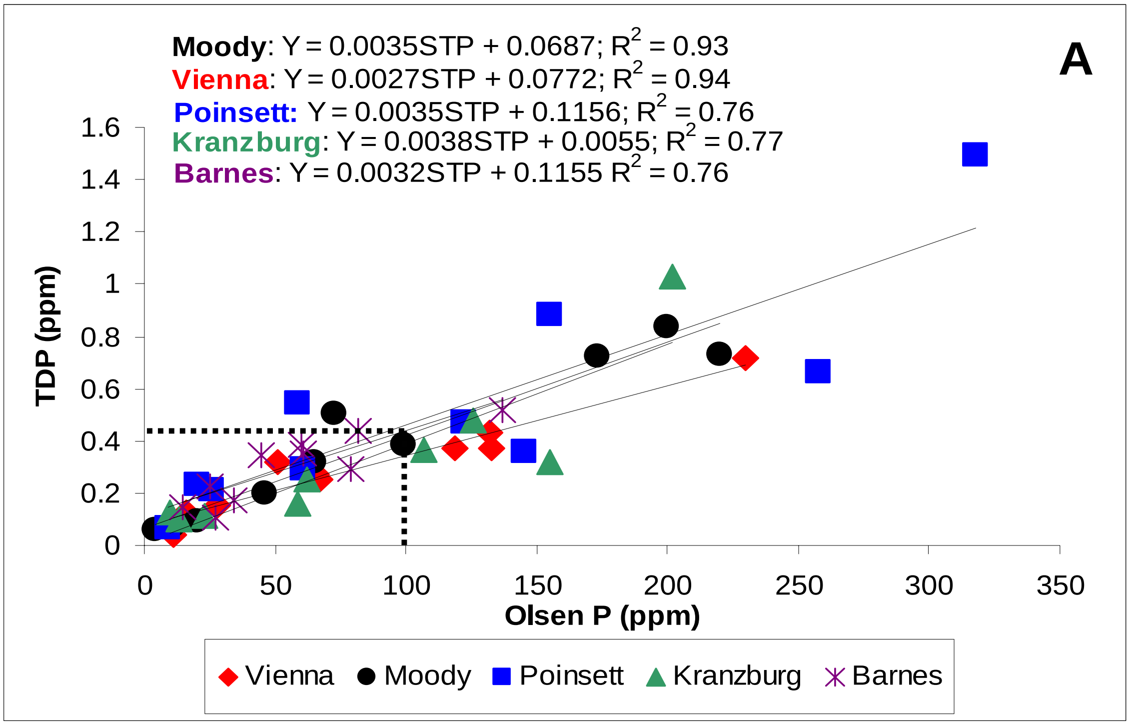
Product 4: *Planned* – Data will be used to develop educational brochures and used by Extension Specialists for manure management education. Data will also be used as the basis for future P-index development for South Dakota, and be incorporated as part of the national P runoff database in accordance with the National Phosphorus Project. Thirty sites (3 soil series x 10 sites per series) and 3 correlations. Sixty soil samples and 180 runoff samples.

Figure 7. Field plot boundary installation. Each replicate was 2 m x 1m in dimension.

Actual – Runoff P, STP, and saturation P correlations were ascertained from field rainfall simulation using the National Protocol (Appendix 1). Field plots (in duplicate) were prepared by placing metal plot boundaries to approximately 5 cm above the ground to isolate surface runoff (Fig. 7). The rainfall simulator was centered over the plot area and rainfall was applied at 6.5 to 7.0 cm hr^{-1} intensity (Fig. 8). Runoff was collected and weighed at 5 min intervals for a total of 30 min (Fig. 9). Composite runoff samples were collected and analyzed for total Dissolved P (TDP) and Total P (TP) (Fig. 9). Since little correlation existed with the TP fractions (attributed to differences in management practices and other edaphic factors), and since TDP is considered the critical fraction contributing to lake eutrophication, only correlations with the TDP fractions are reported. We evaluated five soil series (five series x ten sites per series = fifty sites) and obtained one STP/runoff P and P saturation/runoff P correlation for each of 5 soils (Fig. 10).

Figure 8. Rainfall simulator centered over top of microplot area. Rainfall nozzle was placed at >3 m above plot surface to approximate terminal rainfall velocity.

Figure 9. Surface runoff was collected at 5 min intervals, weighed, and placed into a composite sampling container. Composite samples were collected at the end of 30 minutes and analyzed for TDP and TP concentrations.



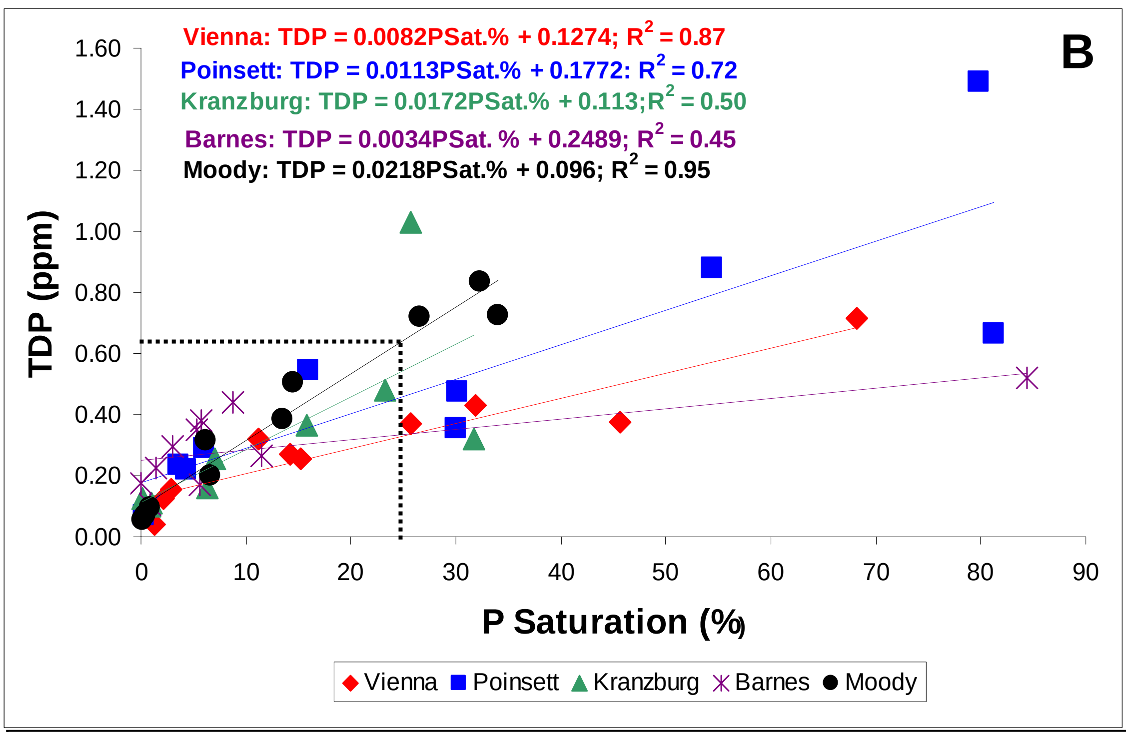


Figure 10. (A) Relationship between Olsen-P and P saturation percentage (B) and total dissolved P concentrations in surface runoff as determined by *in situ* rainfall simulation in the field for the Vienna, Moody, Poinsett, Kranzburg, and Barnes soil series.

Figure 10 depicts the correlations between STP and surface runoff TDP (A) and P sorption saturation percentage and surface runoff TDP (B) for the Vienna, Kranzburg, Poinsett, Barnes, and Moody soil series as determined by *in situ* rainfall simulation in the field. Similar to the indoor results, a strong linear relationship between STP and TDP existed for all soil types (Fig. 10A). At the current identified critical P levels for surface runoff and soil P saturation (i.e., 1 mg total dissolved P (TDP) L^{-1} runoff and 25% P saturation, respectively) (Sharpley et al., 1996), these five soils show that the current manure application guidelines used by DENR for the state of South Dakota (SDDENR, 2003) (i.e., at Olsen-P levels of >100 ppm, manure cannot be applied) should provide reasonable protection against water resource P contamination, since all soils exhibit TDP levels well below the 1 mg TDP L^{-1} critical value. This assertion is, however, predicated on the assumption that the nationally advocated critical level of 1 ppm is in fact, and adequate representation of the critical level for South Dakota. State water quality experts must determine what the "true" or "accepted" critical level is for South Dakota before runoff relationships are quantified.

The P saturation data for the Vienna soil (2002) was instrumental in the development of the current manure application guidelines used by SDDENR. According to the guidelines (SDDENR, 2003), an Olsen-P level of ≥100 ppm is the threshold at which no manure can be applied. This maximum value was determined at a sorption saturation percentage of 25 for the Vienna soil, which corresponds to a STP of nearly 100 ppm. A soil sorption saturation 25% is generally accepted by P researchers and environmentalists as the level at which greater P loss to water resources can be expected. The data was used by the South Dakota Soil Extension Specialist, in developing the current nutrient plans for Concentrated Animal Feeding Operations (CAFOs) (Appendix 3).

Milestones: *Planned* – Rainfall simulator field support equipment constructed by May 2002. First ten evaluation sites to be completed by June 2003. The remaining twenty evaluation sites will be completed by September 2004. Soil and water analyses for field simulations for the first, second, and third benchmark soils will be completed by March 2004.

Actual – Rainfall simulator field support equipment was constructed by May 2002. First ten evaluation sites (Vienna) were completed by August 2002. Ten evaluation sites (Moody) were completed by November 2003. Twenty evaluation sites (Poinsett and Kranzburg) were completed by August 2004. Ten evaluation sites (Barnes) were completed by October 2005.

Objective 3: Provide manure management education to extension educators and livestock producers.

The Cooperative Extension Service (CES) was an important project partner. The SDSU CES has developed extensive statewide contacts with livestock and other producers. This project utilized these CES programs and contacts to the fullest extent possible to transfer information about the improved manure management BMPs developed. Taking advantage of well developed outreach programs at SDSU prevented duplication of effort and provided efficient use of resources. For example, during the first year, an article was published in "South Dakota Farm and Home Research" magazine by the Agricultural Experiment Station at no cost to the project (Nixon, 2001).

Field days and demonstration events were offered and coordinated with rainfall simulation data collection during years two and three. Extension educators, area livestock producers, and environmental stakeholders (public) were given the opportunity to travel to field sites and observe data collection. Results from laboratory simulations and field simulations were summarized in brochures and given to field day participants. The cooperation of livestock producers was vital for the success of field days and demonstration events. Cooperating livestock producers provided field history information concerning manure application and general field management. The field days provided an opportunity to discuss data and results with attendees.

The information gained from this project was also used in a more formal educational format. The CES offers approximately six manure management seminars or short courses each year. The results of the runoff studies were used to raise the awareness of livestock and crop producers concerning BMPs for land application of manure to reduce P loading of South Dakota's water resources. In addition, results generated were used to educate undergraduate students at SDSU. The South Dakota Soil Extension Specialist teaches a unit on manure management in the SDSU Swine Production course (AS 478). Since little information concerning agronomic STP and runoff P was available for state soils, the project provided needed knowledge that could be incorporated into the learner outcomes of the course. This helped students realize the importance of proper manure management and equip them with knowledge they can use back on the home farm.

Task 4: Transfer STP, runoff P (dissolved and sediment P), and saturation P correlation information.

Product 5: *Planned* – Educational brochures, fact sheets, handouts, and pamphlets. These media will explain the field and laboratory results produced and will be distributed to livestock producers, extension educators, and various environmental stakeholders. Information in these educational tools will explain the maximum sorption capacity the studied soils have for phosphorus, the extent the sorption matrix is saturated with phosphorus, and how sensitive these soils are to phosphorus release to surface water resources. A total of 2000 copies of the media will be produced over the project duration.

Actual – Approximately 400 brochures were printed during 2003 and 2004 (800 total), 150 handouts were printed each year for the 2003 and 2004 Northeast Research Farm Tour field day demonstrations, Appendix 4 and Appendix 5, respectively. Two hundred handouts were printed for Dakota Fest in 2004 (Appendix 6). Approximately 1300 total copies of all publication inclusively were printed for the project. Of the total, about 100 copies were sent to the Executive Directors of the SD Corn Utilization Council and SD Pork Producers Council to distribute at their discretion. Examples of the handouts and brochures are located in Appendices 6-8 and 9 and 10, respectively.

Milestones: *Planned* – Approximately 1,000 total copies of several brochures, handouts, and pamphlets will be produced and ready for distribution by the first manure management seminars/training sessions and field day demonstration events (March 1 and June 1, 2003). Updated brochures, handouts, and pamphlets will be prepared for subsequent field day demonstration, workshops, and other manure management presentations (second printing 1,000 copies, total printing 2,000 copies).

Actual – Approximately 1300 copies of media were printed for the project and all were printed and distributed as planned.

Product 6: *Planned* – Six manure management workshops, eight manure and fertilizer training sessions, and press releases.

Actual – Eight manure management workshops and eight manure and fertilizer training sessions were presented in partnership with the SD Cooperative Extension Service, and two press releases were issued during the project. A summary of the workshops, sessions, and activities follows.

Milestones: *Planned* – Conduct at least three manure management workshops and four manure/fertilizer training sessions each year for years 2003 and 2004. Data summary used by PMG in newsletters to members and for press releases by SDSU Ag Communications.

Actual – Eight manure management workshops: Soil testing workshops for ag consultants and fertilizer dealers – 1) Brookings, 2) Parker, 3) Pierre, and 4) Aberdeen, Dec. 2003; 5) Certified Crop Advisor CEU workshop in Sioux Falls, Dec. 2003; Manure application training workshops for people applying for state CAFO permits, 6) and 7) in Pierre, and 8) Huron, Oct, Jan, and March 2003; Eight manure and fertilizer training sessions: Soil Fertility Update meetings for South Dakota livestock producers, agronomists, and extension personnel, 1) Aberdeen, 2) Pierre, 3) Brookings, and 4) Beresford, South Dakota, Dec 9-12, 2002; 5) Phosphorus update for SD DENR and Dept. of Agriculture, Pierre, SD, June 18, 2003; 6) Technical Service Provider training for agricultural advisors who want to write manure management plans for NRCS, Huron, SD, April 9-10 2003; 7) Manure management training for livestock producers - July 13, 2004 in Huron, SD; 8) Manure management training for livestock producers – Oct. 19, 2004 in Pierre, SD; A number of phone inquiries concerning sludge applications – Personal communications with Soil Extension Specialist; Two Press Releases: 1) Farm & Home Research, Vol. 52(4):17-19 (number circulated = 5,738; 2) Farm & Home Research, In Press. Circulation of Farm & Home Research totals 6,050 issues.

Figure 11 shows the SD Soil Extension Specialist conducting a manure management workshop and training session for Livestock producers and extension educators at Mitchell, SD. Phosphorus runoff/soil P correlation information and manure and fertilizer management BMPs were presented to livestock producers, crop producers, extension educators, and other various environmental stakeholders at manure training workshops.

Figure 11. South Dakota State University Soil Extension Specialist conducting a manure management workshop and training session for Livestock producers and extension educators at Mitchell, SD.

Product 7: *Planned* – Six field day demonstration events to be used as a manure management tool. Practical experience and hands-on involvement among livestock producers, extension educators, and various environmental stakeholders with data acquisition and relational development.

Actual – One field day event was conducted each year at the SDSU Northeast Research Farm Tour field day demonstrations: 1) July 2003 and 2) July 2004; Nine runoff demonstrations were conducted at the Dakota Fest Farm Show on August 17-19, 2004; Demonstrations were given at 10:00 a.m., 2:00 p.m. and 4:00 p.m. each day for a total of nine demonstrations. Figure 12 shows information transfer events at field days and Dakota Fest Farm Show. Livestock producers, agronomists, and extension educators had the opportunity to participate in collecting runoff from plot areas, and participated in discussions related to manure and fertilizer management.

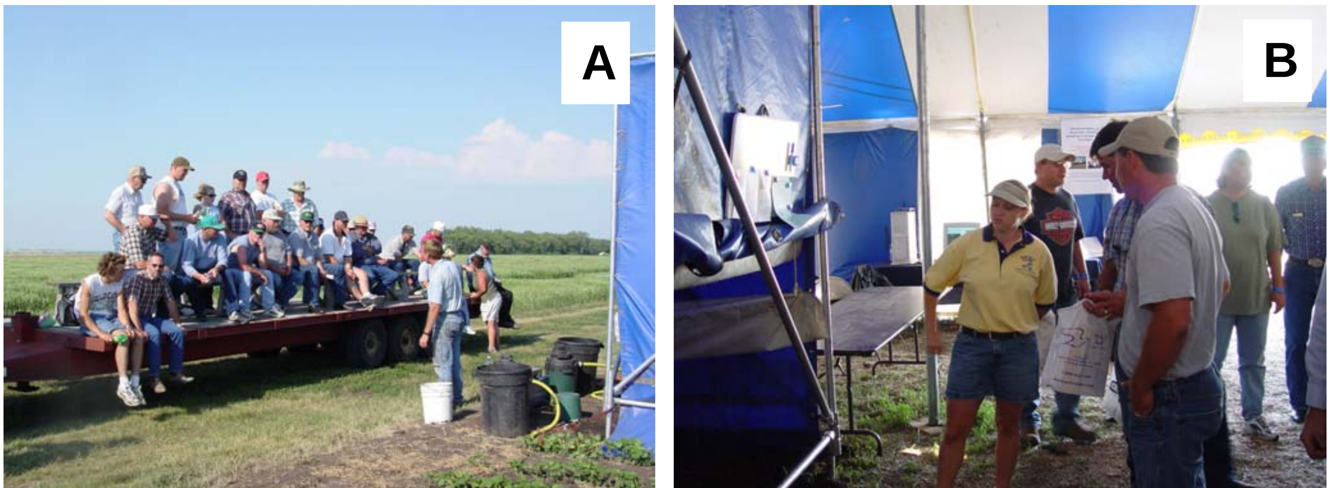


Figure 12. (A) Principal investigator demonstrating and presenting runoff results at the 2003 Northeast Research Farm Tour, and (B) graduate student discussing P runoff protocol and results to interested livestock producers at the 2004 Dakota Fest Farm Show.

Milestones: *Planned* – Conduct three field day demonstration events during the summer months of years 2003 and 2004 for a total of six field day events.

Actual – Two field day events: one in July 2003 and July 2004; Nine runoff demonstrations.

Product 8: *Planned* – Prepare P manure management project mid year annual and final report describing STP, saturation P, P sorption, and runoff P relationships for three benchmark soils of South Dakota, and submit information to scientific journals for publication.

Actual – Prepared two semi-annual reports, three annual reports, one final report (multiple copies), and two manuscripts in preparation: One semi-annual report submitted in April 2003 and 2004 (2 reports total), one annual report submitted in October 2002, 2003, and 2004 (three reports total), one final report submitted in October 2005; Two manuscripts in preparation (see Appendix 12).

Milestones: *Planned* – Prepare semi-annual reports in April 2003, 2004. Annual reports prepared in September 2002, 2003, & 2004. Print ten copies of a final report by December 31, 2004. At least 2 manuscripts will be prepared and submitted for publication in a refereed, scientific journal. *Actual* – two semi-annual reports completed in April 2003 and 2004, three annual reports completed in October 2002, 2003, and 2004, one final report completed in October 2005, and two manuscripts in preparation (see Appendix 12).

Table 2. Planned and actual milestones, products, and completion dates (Page 1 of 1) †

Objective/Task/Products	Quantity‡ Planned /(Actual)	Year 1												Year 2												Year 3												Year 4									
		Jan - Dec 2002												Jan - Dec 2003												Jan - Dec 2004												Jan - June 2005									
Objective 1		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
Task 1: Identify field evaluation sites:																																															
Product 1: Field Evaluation sites	3 (5) Soils 10 sites/soil				O X	O X	O X	O X	O X	O X	O X						O	O			O	O	O						O	O				O	O	O					O	O					
Task 2: Conduct Indoor Simulations																																															
Product 2: Obtain P-sorption & P-saturation data	30 (39) samples										X	X	X	O X	O X	X	X		O	O	O	X	X	X	X	X	X	X			O	O															O
Product 3: Obtain Runoff P correlations from laboratory data	3 (4) correlations													O X	O X	O X	O X					O X	O X	O X	O X	O X	O X	O X				O	O														O
Objective 2																																															
Task 3: Conduct Field Simulations																																															
Product 4: Obtain Runoff P correlations from field data	30 (50) sites and 3 (5) correlations						O	O									O X	O X	O X	O		O X	O X	O				X	O X	O X	X		X	X											O	O	
Soil Samples:	60 (100) samples					O	O										X	X	X	X	X	X	X	X	X	X	X	X					O	O											O		
Water Samples:	180 (294) samples					O	O										O X	O X	O X	O X	X	O X	O X	O X	X	X	X	X	O	O															O	O	
Objective 3																																															
Task 4: Transfer correlation Information																																															
Product 5: Develop brochures, fact sheets, and handouts																																															
1,000 Copies of media items	1000 (800)													O	O	O X	O X	O X	X							O	O	O																			
Updated media items	1000 (800)																							X	X	O X	O X	O X	X	X	X	X	X	X													
Product 6: Manure Mgt. workshops/training, press releases, and newsletters																																															
Workshops	6 workshops													O		O X	X	X					O		O	X	X	X	X																		
Manure/fertilizer training	8 sessions												O			X	O X	X	O X							X	X	X	X			O			O												
Product 7: Conduct field days and demonstrations	6 field days																		X	O X	X										X	O X	O X														
Product 8: Prepare semi-annual, annual and final reports and manuscripts	6 reports 2 manuscripts									O X							O X					O X							O X					O X			X										O

† X = Planned completion dates; O = Actual completion dates

‡ Values in Parentheses are the actual quantity.

COORDINATION EFFORTS

SDSU was the project sponsor. The SDSU Soil and Plant Testing Laboratory - Plant Science Department, Cooperative Extension Service, and the SDSU Water Resources Institute, provided staff, grant funds and facilities to complete the project. Other federal and local agencies and organizations contributed resources to complete the project. The contributions of each are outlined below.

South Dakota Department of Environment and Natural Resources

Staff from DENR administered the project grant and provided oversight of project activities by reviewing quarterly and annual reports and attending project demonstrations and processing of reimbursement requests. DENR staff also kept other agencies informed by providing project updates to the Non Point Source Task Force. Project updates were given to Task Force in February and March of 2003 in Pierre and Aberdeen, SD, and to DENR and EPA personnel at SDSU in September 2004.

The SD Department of Environment and Natural Resources (DENR) was also tasked with developing requirements for P-based nutrient management for South Dakota. Information gained about phosphorus loss in runoff as affected by land applications of livestock manure was used to develop regulations for the General NPDES permit that was adopted during 2003. The permit requirements have been more acceptable to producers since the data was collected in South Dakota.

South Dakota Ag Experiment Station

The South Dakota Ag Experiment Station (AES) provided the initial finding that allowed for the purchase of a rain simulator that met the requirements of the national protocol for rain simulation research. The AES also contributed to the project by supporting the stipend and laboratory studies of one Ph.D. student in the Atmospheric, Environment, and Water Resources program.

United States Department of Agriculture (USDA)—Natural Resources Conservation Service (NRCS)

The NRCS provided technical assistance to project staff to help locate field sites and verification of soil types during selection of individual plots. NRCS staff was often the initial contact with landowners who donated the use of their land for field studies. The local contacts and knowledge of soils contributed by NRCS were very important to the success of this project. The NRCS will use the results of this project in the development of a P-index for South Dakota.

State-wide Producer Groups

The South Dakota Cattlemen's Association played an important role in developing this project by recognizing the need for collecting data on the water quality effects of phosphorus in the soil and developing an educational program that would help livestock producers in South Dakota maintain production while minimizing effects on water quality. The Cattlemen's Association supported a literature review during 2001 that outlined the need for this project. The SDCUC and SDPPC supported the project with cash contributions that provided for an expansion scope of the project to complete soil phosphorus versus runoff phosphorus relationships for two additional soils.

Local Producers

This project would not have been possible without the cooperation of 8 local producers that allowed rainfall simulations to be conducted in their farmed fields. While several producers were compensated for direct crop loss associated with project activities, all of them experienced inconveniences of various sorts to allow this work to be completed successfully. Each producer had a keen interest in the outcome and findings of the project. One producer even modified his feeding and manure spreading activities based on detailed soil phosphorus maps produced during the site identification phase of the project. Many of the producers watched as rainfall simulation runs were conducted and asked good questions regarding how findings would be used.

Upper Big Sioux River Watershed Project

The Upper Big Sioux 319 Project budgeted funds to hire an additional full-time individual whose primary responsibility is to communicate with stakeholders and the general public. The coordinator of the Upper Big Sioux River Watershed Project attended demonstrations that were held at the NE research farm to become familiar with the project and incorporate findings into the information and education portion of the Upper Big Sioux River Watershed Project. Brochures summarizing the results of this project were distributed to the Upper Big Sioux River Watershed Project staff for distribution to improve manure management BMPs. A demonstration of the rain simulator at a Upper Big Sioux River Watershed Project was planned for 2004 but was canceled due to a scheduling conflict.

South Dakota State University and Cooperative Extension Service

The Cooperative Extension Service was a vital project team member. The South Dakota Soil Extension Specialist, Mr. James Gerwing, was the main contact with livestock producers statewide to disseminate results generated by the research. Educational seminars/short courses, field day events, and formal instruction were used to transfer information to area livestock producers, Extension Educators, undergraduate animal science students, and the general public. Mr. Gerwing was also instrumental in development of BMPs and manure management regulations adopted by SDDENR which were based on results from this project.

The Phosphorus Management Group:

A group of SDSU staff and livestock and grain producers met several times during 2001 to discuss ways of collecting sound scientific information on the soil P issue. The attendees included the South Dakota Cattlemen’s Association (SDCA), Pork Producers, Soybean growers, South Dakota Farm Bureau and SDSU staff. This ad hoc group, referred to as the Phosphorus Management Group (PMG), did not meet as a group during the project but members of the original group were in the information transfer activities of this project.

PROJECT GOALS AND MILESTONES NOT MET

The most significant change in the project was the request for a no-cost extension. Because of the exceptionally dry spring in 2004, our farmer cooperators had spread manure on many of the potential Barnes sites. According to the National P Protocol, nine months must elapse before valid field simulations can be conducted on sites that have received manure. Consequently, a no-cost extension was requested and granted with a new completion date of June 30, 2005. All reports were submitted as planned except the final report, which was pushed back because of the no-cost extension and the time needed to complete the Barnes series.

PROJECT BUDGET

This project was funded by an EPA Section 319 Education, Training, and Demonstration Grant provided through the South Dakota Department of Environment and Natural Resources (DENR). Other federal funds included a grant from the United States Geological Survey (USGS) 104b program. Matching funding included state funds administered through South Dakota State University (SDSU) Plant Science Department, SDSU Agricultural Experiment Station, and the Water Resources Institute as well as contributions from the South Dakota Corn Utilization Council (SDCUC) and the South Dakota Pork Producers Council (SDPPC). Table 3 depicts the original and actual expenditures and funding sources for the Manure Management BMPs Based on Soil Phosphorus project. Detail explanations of the funding sources and their contributions follow.

Table 3. Original and Actual Expenditures for Manure Management BMPs Based on Soil Phosphorus project.

Original and Actual Expenditures

Manure Management BMPs Based on Soil Phosphorus

	EPA 319			USGS 104b		Local Match		Other Federal Funds		
	Original	Actual	Original Proposed Match (SDSU and WRI)	Federal	Proposed Match	SD Corn Utilization Council Budget (2 Yrs)	SD Pork Producers Council Budget (3 Yrs)	Ag Experiment Station	Plant Science	Cooperative Extension Service
Salary	$ 66,491.00	$52,348.75	$49,389.00	$21,451.79	$25,365.00	$27,752.06			$27,438.67	$ 12,000.00
Benefits		$12,020.68	$10,479.00	$ 1,053.91	$ 6,005.00	$ 6,556.65				
Tuition Remission				$ 1,393.32						
Travel	$ 6,236.00	$ 6,029.57		$ 1,117.98		$ 1,070.65	$ 321.54	$ 200.00		
Contractual	$ 11,659.00	$16,143.84		$ 461.21		$ 2,787.09	$ 3,190.34	$ 8,952.00		
Supplies	$ 6,025.00	$ 4,068.30		$ 1,609.80		$ 1,658.11	$ 6,488.12	$ 3,100.00		
Printing	$ 884.00	$ 683.86		$ 50.12		$ 175.44		$ 400.00		
Capital Assets				$ 798.00						
Indirect Costs	$ 20,705.00	$20,705.00	$15,566.00		$24,484.00					
	$112,000.00	**$112,000.00**	**$75,434.00**	**$27,936.13**	**$55,854.00**	**$40,000.00**	**$10,000.00**	**$ 12,652.00**	**$27,438.67**	**$ 12,000.00**

EPA Section 319 Education Training and Demonstration

The original project budget contained a total of $112,000 in 319 grant funds. The largest expenditure was to provide salary and benefits for one Principal Investigator (PI), a Ph.D. graduate student and several undergraduate students. Funds were also included for travel to field sites and demonstrations, contractual services primarily for lab analysis, supplies for the rain simulator and printing costs for reports and brochures. The budget also included indirect costs to SDSU. Actual expenditures of EPA 319 funds closely followed the original budget on Table 3. Slightly less than planned was spent on salaries, travel, supplies and printing but additional funds were needed for lab analysis under contractual services (Table 3).

Producer Groups

The original project budget did not include funding from the SDCIC or the SDPPC. Contribution of funds from these producer-groups allowed expansion of the project from the original three soil series in the Upper Big Sioux project area to a total of five soil series. The SDCUC grant of $40,000 was used mostly for salary support for one PI and travel, supplies, and laboratory services associated with the additional field sites. The SDPPC contributed $10,000 which was primarily used for lab analysis and supplies (Table 3).

US Geological Survey 104b Program

The original project budget included funds to support a masters-level graduate student for two years. A federal grant from the USGS through the Water Resources Institute's 104b program was used to provide the additional support for a Ph.D. student. The grant funds allowed for the additional time needed to complete a Ph.D. program and a more intense laboratory research component that yielded data on phosphorus saturation characteristics of the five soil series and determination of the existence of change points in soil test phosphorus that were not included in the original proposal. It also helped fund evaluation of an additional soil series.

Agricultural Experiment Station

The Agricultural Experiment Station (AES) supported this project in several ways. AES provided the seed money to purchase the rain simulator, salary support to the Ph.D. student through the Plant Science Department, and supplies and lab analysis costs associated with the expanded laboratory studies conducted by the Ph.D. student.

Local Match:

In the original project budget, match for the EPA 319 was to be provided by SDSU from salary and benefits for PIs German and Gelderman paid by state funds. In the actual expended budget, grants from producer-groups were used to replace much of the SDSU match. The time and effort planned was expended by PIs German and Gelderman but a portion of the match was shifted to match federal funds from the USGS 104b program (Table 3).

FUTURE RECOMMENDATIONS

As indicated in the soil P/runoff P relationships (Figs. 5A and 9A), even at STP levels considered low by agronomic standards (i.e., <10 ppm), total dissolved P (TDP) is already above levels deemed by water quality experts to be critical for accelerated lake eutrophication (i.e., 0.03 to 0.05 ppm). Concentrations of TDP in runoff can change significantly from the point of loss in the field to the point of entry into a P limited water body. That is, sediments in streams and drainageways connecting fields with sensitive water bodies may serve as sinks or sources for TDP depending on inherent chemical and physical properties (Sharpley et al., 1996). Consequently, overland flow from field runoff may become enriched or depleted in TDP relative to its initial concentration during the transport process. No previous studies regarding P loss on a watershed scale have been completed in South Dakota. Evaluating how the P in surface runoff changes as it moves toward receiving water bodies in typical watersheds of South Dakota is needed to fully address producer concerns and to instill in them the desire to promote and implement manure and fertilizer P best management practices.

The question “how much P is actually leaving the field and entering and adversely effecting nearby water bodies”, has been posed by livestock and crop producers, and environmental stakeholders in the state of South Dakota. The question was asked at many of the manure application training seminars and workshops offered by the South Dakota Soil Extension Specialist, and had surfaced at the field and laboratory rainfall demonstrations offered through this project as well. Although this project provides estimates of total P loss, it can not adequately answer this question because total P loss estimates are only valid at the micro-plot level and say nothing about the amount of P lost over a larger, watershed area. In addition, the primary objective of this project was to evaluate the relationships that exist between STP and runoff P concentration. Research has shown that there is little to no relationship between STP and P loss (Sharpley et al. 1996). The primary reason for this lack of correlation is that total P loss is governed by many contributory parameters, and STP can not account for changes in topography, climate, agronomic practices, or other edaphic (i.e., inherent in the soil) factors. Therefore, to adequately address the concerns of South Dakota producers and more fully answer the question how much P is leaving the field and entering and adversely effecting nearby water bodies, a project, funded by a 319 grant awarded through the DENR, is currently being implemented that evaluates P loss on a watershed scale and evaluates the relationship between P loss at the micro-plot level with that at the watershed scale.

As shown in Figs. 6A and 10A, slopes of the regression equations are similar; suggesting the rate of P release to surface runoff is nearly the same for all studied soils. Cattle producers and other environmental stakeholders in South Dakota have communicated the need to develop irrefutable evidence in favor of or against the current manure application guidelines. However, to provide such evidence, the runoff P/soil P relationships for additional South Dakota soils must be evaluated. The previous study evaluated five glacial till soils with very similar diagenetic history. All were mollisols formed under ustic (dry) to udic (humid) moisture regimes and calcium carbonate influences (e.g., Calcic Hapludolls). The extent of P release to surface runoff for other dominant South Dakota soils may not parallel that of the five soils evaluated, as other soils in the state possess significantly different diagenetic histories. For example, the Pierre and Millboro soils of western South Dakota developed under weathered shale deposits and are thus classified as vertisol soils high in layer (phyllo) silicate clay. The Highmore, Williams, and Houdek soils are mollisols that possess regions of illuvial accumulations of phyllosilicate clay or argillic horizons (Typic Argiustolls). The Aberdeen soil has both clay and exchangeable sodium accumulations in its subsurface horizons (Glossic Natrudolls).

P fixation is directly related to the amount of clay-sized particles. The innate chemical differences that exist between the studied soils and the unstudied soils undoubtedly influence the fate and transport of P within these systems. Consequently, it cannot be assumed that the unstudied soils would respond the same in terms of their capacity to release P to surface runoff.

It is imperative, therefore, that the relationship between runoff P and soil P be determined for other dominant South Dakota agricultural soils. By doing so, a more complete data set describing the relationship between soil and runoff P will be established for the state of South Dakota. This data set is needed in order to verify the validity of or justify revisions to the current manure application guidelines.

According to the State of South Dakota Occurrence of Soil Series and Development of a Phosphorus Index map (Appendix 11), there are thirteen soil series that support the majority of South Dakota's permitted Confined Animal Feeding Operations (CAFO's). P runoff/soil test P relationships have been established for five of the thirteen. All five of the completed soils are located along a relatively narrow area along the I29 corridor. This leaves a very broad area of soils with high P accumulation potential that have yet to be evaluated for their P loss potential. It is recommended that soil P/runoff P correlations be conducted on eight additional soil series (i.e., the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams series), and that the results be used to refine the current manure application guidelines and promote improved P management strategies.

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LIST OF TABLES AND FIGURES

APPENDIX 1: National Research Project for Simulated Rainfall - Surface Runoff Studies.

National Research Project for Simulated Rainfall Surface Runoff Studies

PROTOCOL

The field objectives of the National Phosphorus project are to characterize soil test P (STP) - runoff P relationships for a representative cross-section of important agricultural soils across all Major Land Resource Areas in the U.S. Soils subject to past manure additions from the range of major animal production systems (i.e. dairy cattle, beef cattle, hogs, poultry, etc.), will be covered. These soils will be located in watersheds contributing to the range of different types of waterbodies and different climatic regions. The initial goal of the National Phosphorus Research Project is to relate soil test P and surface runoff P, with other confounding factors such as fertilizer or manure application minimized. However, while the plots are in place and after the they have been rained on several times, it is the perfect time to apply fertilizer or manure as per location guidelines and expand the research program.

Plot establishment

- Select area for plot establishment on slopes typical of the benchmark soil, but with sufficient slope (>2%) to generate runoff; avoiding sites with significant depression storage areas; select cropping system with typical percent cover; and either identify sites with a preexisting range of STP levels or adjust STP levels (see below).
- Construct runoff plots at each site with dimensions of 2 m long and width of 0.75 to 2 m. The long axis should be oriented down the slope. Under situations of intrasite variability, plots should be 1.5- to 2-m wide by 2-m long. Preliminary studies have shown a minimum of 10 paired sites are needed to accurately describe the soil - runoff P relationship.
- Install metal borders (0.08 inch thick and six inches wide) 5 cm above the ground to isolate surface runoff.
- Install runoff collection gutter at the downslope edge of each plot to divert runoff to a collection point. See Figure 1.
- If plots are established in pastures, mow the plots to a uniform height of approximately 10 cm, one week before the rain simulation and remove the grass clippings.

Adjustment of soil P levels

- Identify sites that provide a range of STP levels on the same soil due to previous manure and fertilizer applications by the landowner, with no P applied in the previous nine months.
- Adjust STP levels of individual plots to obtain a STP range from "low" to "very high" by additions of manure. Levels that qualify as "low" and "very high" may depend on the location and extractant used. In pasture situations, adjustment of STP levels may require several applications of manure to the same plot with follow-up soil testing to ensure attainment of the desired levels, and adjustments may take up to a year or longer to accomplish. In tillage situations, STP adjustments could be done more quickly because more manure could be applied and incorporated at each application.

Soil sampling

- The simplest method is to collect and bulk in the field, 10 cores for each sampling depth (0-5 and 0-15 cm) from within each plot, after raining.
- A more rigorous approach is to air dry the 10 cores and mix equal weights of each core thoroughly to form a composite sample. Run analyses on composite sample, and, if necessary, determine variation in properties from individual samples.

  If collection of individual cores and bulking after air drying is impractical, participants should note that variability in single sample volumes may result in significant, unpredictable sampling error. This error can *affect associations between STP and runoff P, resulting in poor correlation of these variables. We feel that at a minimum, a consistent sampling and bulking method must be used throughout your study.*

- If the plots are to be used in subsequent manure management studies, then soil samples should be taken outside but adjacent to the plots. If soil cores are taken inside the plot, the insitu hydrologic properties of the plots will be destroyed.

Soil analyses

- Air dry soil samples and sieve (2-mm) to remove larger rock particles and most of the grass thatch material.
- Analyze the samples using one or more of the extractants appropriate for your area, e.g., Texas A&M, Mehlich III (Mehlich, 1984), Bray-Kurtz P1 (Bray and Kurtz, 1945), Olsen (Olsen et al., 1954), Fe oxide-impregnated paper strip (Sharpley, 1993), distilled water (Pote et al., 1996), and ammonium oxalate (Sheldrick, 1984; Pote et al., 1996).
- Archive remaining soil sample for further analysis.

Source-water testing

- Collect sample of the source water to be used for the rain simulations.
- Perform as complete analysis of the source water as possible to gain a perspective of the general quality of the source water. Conductivity, pH, and ICAP (inductively coupled argon plasma spectrometer) analysis will provide a perspective of the overall quality and concentrations of potential cations (Al, Fe, Ca) that could interact with the phosphate ion.
- Test source water (outlined below) to determine if dispersion of soil particles is greater than would be produced by rain water.
  1. In a test tube, mix a sample of the surface soil receiving simulated rainfall into a water sample from the water source to be used. Use a ratio of 1 g of soil for each 8 mL of source water (e.g., 5 g of soil in 40 mL of water). Conduct duplicates.
  2. Repeat above step but substitute deionized water for the source water.
  3. Cap the test tubes and shake for about 30 min on a reciprocating shaker.
  4. Place the test tubes in a rack and let stand motionless for three hours.
  5. Observe any visual difference between the clarity of the suspension between the two treatments (deionized water vs source water).

     Assume the deionized water represents low buffered rainwater, serves as the control, and produces little soil dispersion. Most of the solids should settle out in the 3-h period. If the dispersion properties of the source water are similar to the control, then the source water will not affect the dispersion properties of the soil and can be used as source water for simulated rainfall. If, however, dispersion still exists after 3 h (as evidenced by turbidity in the treatment test tubes), the source water can influence dispersion and an alternative source water should be found.

  6. Each soil receiving simulated rainfall should be tested for dispersion effects.
  7. Source water effects on soil P release can be determined by extraction of soil with various source waters (e.g., distilled, tap, ground water, well water, and carbon filtered) at a soil to solution ratio of 1 to 10 for 30 min. The soil to solution ratio and short time approximate suspended sediment concentration of the simulated rainfall-runoff event.

- Transport water to the site (if necessary), preferably not more than 24 h before simulations (Figure 2). Hose reels (Figure 3) can greatly simplify the mechanics of conducting the simulations.

Antecedent moisture

- Determine the antecedent moisture conditions at the site using a soil moisture probe (similar to DELTA-T DEVICES *ThetaProbe*, type ML2). To identify θ_v corresponding to field capacity, conduct the following analyses:

1. Position the open end of a plastic bucket (open on each end) in the soil to a depth of about 5 cm to form a watertight seal. Run duplicates.

2. Gradually add water to the bucket to form a head (~15 cm) and allow to drain.
3. Repeat the above process several times to ensure saturation and then cover the site with an evaporation barrier (plastic) and wait 48 h. After 48 h, take readings with the *ThetaProbe* and take soil samples (5 cm) for determination of θ_v.
4. Allow the system to continue to dry, taking *ThetaProbe* measurements and soil samples for θ_v determinations. Depending on conditions, this could be one- to two-day intervals.
5. From this data, you will know the θ_v that represents field moisture content and also be able to construct a graph of the *ThetaProbe* output vs. θ_v and perform a soil-specific calibration as outlined in the manual.

Rain simulators

- Rain simulators based on design of Miller (1987).
- Each simulator has one TeeJet™ ½HH-SS50WSQ nozzle placed in the center of the simulator and 305 cm (10 ft) above the soil surface. The nozzles and associated water piping, pressure gauge, and electrical wiring are mounted on an aluminum frame. The frame is fitted with tarps to provide a windscreen.
- A pressure regulator is used to establish a water flow rate of 210 mL/sec at each nozzle. The regulator must be placed adjacent (on the same level) to the nozzle on top of the simulator (see Fig. 1). Obtaining the correct flow rate out of the nozzle is the first step to ensuring proper amount and distribution of kinetic energy.
- Measure flow rate by sticking tube (we use a 10 foot length of 2 inch pvc pipe) around nozzle and collecting effluent from tube. The #50 nozzle should have a flow rate of 210 mL/sec. If a #30 nozzle is used, this should have a flow rate of 125 mL/sec.
- Given the proper flow rate, measure rainfall intensity by pan method, NOT by the cup method. In short, collect rain with a tray that covers the entire area of the runoff plots. Using cups results in an overestimation of rainfall intensity.
- Before each simulation run, center the nozzle over the plot. By knowing the dimensions of your simulator and the position of the nozzle, you can tape (duct-tape) markers on the bars of the simulator so once the simulator is aligned correctly (downslope and across slope) the simulator will be centered.

Cautionary notes on simulator

- The temperature of the water makes a difference. The Arkansas crew did intensity runs with water out of the cold water tap (around 70 F) and got the desired 6.97 cm/h and then changed to the hot water tap. We wanted to know what effect this has because sometime we may fill the tank on Friday for a run on Monday. During that time the water will warm up, relative to the cold water tap. Anyway, you get the picture if you are doing runs in Erath County, TX, with the temperature a chilly 104 degrees! With the hot water, we reduced our intensity to 6.2 cm/h. So, we would recommend collecting the water on the day of the runs rather than several days in advance.
- The ½ HH SS 50WSQ is an industrial nozzle, with a spray angle of 104 degrees plus or minus 5%. The nozzles wear with time, affecting both intensity and uniformity. With use this should be checked and the nozzles changed at least each season.
- The pressure regulator, which is used to set the flow rate and intensity for each simulation, **must** be at the same level as the nozzle.
- The simulator should be entirely enclosed with tarps to minimize wind disturbance of rainfall intensity.

Rain simulation

- If the plots are established in pasture or conservation tillage (residue management) systems, measure the percent cover using the string method (Laflen et al., 1981).
- Evaluate the moisture conditions at the test site as outlined above (**Antecedent Moisture**).
- Conduct the simulation run at an intensity of approximately 70 mm/h. Alternatively, conduct the simulation at an intensity corresponding to a ten-year storm for the location. The 70 mm/h intensity is intended to permit comparisons between sites, whereas the intensity of the ten-year storm is intended to approximate local conditions.
- Three rainfall simulations to be conducted at one-day intervals. The first rainfall is conducted at site soil moisture conditions and time to initiation of surface runoff noted for later evaluation of site hydrologic response. The sites will be at approximately field capacity for the second and third rainfalls.
- Collect runoff *in toto* for 30 min, weigh to determine runoff volume, and take a subsample of the collected runoff. A runoff sample at the end of the 30-minute event should also be collected for analysis to reflect an equilibrium P

value. Note: Collection of runoff *in toto* is impractical if plots are much larger than 1 x 2 m, since the runoff volumes produced are large. Alternatively, collect runoff samples of approximately 1 L at 5-min intervals during the runoff event beginning 2.5 min after the start of continuous runoff (six discrete samples/plot/rain), giving a total runoff time of 30 minutes. Record sample volumes and the times required to collect them to calculate the mean runoff flow rates and total runoff volumes and to construct a composite sample from the six discrete samples. The discrete samples can be analyzed individually, but analysis of the flow-weighted composite is less expensive.

- It is recommended that discrete samples be taken during an event for the first few simulations to define the P chemograph. Subsequent simulations only require a single sample of the total flow. This dramatically reduces field and analytical labor and in most cases, a flow-weighted event P concentration will be used.
- Filter (0.45-µm pore diameter) subsample of each composite sample to remove particulate matter.
- Keep the filtered and unfiltered runoff samples at 4^{o}C until analyzed. Alternatively, acidify the filtered and unfiltered runoff samples with concentrated HCl. **NOTE:** acidification for sample storage will not allow the subsequent determination of algal-available P by either strip or resin membrane methods. Add 1 drop of concentrated HCl to each 10 mL of runoff sample to lower pH to approximately 2.
- Analyze soil and water samples as soon as possible or store soil and runoff samples in the dark at 4EC until analyzed.

Runoff Sample Analyses

- Analyze samples following procedures in APHA (1992; Pierzynski, 2000): Dissolved molybdate reactive/soluble P, total dissolved P, total P, bioavailable P, suspended sediment, pH.

Data analyses

- Analyze relationship between STP levels and runoff P concentrations by regression analysis. Develop regressions and correlation coefficients for each soil series. Determine (a) if a significant relationship exists between STP and runoff P levels for each of the soils and (b) if the relationship between STP and runoff P is the same between soils.

Indoor Soil Box - Rainfall Simulation Protocol

The indoor soil box protocol has been established for specific conditions and objectives. Firstly, when a site is extensively tilled to achieve plot uniformity, it is suggested that similar relationships between soil P and surface runoff P will be obtained with indoor runoff boxes as with field plots. However, it cannot be emphasized strongly enough that indoor boxes are not intended to replace field plots and are to be used in conjunction with field plots. The second scenario under which the indoor boxes may be used is to broaden the selection of soils evaluated. Clearly, the number of field plot sites that can be evaluated over the next two to four years will be limited. The indoor boxes will help strengthen the data base relating soil P and surface runoff P as a function of soil type.

Soil Collection

- Soil from the surface 7.5 cm of selected benchmark soils should be collected in a relatively dry condition with as little residue as possible. The sampled soil depth equates to the depth of soil used in the runoff boxes.
- Physical, chemical, and mineralogical properties are determined on each soil as per National P field protocol.
- Soils are air-dried in the laboratory, then sifted through a 19-mm sieve, and thoroughly mixed. Pretreatment of soil is minimal and a coarse sieve used to retain as much as possible.

Runoff Box Construction

- We propose 1-m long, 20-cm wide, and 7.5-cm deep soil boxes, with side and back walls 2.5 cm higher than the soil surface (Figure 4a). The height of side wall is similar to the height of the field plot boundaries and should not result in any rain shadowing effect in boxes not in the center of the rainfall simulator.
- The boxes are constructed with stainless steel, galvanized sheet metal or plywood. The former are more expensive but will be sturdier, easier to clean, and last longer. If made from wood, the side walls, ends and bottom should be screwed and glued together and then caulked from the inside to seal them. The caulking may need to be touched up occasionally. As long as damp soil is not left in the box for a long time after an experiment has been completed, the wooden boxes can last for several years. However, the general consensus of the group is that metal boxes will be easier to maintain and their additional cost is small compared to other project expenditures.

- Drainage holes (5-mm diameter) are located on the base of the box, at upper, mid, and lower locations (Figure 4b). Although this will not replicate field drainage, several group members thought some drainage was necessary and would improve reproducibility. Surface runoff is collected at the downslope end by a V-shaped aluminum trough. The shaped metal is screwed and caulked to the outside lip of the box (see Figure 5). A cover is attached to the end of the side-wall to protect the runoff collector trough from direct input of rainfall.

Packing the Box with Soil

- The box is packed with a predetermined weight of soil, so that the final weight of soil in the box is known and the approximate bulk density of field soil can be achieved. Cheesecloth is placed on the bottom of box, followed by the addition of 5 cm of soil. Soil is usually added several times to achieve the appropriate bulk density. We use a wooden tamper to pack the soil during filling (Figure 4c).
- Soil is added until it is level with the lower lip of the runoff box. After the desired bulk density is achieved by soil addition and tamping, the box is then placed at the required distance below the simulator nozzle (3.05 m or 10 feet). To a certain extent, packing is somewhat subjective depending on the "packer". However, a personal or individual protocol is developed after a couple of boxes are packed. Soils will be evaluated in triplicate, so that each soil should be packed into three different boxes for the runoff study.

Simulating Rainfall and Chemical Analyses

- This portion of the protocol closely follows the field protocol discussed previously. Soils are pre-wet to control for antecedent moisture. A furnace filter is placed on the soil surface to protect the soil from raindrop impact, simulating crop cover. The soil is saturated using the rainfall simulator and the furnace filter removed. Saturated soils are left to drain for 24-36 hrs (covered with plastic) until field capacity is achieved. Volumetric soil moisture content is determined by theta probe. Depending on user capabilities and amount of soil, it is recommended that for each soil, a "prewetted" and "air-dried" condition (no prewetting) be evaluated.
- Runoff boxes can be set at two slopes, a field slope and a "common" slope (about 4 to 5%), with the field slope offering comparison with field data, and the common slope enabling comparison across the National P Project. At a minimum, soils should be evaluated under the common slope.
- Rainfall simulations are conducted three times, at one-day intervals between rainfall events to allow the soil to return to field capacity. Rainfall is applied at 7.0 cm hr^{-1} until 30 minutes of runoff has been collected (same protocol as for the National P field plots). A single bulk runoff sample (typically 5 to 7 L) is collected for the 30-min event. As per field protocol, discrete samples can be collected during the first few storms to define the P chemograph.
- Runoff volume, sediment yield, and P are measured as defined under the field protocol. Dissolved, algal-available, and total P forms should be measured. Soil samples for chemical analysis should be collected from the material during packing. If samples are needed after a rainfall, a sample can be taken from the up-slope end of the box and replaced with a small amount of the original soil. As the boxes are prepacked, limited sampling at the upper end of the box will not effect flow pathways as in the field plots.

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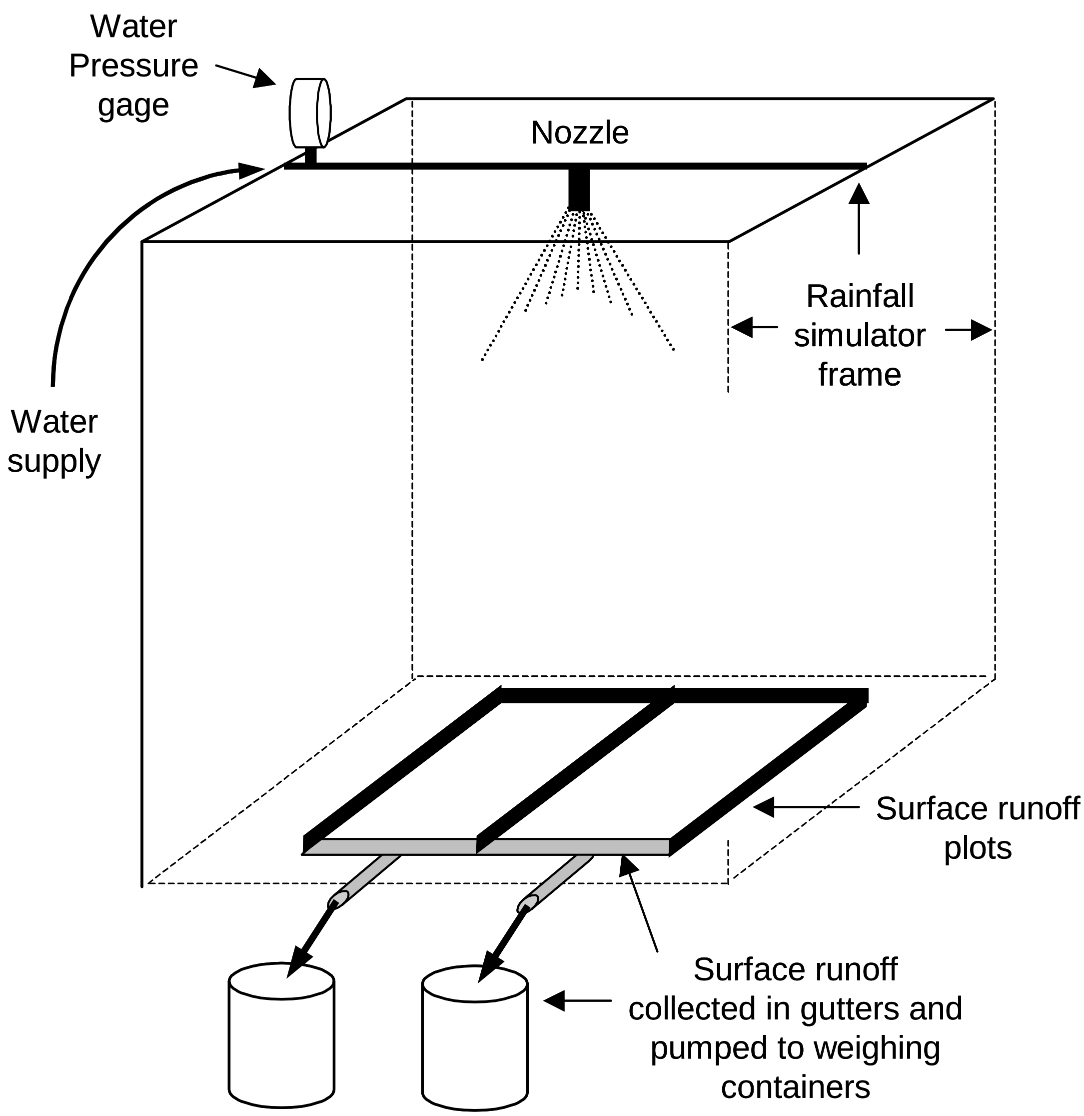


Figure 1. Plan of the rainfall simulators, surface runoff plots, and water collectors.

Arkansas prototype

Pennsylvania prototype

Figure 2. Goose-neck trailer with 1600-gal. capacity water tank. (Chem-tainer Industries, Inc. 361 Neptune Ave. West Babylon, NY 11704, 516-661-8300).

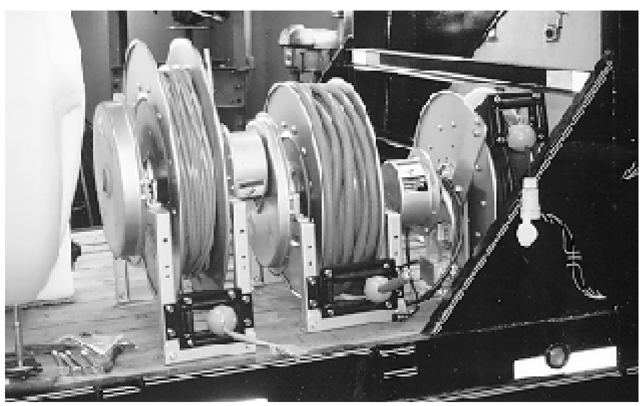


Figure 3. Hose reels for power cords, "brain stem," and water lines. (Hannay Reels, 553 State Route 143, PO Box 159, Westerlo, New York 12193-0159, 518-797-3791,

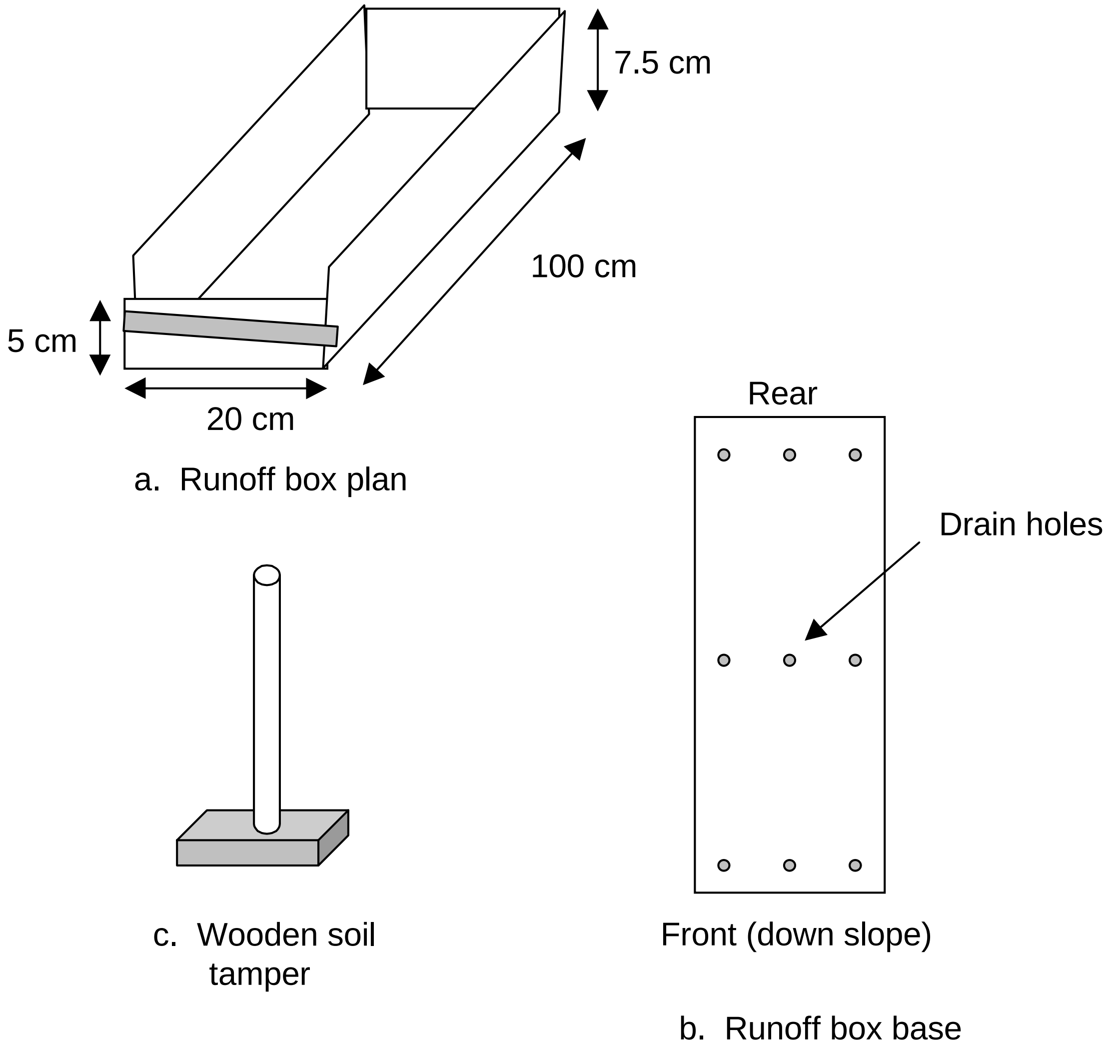
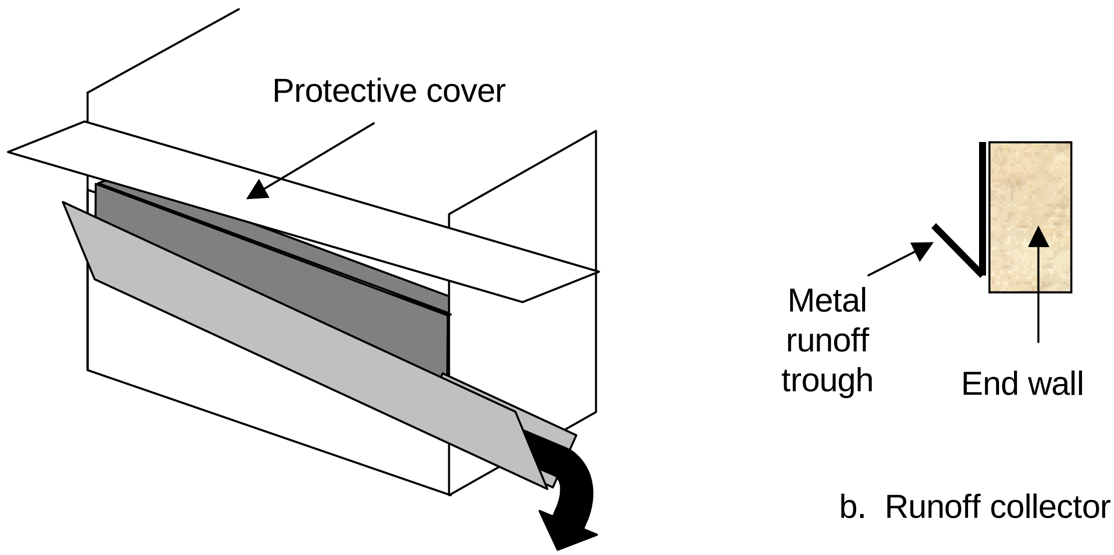


Figure 4. Runoff box plan.



a. Front plan with runoff collector

b. Runoff collector

Figure 5. Runoff collection.

APPENDIX 2: Letters of Support

WORKING TOGETHER FOR THE WATERSHED
UPPER BIG SIOUX RIVER WATERSHED PROJECT

810 10th Avenue SE #3
Watertown, SD 57201-5456
Email: ubsrw@hotmail.com

Phone: 605-886-8202 #3
605-882-4989
FAX 605-882-1930

May 1, 2001

CSREES Revisions
USDA STOP 2245
1400 Independence Avenue SW
Washington, DC 20250-2245

To Whom It May Concern:

The Upper Big Sioux River Watershed Board of Directors supports the proposed project of South Dakota State University to test phosphorus levels in the various soils present in this watershed.

The UBSRWP has identified phosphorus and soil erosion as our main surface water contaminates and is looking for ways to reduce phosphorus loading of our streams and lakes. Part of our project deals with animal nutrient containment and the proper application of those nutrients to cropland.

Repeated nutrient applications on the same fields year after year are of concern to us. Currently we do not know how much our major soil groups can carry before the excess is transported to our waterways. We need some hard numbers to present to the livestock owners. We are working with the South Dakota Animal Nutrient Management team to test manure, to test soils and to weigh the amounts being applied, but we are uncertain of the tolerance of the area soils.

The UBSRWP has a sizeable budget for manure confinement systems and manure application plan incentives and shares the same goals as the SDSU proposed Run-off P project but there is a big hole in our information base. The knowledge gained from soil phosphorus saturation relationship studies would be a big assist to our watershed restoration program.

Respectfully Submitted,

Mike Williams
Project Coordinator

SOUTH DAKOTA FARM BUREAU

May 10, 2001

USDA_CSREES
Competitive Grants Program
Integrated Research, Education and Extension
Water Quality Program

Dear Selection Committee:

The South Dakota Farm Bureau supports the objective of the Soil Test Phosphorus and Run-off P Relationships for soils in the Upper Big Sioux Watershed Area. It is vital for producers to have the proposed research data enabling them to manage their operations without damaging the environment. The relationship of water quality and the soils ability to hold, store, or release phosphorus from manure will help with manure management plans in the future.

Concerns for the environment and regulatory guidelines must be based on sound science. This project will begin to provide that sound science for producers. Farm Bureau policy supports protecting the environment while keeping the regulatory burden at a minimum. Manure applications using phosphorus standards are rapidly approaching. We need this research and outreach now!

Sincerely,

Wayne Smith

Wayne Smith, SDFB

2225 Dakota Avenue South • PO Box 1426 • Huron, SD 57350 • (605) 353-8050 • sdfb@basec.net

South Dakota
State University
SDSU

COOPERATIVE
EXTENSION
SERVICE

College of Agriculture and
Biological Sciences

Office of Director/Associate Dean

Ag. Hall 154, Box 2207D SDSU
Brookings, SD 57007-0093
Phone: 605-688-4792
FAX: 605-688-6347

TO: USDA – CSREES – NRI
Cooperative Grants Program

FROM: Larry J. Tidemann, Director
SD Cooperative Extension Service

DATE: May 9, 2001

RE: Letter of Support for *Soil Test Phosphorus and Run-off P Relationship for Soils in the Upper Big Sioux Watershed Area* Proposal

It is timely to offer this letter of support for the grant proposal on *Soil Test Phosphorus and Run-off P Relationships for Soils in the Upper Big Sioux Watershed Area.* Proposed EPA regulations on manure management and the clean water act could serve a devastating blow to livestock producers if not armed with the research-based answers and best management practices in the handling and application of livestock wastes.

South Dakota's variable climate and the impact this has on crop production provide a unique variable in the crop uptake and use of these nutrients.

Livestock producer groups including beef, dairy, and swine as well as the Farm Bureau and crop commodity groups support immediate research answers to this situation.

Thus, it is timely for dollars to be allocated to address the issue that places the livestock industry at a crossroad for future investment.

LT:ec

Making a Difference

United States Department of Agriculture

USDA

NRCS Natural Resources Conservation Service

Federal Building, 200 Fourth Street SW, Huron, SD 57350-2475 (605) 352-1200

January 28, 2002

Mr. Frank Schindler, Project Manager
South Dakota State University
Plant Science Department
Box 2207A
Brookings, South Dakota 57007

Dear Mr. Schindler:

The Natural Resources Conservation Service (NRCS), in South Dakota, supports the research project for the "Improvement of Manure Management based on Soil and Runoff Phosphorus Relationships for Soils in the Upper Big Sioux Watershed."

NRCS is committed to help people conserve, maintain, and improve our natural resources and environment. This project will improve our understanding and add to our knowledge base concerning phosphorus management. Additional information and field validation in South Dakota is needed to understand the relationships of phosphorus loading of soils and the associated phosphorus concentrations in runoff. This information will help us work with producers to improve manure management strategies, as well as, improve or develop better environmental risk assessment tools.

We fully support efforts such as this project that help conserve our natural resources in South Dakota and provide producers with viable economic, as well as, environmentally sound resource solutions.

Sincerely,

JANET L. OERTLY
State Conservationist

South Dakota Cattlemen's Association

PO Box 314
Kennebec, SD 57544-0314
Phone 605-869-2272
Fax 605-869-2279
e-mail: sdcattl@wcenet.com
www.sdcattlemen.org

May 11, 2001

Jim Gerwing
South Dakota State University
Cooperatuve Extension Ag Hall
Brookings, SD 57007

Dear Mr. Gerwing:

The South Dakota Cattlemen's Association (SDCA) supports the application for the Soil Test Phosphorus and Runoff P relationships for Soils in the Upper Big Sioux Watershed Area Research. Lack of data makes it difficult for farmers and rancher to proper manage nutrient applications to the land.

South Dakota soils are diversified and differ from other states, so it is necessary to develop a phosophorus index based on our soil types. The need for this research is great as the proposed CAFO/AFO rules include a phosphorus based nutrient management plan. It is pertinent to environment and agriculture that these requirements are based on sound science.

With an expanding livestock feeding industry, South Dakota cattlemen will have the opportunity to benefit crop production in a positive light.

Thank you for you time and consideration.

Sincerely,

Tonya L. Ness

APPENDIX 3: EPA Region 8 2004 Environmental Achievement Award.

ENVIRONMENTAL PROTECTION AGENCY

EPA
Region 8
2004

Environmental Achievement

Presented to

Jim Gerwing

In recognition of superior leadership and creativity in developing nutrient management plans for concentrated animal feeding operations in South Dakota.

Robert E. Roberts, Regional Administrator

APPENDIX 4: Northeast Research Farm Summer Tour 2003

NORTHEAST RESEARCH FARM SUMMER TOUR

Plant Science Department, College of Agriculture & Biological Sciences,
SDSU Agricultural Experiment Station & Cooperative Extension Service

WHEN: WEDNESDAY JULY 2, 2003 - 4 p. m.

WHERE: JCT HWY 20 AND OLD HWY 81 OR 2 MILES WEST OF THE SOUTH SHORE EXIT ON I-29

EDUCATIONAL TOURS INCLUDE:

1. **HERBICIDE STUDIES –**
   Leon Wrage, Extension Agronomist – Weeds
   Darrell Deneke, I.P.M. Coordinator

2. **SPRING SEEDED SMALL GRAIN VARIETIES –**
   Bob Hall, Extension Agronomist – Crops

   SMALL GRAIN DISEASE UPDATE –
   Marty Draper, Extension Plant Pathologist

3. **SOIL FERTILITY, SOIL PHOSPHORUS STUDIES –**
   Jim Gerwing, Extension Soils Specialist
   Frank Schindler, Chemistry Dept

   SPRING WHEAT PROJECT –
   Karl Glover, Wheat Breeder

4. **CORN and SOYBEAN INSECTS –**
   Mike Catangui, Extension Entomologist

   ALFALFA VARIETIES–
   Vance Owens, Forages

POST-TOUR LUNCH SPONSORED BY:

Area County Crop Improvement Associations,
Dow Agrosciences,
Farm Credit Services,
South Dakota Wheat Commission

APPENDIX 5: Northeast Research Farm Summer Tour 2004

NORTHEAST RESEARCH FARM SUMMER TOUR

Plant Science Department, College of Agriculture & Biological Sciences,
SDSU Agricultural Experiment Station & Cooperative Extension Service

WHEN: MONDAY JULY 19, 2004 – 2- 6 p. m.

WHERE: JCT HWY 20 AND OLD HWY 81 OR 2 MILES WEST OF THE SOUTH SHORE EXIT ON I-29

EDUCATIONAL TOURS INCLUDE:

1. **HERBICIDE STUDIES –**
   Leon Wrage, Extension Agronomist – Weeds
   Darrell Deneke, I.P.M. Coordinator

2. **SPRING SEEDED SMALL GRAIN VARIETIES –**
   Bob Hall, Extension Agronomist – Crops

   SMALL GRAIN DISEASE UPDATE –
   Marty Draper, Extension Plant Pathologist

3. **WEATHER NET UPDATE –**
   Dennis Todey, State Climatologist

4. **SOIL FERTILITY, SOIL PHOSPHORUS STUDIES –**
   Jim Gerwing, Extension Soils Specialist
   Frank Schindler, Chemistry Dept

5. **CORN and SOYBEAN INSECTS –**
   Mike Catangui, Extension Entomologist

6. **FORAGE CROP UPDATE–**
   Peter Jeranyama, Extension Forage Specialist

POST-TOUR LUNCH SPONSORED BY:

Area County Crop Improvement Associations,
Dow Agrosciences,
Farm Credit Services,
South Dakota Wheat Commission,

WEST NILE VIRUS UPDATE—Jim Wilson, Pesticide Application Training and Certification

APPENDIX 6: Dakota Fest Farm Show (August 17-19, 2004)

Phosphorus Runoff Research in South Dakota

Research Need:

- ✓ Declining water quality has been linked to poor manure management
- ✓ When meeting N needs of the crop with manure, P is often over-applied for crop needs
- ✓ Average soil test P (STP) levels of manured soils in South Dakota have increased
- ✓ Soil and Runoff P relationships need to be developed for South Dakota soils to ensure the development of sound P management strategies

Objectives:

- ✓ Develop correlation between runoff P and soil test P on select soils of South Dakota using rainfall simulation
- ✓ Evaluate P sorption saturation relationships to runoff P
- ✓ Relate field runoff to indoor runoff

Methods:

- ✓ Identify Field Sites (Vienna, Poinsett, Kranzburg, Barnes, and Moody)
- ✓ Sites range from low to very high STP
- ✓ Use National P protocol (SERA-17)
- ✓ Use Rainfall Simulation

Results:

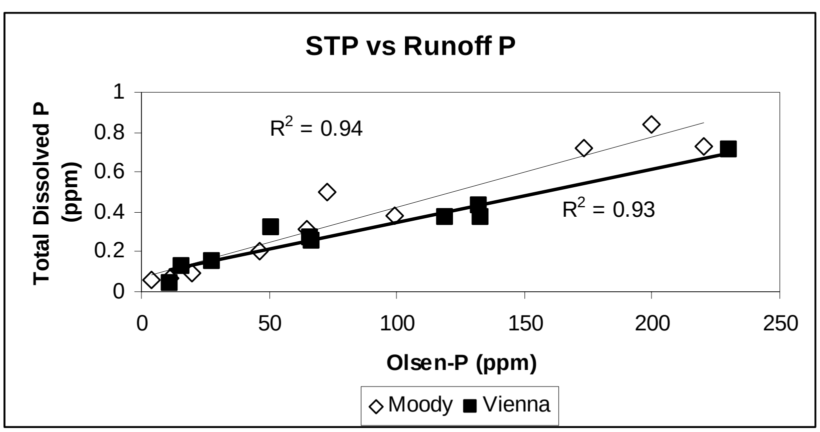


Figure 1. Relationship between Olsen Soil Test P (STP) and total dissolved P in runoff for the Vienna and Moody soil series at 0-2 inch soil depth.

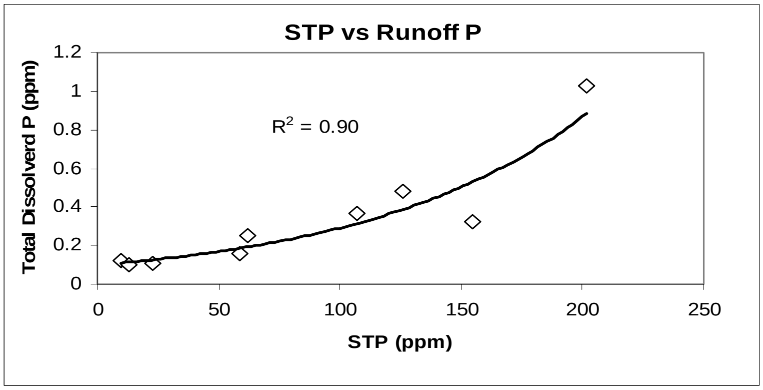


Figure 2. Relationship between Olsen Soil Test P (STP) and total dissolved P in runoff for the Kranzburg soil series at 0-2 inch soil depth.

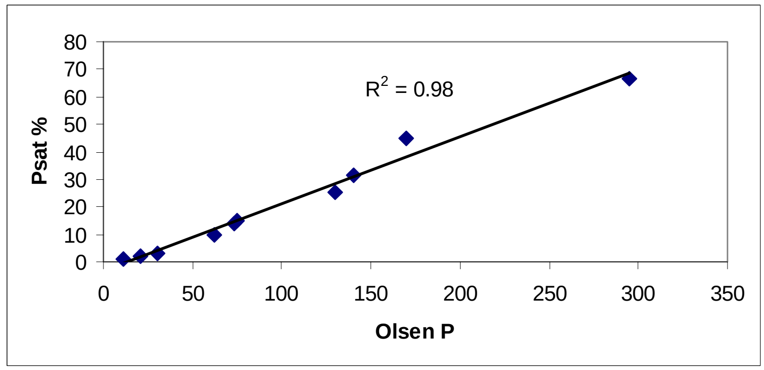


Figure 3. Relationship between P sorption saturation and Olsen-P for the Vienna soil series.

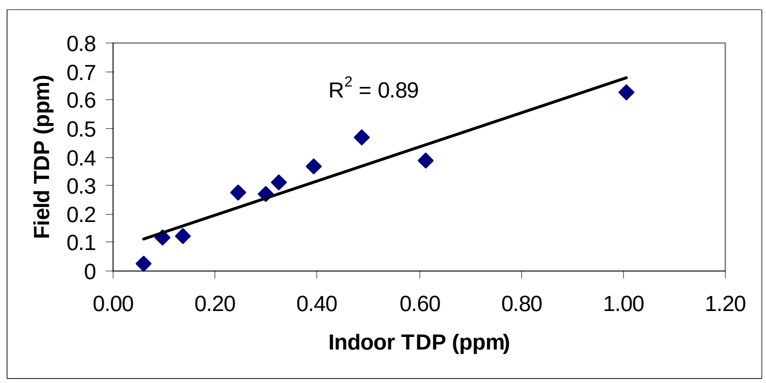


Figure 4. Relationship between TDP in field runoff and TDP in indoor runoff for the Vienna soil series.

Financial Support Provided by:

- South Dakota Department of Environment and Natural Resources
- SD Corn Utilization Council
- SD Pork Producers Council
- National Institutes for Water Resources-US Geological Survey
- South Dakota Agricultural Experiment Station

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APPENDIX 7: Northeast Research Farm Summer Tour 2003 Handout

Phosphorus Runoff Research in South Dakota

SDSU

Research Need:

- ✓ Declining water quality has been linked to poor manure management
- ✓ When meeting N needs of the crop with manure, P is often over-applied for crop needs
- ✓ Average soil test P (STP) levels of manured soils in South Dakota have increased
- ✓ Soil and Runoff P relationships need to be developed for South Dakota soils to ensure the development of sound P management strategies

Objectives:

- ✓ Develop correlation between runoff P and soil test P on select soils of South Dakota using rainfall simulation
- ✓ Evaluate P sorption capacity and P saturation relationships to runoff P

Methods:

- ✓ Identify Field Sites (Vienna, Poinsett, Kranzburg, Barnes, and Moody)
- ✓ Sites range from low to very high STP
- ✓ Use National P protocol (SERA-17)
- ✓ Use Rainfall Simulation

Results:

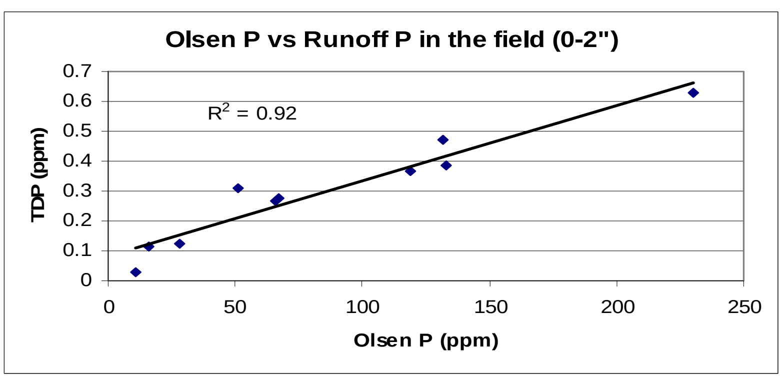

Figure 1. Relationship between Olsen Soil Test P (STP) and total dissolved P in runoff for the Vienna soil series.

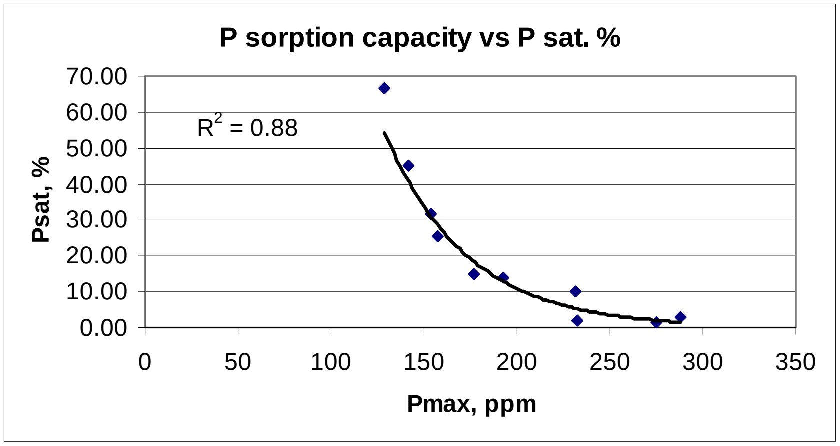

Figure 2. Relationship between sorption capacity and P saturation percentage for the Vienna soil series.

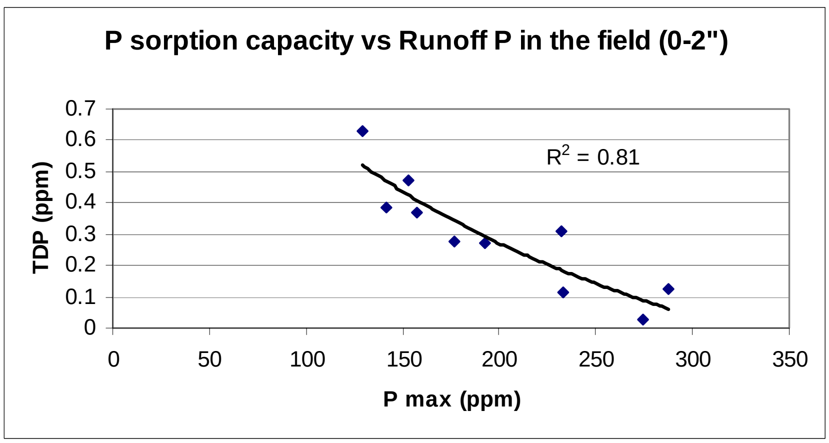

Figure 3. Relationship between P sorption capacity and total dissolved P in runoff for the Vienna soil series.

Financial Support Provided by:

- South Dakota Department of Environment and Natural Resources
- SD Corn Utilization Council
- SD Pork Producers Council
- National Institutes for Water Resources-US Geological Survey
- South Dakota Agricultural Experiment Station

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Water Resources Institute
Department of Plant Science
Cooperative Extension Service

SDSU

APPENDIX 8: Northeast Research Farm Summer Tour 2004 Handout

Phosphorus Runoff Research in South Dakota

SDSU

Research Need:

- ✓ Declining water quality has been linked to poor manure management
- ✓ When meeting N needs of the crop with manure, P is often over-applied for crop needs
- ✓ Average soil test P (STP) levels of manured soils in South Dakota have increased
- ✓ Soil and Runoff P relationships need to be developed for South Dakota soils to ensure the development of sound P management strategies

Objectives:

- ✓ Develop correlation between runoff P and soil test P on select soils of South Dakota using rainfall simulation
- ✓ Evaluate P sorption saturation relationships to runoff P
- ✓ Relate field runoff to indoor runoff

Methods:

- ✓ Identify Field Sites (Vienna, Poinsett, Kranzburg, Barnes, and Moody)
- ✓ Sites range from low to very high STP
- ✓ Use National P protocol (SERA-17)
- ✓ Use Rainfall Simulation

Results:

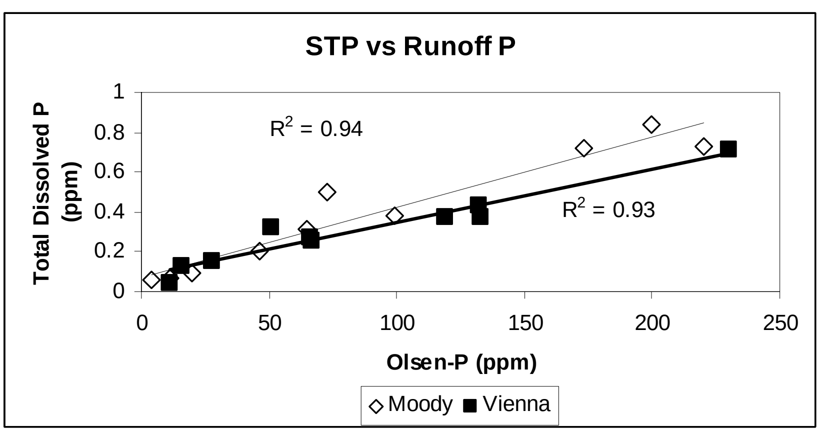


Figure 1. Relationship between Olsen Soil Test P (STP) and total dissolved P in runoff for the Vienna and Moody soil series at 0-2 inch soil depth.

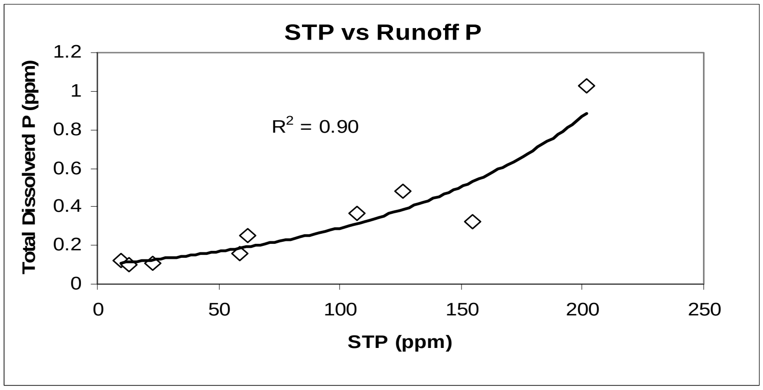


Figure 2. Relationship between Olsen Soil Test P (STP) and total dissolved P in runoff for the Kranzburg soil series at 0-2 inch soil depth.

Figure 3. Relationship between P sorption saturation and Olsen-P for the Vienna soil series.

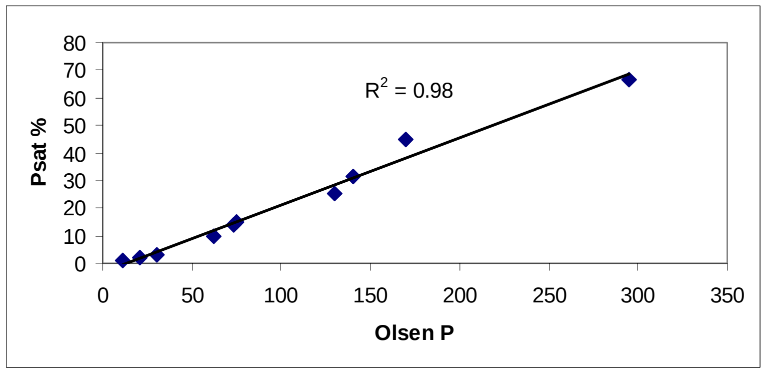
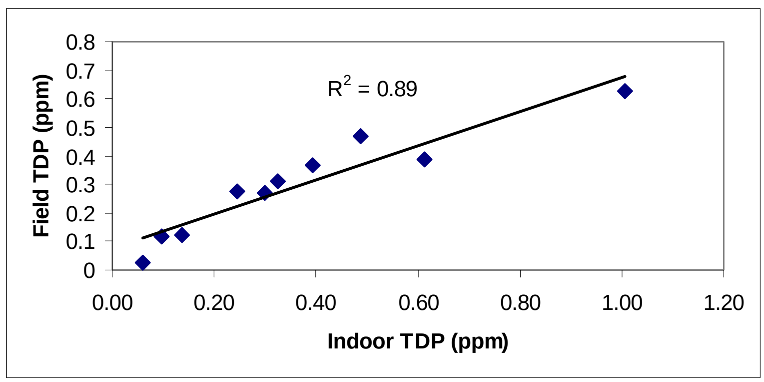


Figure 4. Relationship between TDP in field runoff and TDP in indoor runoff for the Vienna soil series.



Financial Support Provided by:

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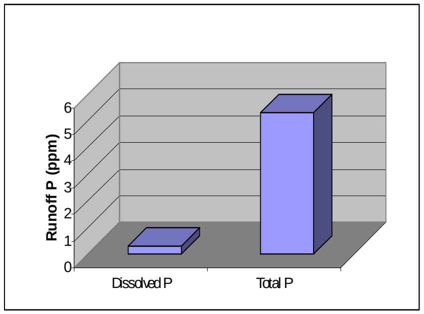

- Total P is about 17 times greater than total dissolved P, which is indicative of high amounts of sediment-bound P.

- This is not surprising since our plots were established to mimic conventionally tilled conditions with little to no residue cover.

D. Discussion

- While STP is related to runoff P concentrations for a single soil series, we need to compare our results with the Vienna soils to other common cropped soils in the state.

- Variability in runoff volume and erosion as a result of varying climatic and topographic factors, and/or agronomic practices will undoubtedly play a more significant role in determining P loss than STP alone.

- P runoff can be reduced by…
  - ✓ Considering the P requirements of the crop
  - ✓ Implementing conservation tillage practices that minimize runoff and erosion
  - ✓ Not applying manure or fertilizer P to frozen ground
  - ✓ Using cover crops and residues to increase water infiltration
  - ✓ Using filter strips, natural or constructed wetlands to capture excess P before it enters mainstream channels

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Phosphorus Runoff Research in South Dakota

APPENDIX 9: 2003 P runoff Brochure (page 2 of 2)

Introduction:

- Eutrophication is a widespread water quality problem
- Declining water quality has been linked to poor manure management
- Manure applications for permitted facilities in South Dakota are based on both the N and P needs of crop, and soil test
- When meeting N needs of the crop with manure, P is often over-applied for crop needs
- Average soil test P (STP) levels of manured soils in South Dakota have increased 22 ppm over the past 15 years
- Nearly 60% of manured soils in South Dakota possess soil test P levels in the very high category for crop growth
- The national P research effort has shown that as soil P levels increase, P concentration in surface runoff also increase
- Declining water quality and Eutrophication due to P runoff are not unique to the heavily manured soils of the Atlantic Coastal states
- Soil and Runoff P relationships need to be developed for South Dakota soils to ensure the development of sound P management strategies

Developing Soil and Runoff Phosphorus Relationships

A. Objectives

- Develop correlation between runoff P and soil test P on select soils of South Dakota using rainfall simulation
- Evaluate P sorption capacity and P saturation relationships to runoff P

B. Methods and Materials

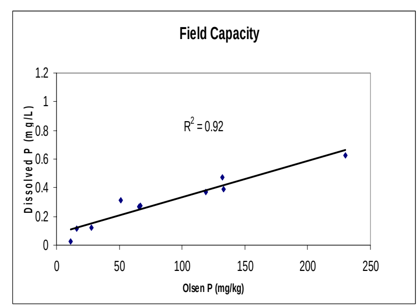
- Identified Vienna Field Sites
- Sites ranged from low to very high STP

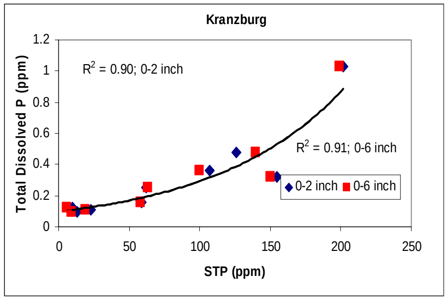
Fig. Rainfall Simulator

- Use National P protocol (SERA-17)
- Used Rainfall Simulation

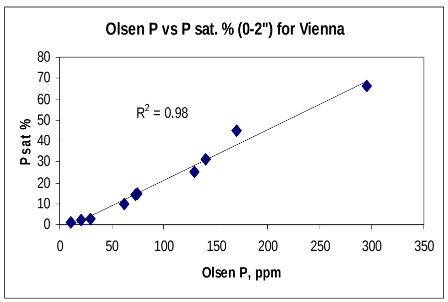
C. Results

- Data show very good linear relationships between STP and runoff P for the Vienna soil.





- Kranzburg soil exhibited a curvilinear relationship. Greater P loss to surface water at excessively high STP levels (i.e., >180 ppm) may be evident



- P saturation of Vienna soil is strongly related to Olsen soil test implicating STP as a possible environmental indicator. More comparisons are being made

D. Management

- Variability in runoff volume and erosion as a result of varying climatic and topographic factors, and/or agronomic practices will undoubtedly play a more significant role in determining P loss than STP alone.

- P runoff can be reduced by…
  - ✓ Considering the P requirements of the crop
  - ✓ Implementing conservation tillage practices that minimize runoff and erosion
  - ✓ Not applying manure or fertilizer P to frozen ground
  - ✓ Using cover crops and residues to increase water infiltration
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Brookings, SD 57007

Revised January 2004

Phosphorus Runoff Research in South Dakota

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- Use National P protocol (SERA-17)
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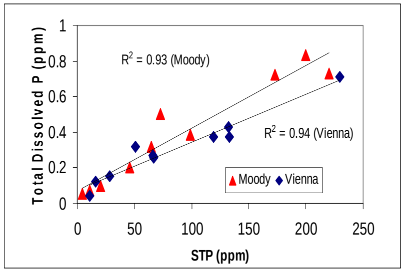
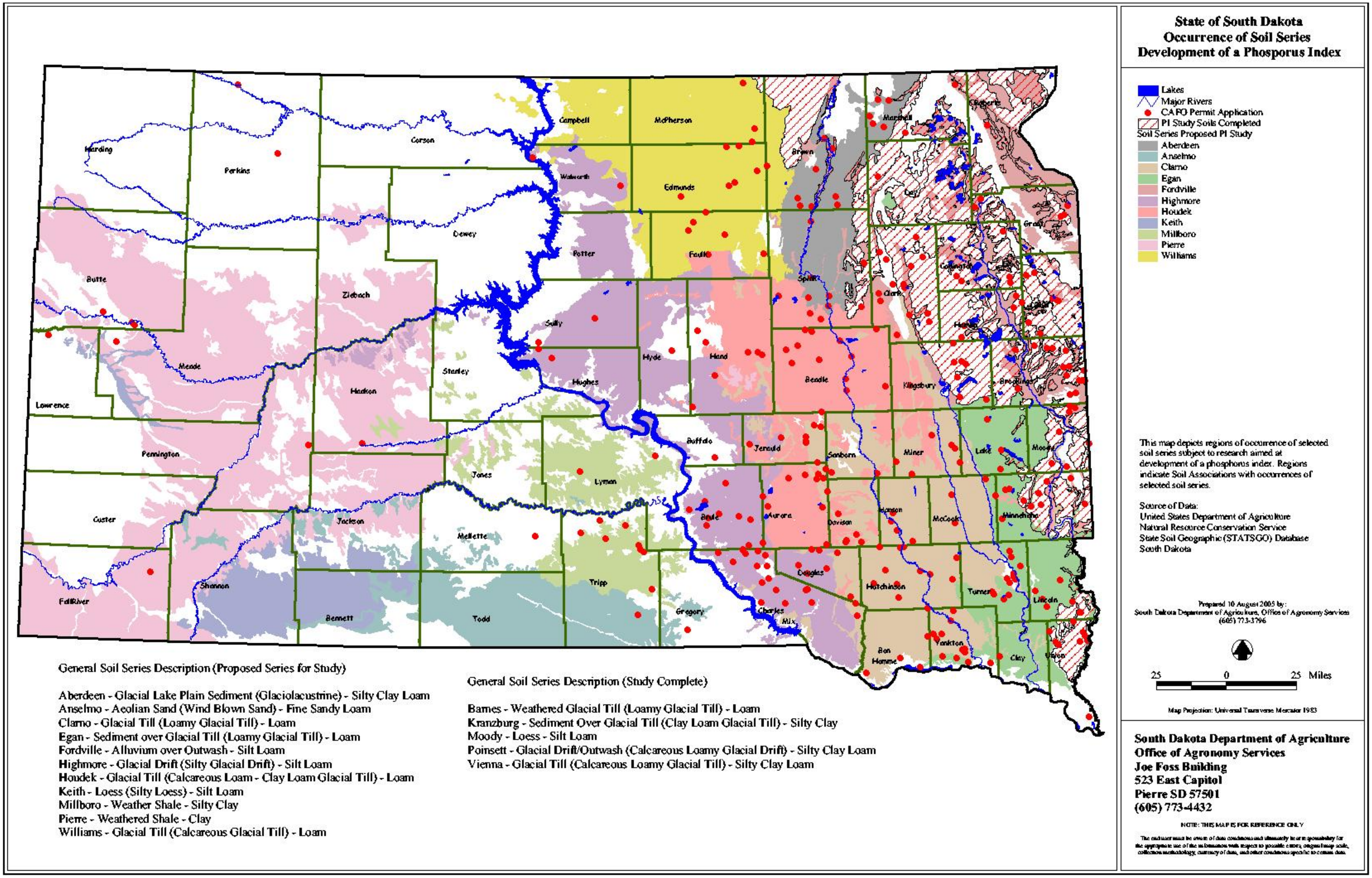
C. Results

- Data show very good linear relationships between STP and runoff P for the Vienna and Moody soil.



APPENDIX 11: State of South Dakota Occurrence of Soil Series and Development of a Phosphorus Index map.



APPENDIX 12: List of Publications and Presentations related to the Manure Management BMPs Based on Soil Phosphorus Education and Information Project.

Publications:

Schindler, F.V., A. R. Guidry, D. R. German, R. H. Gelderman, and J.R. Gerwing. 2005. Using Simulated Rainfall to Evaluate Field and Indoor Surface Runoff Phosphorus Relationships. In preparation.

Schindler, F.V., A. R. Guidry, D. R. German, R. H. Gelderman, and J.R. Gerwing. 2005. Relationship between Soil Test Phosphorus and Phosphorus in Runoff from South Dakota Soils. In preparation.

Schindler, F.V., D. German, A. Guidry, and R. Gelderman. 2003. Assessing Soil and Runoff Phosphorus Relationships for the Moody and Kranzburg Soils. In Soil and Water Research 2003 - South Dakota State University, Plant Science Department Annual Progress Report, Pamphlet No. 9, Soil PR 03-42.

Schindler, F.V. 2003. Phosphorus study focuses on South Dakota agricultural soils. In South Dakota Corn Council Review, June 2003 Newsletter, p. 5. South Dakota Corn Utilization Council.

Schindler, F.V., D. German, A. Guidry, and R. Gelderman. 2002. Developing soil and runoff phosphorus relationships for dominant agricultural soils in South Dakota. In Soil and Water Research 2002 - South Dakota State University, Plant Science Department Annual Progress Report, Pamphlet No. 9, Soil PR 02-44.

Presentations:

Guidry, A.R., F.V. Schindler, D. R. German, R. H. Gelderman, and J.R. Gerwing. 2004. Influence of Soil Test Phosphorus on Phosphorus Runoff Losses from South Dakota Soils. 34th Annual North Central Extension-Industry Soil Fertility Conference. Des Moines, Iowa Nov. 17-18, 2004.

Guidry, A.R., D. R. German, R. H. Gelderman, J.R. Gerwing, and F.V. Schindler. 2004. Evaluating phosphorus loss from Midwestern soils Using Simulated Rainfall. ASA, CSSA, SSSA Annual Meetings. Oct. 31-Nov.4, 2004. Seattle, Washington, abstract No. 3277.

German, D.R., A.R. Guidry, R. H. Gelderman, F.V. Schindler, and J.R. Gerwing, 2004. Soil and runoff P relationships: Implications for lake and watershed management. ASA, CSSA, SSSA Annual Meetings. Oct. 31-Nov.4, 2004. Seattle, Washington, abstract No. 4732.

Schindler, F.V. 2004. Soil and Surface Runoff Phosphorus relationships of South Dakota Soil: What are the implications? Presented to the Soil Science Department, University of Wisconsin, 25 January 2004.

German, D.R., A. Guidry, and F.V. Schindler. 2004. Predicting phosphorus in runoff based on soil phosphorus. South Dakota State University, Agricultural Engineering Department, Soil Moisture Workshop, January 2004.

Schindler, F.V., D.R. German, and A. Guidry. 2003. Developing soil and surface runoff P relationships using simulated rainfall. A demonstration of indoor rain simulation and presentation of research results to South Dakota Cattlemen Association and SD DENR Project Directors. South Dakota State University, Agricultural Engineering Department, January 2003.

Schindler, F.V., D.R. German, and A. Guidry. Developing soil and surface runoff P relationships using simulated rainfall. South Dakota Department of Environment and Natural Resources. 319 Project update, Aberdeen, SD. February 2003.

Guidry, A. 2003. Presented two presentations of the P runoff work in February 2003. One presentation was for her seminar class and the other was presented in Pierre, SD for a scholarship requirement.

Schindler, F.V., D.R. German, and A. Guidry. 2003. Developing soil and surface runoff P relationships using simulated rainfall. South Dakota Department of Environment and Natural Resources. 319 Task Force update, Pierre, SD. March 2003.

Schindler, F.V., D.R. German, and A. Guidry. 2003. Manure Management BMPs based on soil phosphorus. Field day demonstration. South Dakota State University, Northeast Research Farm Summer Tour, Watertown, SD. July 2, 2003.

Schindler, F.V. 2002. Developing soil and surface runoff phosphorus relationships using simulated rainfall. Soil Fertility Update meetings for South Dakota livestock producers, agronomists, and extension personnel. Meetings in Aberdeen, Pierre, Brookings, and Beresford, South Dakota. Dec 9-12, 2002.

Schindler, F.V., D.R. German. 2004. Evaluating Phosphorus Loss on a Watershed Scale. South Dakota Department of Environment and Natural Resources. 319 Task Force. Pierre, SD. 09 September 2004.