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Agricultural NPS Control of Phosphorus in the New York State, Lake Ontario Basin

Volume III — The Influence of Tillage on Phosphorus Losses from Manured Cropland

FOREWORD

The U.S. Environmental Protection Agency (USEPA) was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment.

The Great Lakes National Program Office (GLNPO) of the U.S. EPA was established in Chicago, Illinois to provide specific focus on the water quality concerns of the Great Lakes. The Section 108(a) Demonstration Grant Program of the Clean Water Act (PL 92-500) is specific to the Great Lakes drainage basin and thus is administered by the Great Lakes National Program Office.

Several demonstration projects within the Great Lakes drainage basin have been funded as a result of Section 108(a). This report describes one such project supported by this office to carry out our responsibility to improve water quality in the Great Lakes.

We hope the information and data contained herein will help planners and managers of pollution control agencies to make better decisions in carrying forward their pollution control responsibilities.

Director
Great Lakes National Program Office

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AGRICULTURAL NONPOINT SOURCE CONTROL OF PHOSPHORUS IN THE NEW YORK LAKE ONTARIO BASIN

VOLUME 3. THE INFLUENCE OF TILLAGE ON PHOSPHORUS LOSSES FROM MANURED CROPLAND

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D I S C L A I M E R

ABSTRACT

A sprinkling infiltrometer was used to evaluate total phosphorus (TP) and total soluble phosphorus (TSP) losses in surface runoff from plots receiving manure application rates of 22-135 MT/ha and from plots where manure had been incorporated to depths varying from 0-20 cm. Both laboratory and field trials were conducted utilizing simulated precipitation. Infiltrometer runs were repeated for various drying conditions of the soil manure mixture at time intervals varying from 1-30 days.

Significantly higher TP and TSP loads in surface runoff were associated with surface applications of manure immediately followed by a precipitation event. For the standard 12-cm, 60-minute event, TP and TSP loads were as high as 13.4 and 7.7 kg/ha, respectively. These loads were 20-25 times greater than observed TP, TSP loads from control plots. Typically, the high loading rates were short-lived with the positive effects of manure amendments on infiltration, moisture retention and phosphorus sorption being observed after drying periods of 5-25 days. Generally, after several wet-dry cycles TP, TSP loads approached control levels.

With the incorporation of manure to depths of 3, 10 or 20 cm, both TP and TSP loads were greatly reduced. In particular, minimal incorporation of 3 cm resulted in 70-90% reductions in TP, TSP loads in surface runoff from the initial high loading case.

When TP, TSP loads were normalized for application rate, losses of TP, TSP in surface runoff per kg of manure applied were greater for the lower rates. For the case of TP, TSP loads normalized by depth of incorporation, losses from surface applications were three to five times greater than that of other incorporation depths. Incorporation depths as little as 3 cm indicated 50-60% reductions in TP, TSP, loads in surface runoff for each unit of manure applied.

The conflicting objectives of maintaining surface residues with reduced tillage systems and minimizing phosphorus losses through manure incorporation reflect a need for the development of tillage-manure systems. These systems could take advantage of three to five year tillage rotations where a moldboard or chisel plow would be used periodically on no-till fields. In addition, variable application rates and surface incorporation methods could be utilized to decrease overall farm losses.

The sprinkling infiltrometer provides the basis for a promising method of on-site evaluation of tillage-manure systems. The versatility of such an instrument in a laboratory and field setting is advantageous. Tillage-manure systems and other phosphorus control measures can be accurately compared using such techniques. Lastly, the accumulation of a data bank from infiltrometer runs provides a basis for more comprehensive comparisons of tillage-manure phosphorus control options.

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SYMBOLS AND TERMS

kg/ha/yr	- kilograms per heactare per year
MT/ha	- metric tonnes per heactare
TP	- total phosphorus
TSP	- total soluble phosphorus
Load	- mass
Flow	- runoff volume
C/N	- carbon to nitrogen ratio
P	- phosphorus
N	- nitrogen
NH_3	- ammonia nitrogen
ON	- organic nitrogen
TKN	- total kjeldahl nitrogen
VS	- volatile solids
rate	- manure application rate
depth	- depth of manure incorporation
Hg	- mercury
mL	- milliliters
g	- gram
mg	- milligrams
SS	- suspended solids
PWSI	- Purdue-Wisconsin Sprinkling Infiltrometer
LGX	- laboratory series utilizing Genesee silt loam, X-run number
LBX	- laboratory series utilizing Bath silt loam, X-run number
FBX	- field series utilizing Bath silt loam, X-run number
AOV	- analysis of variance
PIR	- precipitation to initiate runoff
Normalized	- load conversion based on unit manure application
Nutrient	- nitrogen and phosphorus

SECTION I
INTRODUCTION

BACKGROUND

The application of manure to cropland has been a valued source of plant nutrients for centuries. Tunney (1978) estimated that, on a worldwide basis, more nitrogen and phosphorus are made available from manure production than are applied through inorganic forms. Improvements in soil aggregation, tilth, surface permeability and water holding capacity are also associated with manure applications to soil.

Although once an essential resource in farm fertility management, animal manures are now often considered a waste product to be disposed of in the least costly manner. Until the late nineteenth century, agriculture depended almost exclusively on animal manures and legumes as nutrient sources to maintain crop yields (Stewart, 1980). The availability of inexpensive inorganic nutrients and their relative advantages in handling and application have intensified manure disposal problems. Increased herd size and confinement coupled with decreased reliance on foraging have further encouraged agricultural technologies which do not include efficient utilization of livestock manures.

Where poor management and inefficient utilization of manurial nutrients are evident, contamination of surface and groundwater is possible. In particular, impoundments subjected to accelerated nutrient loading can become eutrophic. The subsequent degradation of water quality can impair drinking water supplies, survival of fish and other aquatic species, and recreational water uses.

During the past decade tillage technology has evolved rapidly. This trend has resulted in systems which minimally disrupt the soil while substituting chemical weed and insect control. Currently over 30% of the nation's cropland is in some form of reduced tillage (USDA, 1985). This level is approximately three to four times the 1975 level. USDA projections indicate that this trend is likely to continue through the 1990s.

New York farmers have not adopted reduced tillage systems as rapidly as other states. However, the area of cropland under reduced tillage has increased from 800 ha in 1980 to 130,000 ha in 1985 which accounts for about 13.5% of the state's cropland (SCS, 1985).

OBJECTIVES

The disposal of livestock waste on soil within the context of reduced tillage systems imparts an additional dimension to potential nutrient losses from cropland. Manure application rate, incorporation depth, method of incorporation, location and time, can all potentially influence nutrient loads in surface runoff. To begin identifying which variables are most important in the loss of phosphorus from manure spread cropland, a series of experiments were designed. The objectives of the laboratory and field experiments conducted during the 29-month period of study are the following:

1. To observe total phosphorus (TP) and total soluble phosphorus (TSP) concentration and load changes in surface runoff for different manure application rates and depths of incorporation

2. To observe changes in TP, TSP concentrations and loads over time

3. To utilize the above results (1 and 2) as a basis for estimating the effect of tillage on the incorporation of manure and subsequently the effect of tillage on TP, TSP loads

4. To utilize the above results (1, 2 and 3) to identify tillage-manure systems which are likely to reduce TP, TSP loads from cropland

REVIEW OF RELATED RESEARCH

To accomplish study objectives and benefit from related research efforts, the following literature review accessed two extensive data bases; the Commonwealth Agricultural Bureau (CAB, 1984) and the Computerized Agricultural Information Network (CAIN, 1984). Key words were organized to extract information on the effect of manure applications and tillage on the hydrologic response and associated phosphorus losses from agricultural soils.

NUTRIENT LOSSES FROM AGRICULTURAL AREAS

The fact that phosphorus has been identified as the limiting nutrient in most lake eutrophication processes has initiated a considerable body of research directed toward the effect of tillage on phosphorus losses from cropland. Logan and Adams (1981) have assessed loading data from all monitored U.S. tributaries draining into Lake Erie. They estimate that 30% of the total tributary load is sediment bound and that 70% of the nonpoint phosphorus load originates from cropland.

Logan and Adams (1981) conclude (from work accomplished by other researchers) that the equilibrium phosphorus concentration of the top few centimeters of soil under a no-till system would be higher than that under conventional tillage. Oloya and Logan (1980) and Romkens et al (1973) have shown increased accumulation of no-till fields of phosphates at the surface of no-till fields resulting in a relatively high level of soluble phosphorus in surface flow. Barisas et al (1981) evaluated conservation tillage practices for nutrient control from cropland. They concluded that conservation tillage was not as effective in reducing losses of nutrients in the dissolved phase. However, they did indicate that conservation tillage would decrease total nutrient load by reducing the losses of the sediment bound fraction.

Logan and Adams (1981) point out that fertilizer practices can influence nutrient concentration in runoff, as demonstrated by several researchers (Romkens and Nelson, 1974; Oloya and Logan, 1980, Baker and Laflen, 1981 and McDowel et al 1980). The interaction of phosphorus fertilizers with the soil are complex and dynamic. Although much of the fertilizer phosphorus (P) applied is 100% water soluble at the time of application, only 10-20% of the fertilizer P remains available with much of the initial application being quickly converted to highly insoluble precipitates of P. A fraction of the fertilizer P applied becomes sorbed to soil surfaces and remains available for plant growth, while some is lost in runoff if soil conditions are favorable. Despite this partitioning between soluble and insoluble forms of P, a significant correlation between soluble P concentration in runoff and extractable P associated with soil particles was observed.

SEASONAL DIFFERENCES IN NUTRIENT LOAD FROM MANURED CROPLAND

Converse et al (1975) compared yearly losses to seasonal losses from manured plots. Over three years no significant differences in nitrogen or phosphorus losses were observed. Runoff volume, however, was consistently less from the fall manured plots than from the winter or spring applications.

In the third year of a study by Young and Mutchler (1976), increased nutrient flux was observed from the spring manured plots. Heavy spring rains which occurred during the snowmelt period and acted on the exposed spring application were associated with accelerated loss of nutrients in surface runoff.

Hensler et al (1970), Young and Holt (1974), Klausner et al (1976) and Steenhuis et al (1977), examined nutrient losses occurring during snowmelt/rainfall runoff events. Both Klausner et al (1976) and McCaskey et al (1971) varied the application rate in order to evaluate the effect of manure loading rate on nutrient load in runoff. Long et al (1979) spread dry dairy manure on the surface of fields during five different periods in a year. Muck et al (1975) studied the influence of flow rate on nutrient concentrations using poultry manure. Results of all of these studies indicate that nutrient load in surface runoff is strongly influenced by the time between manure application and runoff events. The conditions which induce these events can be snowmelt, precipitation or both. Hensler et al (1970) applied manure during the winter over a two-year period. During the first year nutrient losses from the manured plots were six times that of the control plots. In the second year, losses from manured and control plots were similar with a slightly lower flux from the manured plots. These contradictory results were explained by examining the precipitation patterns for the two-year monitoring period. Within 24 hours after manure was applied the first year, warm temperatures induced snowmelt and a 1.9 cm precipitation event greatly enhanced losses. During the second year, similar events did not occur combined with a generally lower level of precipitation.

Steenhuis et al (1977) studied winter spreading of manure under two sets of conditions. On one group of plots, manure was applied on frozen ground in late January, snow was allowed to accumulate, and runoff losses were measured during the snowmelt events in late February. On the other group of plots, manure was applied on 0.6 cm of ice resulting from sleet in early March. More snow and sleet accumulated and runoff was monitored until the melt was completed in mid-March. Nutrient losses from these later plots were 20-30 times greater than those of the corresponding control plots while the January application resulted in losses which were considerably less.

Although the above studies demonstrate elevated nutrient load during thaw periods, a number of field studies have reported small differences between the manured and unmanured cases. Young et al (1977) measured nitrogen loads from manured plots for three years. Runoff volume from the manured plots was less than from the corresponding control plots, while phosphorus losses were slightly higher. Converse et al (1975) recorded total nitrogen, inorganic nitrogen and total soluble phosphorus in runoff from both control and manure treated plots. Although nutrient concentrations in runoff from most manured plots were higher, total nitrogen and total phosphorus losses from the manured plots were not significantly different than the losses from control plots. An exception to these findings was that inorganic-N losses from the manured plots were found to be significantly greater than the control plots.

McCaskey et al (1971) reported increased total -N, inorganic -N and TSP losses from two plots and decreased losses from the third. Plots received 52.8, 104.5 or 157.3 MT/ha of manure distributed over 45 weeks. The plots which received the greatest loading exhibited a decreased nutrient loss rate per unit manure applied.

Although all of the above experiments were carried out on corn, alfalfa or grass plots, few researchers compared the three. Young and Mutchler (1976) observed snowmelt nutrient losses from corn and from alfalfa plots. Losses of nitrogen and phosphorus from the manured alfalfa plots were considerably higher than those from the manured corn plots. The authors reasoned that some of these differences were due to the rougher surface of the corn plots which would accommodate more surface storage.

Young and Holt (1974) simulated a 12.7 cm, two-hour rainfall five days after a late spring manure application. Nutrient flux from the manured plot was appreciably greater than the flux from the control plots.

Klausner et al (1976) applied manure at annual rates of 16.5, 49.5 and 99 MT/ha on corn plots over a three-year period. The monitoring period was during late winter and early spring. With one exception, losses from all plots measured less than 9.0 kg/ha and 3.5 kg/ha for inorganic nitrogen and TSP, respectively. However, during the first year of monitoring the plot receiving 49.5 MT/ha of manure lost 51.7 kg/ha of inorganic -N and 9.9 kg/ha of TSP. This was the only time a plot was applied with manure while snow was actively melting. During the last two years of the study, when all manure applications were to frozen ground which was subsequently covered by snow, no appreciable difference in nutrient load was observed between the three application rates.

SOME EFFECTS OF MANURE ON THE HYDROLOGIC AND NUTRIENT PROPERTIES OF SOIL

The application of manure to soil alters the physical, chemical and biological properties of the soil and soil environment. The following elements of the literature review emphasize a number of the physical changes in soil as a result of manure applications. A number of the physical variables relate directly to the hydrologic response of manure amended soils. These relationships in turn influence TP and TSP loading.

The Influence of Manure on Infiltration and Moisture Retention

The average water content of the fresh feces of a dairy cow, on a wet basis is 85-90 percent (Sobel, 1966). Physically this means, depending on application rate and incorporation depth, that a relatively large quantity of water is applied to the surface or mixed into the soil profile with each manure application.

The effect of soil manure amendments on soil water capacity has been researched by Unger (1974). He studied the influence of feedlot wastes on various soil characteristics including soil water holding capabilities. He reported that the effect of manure on pore size and space appears to negate some of the benefits an increase in percent organic matter might have on field capacity. For the case of fresh manure applications, Unger (1974) concluded that a net decrease in field capacity would result. Unger (1974) also reported that soil bulk densities decreased with larger application rates due not only to an increase in percent organic matter, but also to an increase in percent air space. This is supported by an observed increase in water content at the level of saturation.

Organic Matter Accumulation and Decomposition

A number of researchers who have looked at livestock waste disposal treat it as a simple addition to the pool of organic matter in soil. Johnston (1980) reported on the long-term monitoring of soil organic matter, concluding that changes in soil organic matter vary directly with the quantity of organic matter added and the oxidation rate. VanDyk (1980) and Sochtig and Sauerbeck (1980) studied how organic matter accumulation, degradation and decomposition vary with soil properties and environmental conditions.

Several researchers have studied how organic matter contributes to the nutrient status of soils. Johnston (1980) suggests that an important contribution of organic matter is the stabilization of soil structure. In addition, he points out that increases in cation exchange capacity and the release of nitrogen, phosphorus, sulfur and micronutrients during oxidation of organic matter directly benefit plant growth. Climatic factors and farming systems will circumscribe the short-term advantage of these processes. Dutil (1980) points out the importance of the quality of organic amendments and their influence on carbon to nitrogen (C/N) ratios in the short-term. He concludes that a buildup of organic matter in the short-term will occur only if extremely large quantities of waste are added. He cautions that this could depress crop yields unless sufficient quantities of nitrogen are supplemented.

Newhould (1980) concluded that organic matter was the key influence on soil structure in unstable soils. Similar to other investigators (Sauerbeck, 1982; Parvlson and Jenkinson, 1981), Newhould (1980) observed small changes in organic carbon levels as a result of farming practices. After 60 years of continuous cultivation, organic carbon levels typically changed less than one percent. Although McGrath (1980) observed larger changes in organic carbon content for continuously farmed plots, he demonstrated that much of the difference can be attributed to the redistribution of organic matter when a grassland soil is tilled.

The Influence of Soil Moisture

The influence of crop system, tillage and manure amendments on soil moisture have been documented by several investigators. Jovanove and Veskove (1974) reported that stable manure treatments affected soil moisture more than plant residues. Kuipers (1982) documents a 30% increase in surface storage with tillage methods which left a roughened surface. Kuipers (1980) also observed an increase in infiltration rate at moderate rainfall intensities. Davies (1980) concluded that moisture retention properties of no-tilled soils in the short-term are related to their ability to retain sufficient coarse porosity at the surface. Larson (1980) documented the advantages of surface infiltration when residues are present.

Sarkan et al (1973) observed increases in hydraulic conductivity, percent saturation and a decrease in the percent of soil dispersion associated with manure applications. Biswas and Khasla (1971), Long et al (1975), and Mazurak et al (1955) recorded changes in soil-water intake and storage as a result of manurial soil amendments. Mazurak et al (1955) noted that the rate of water intake for manured row crops was nearly twice the rate of the unmanured plots.

Soil Management and Nutrient Availability, Retention and Losses

Several investigators have studied the influence of farming practices on the decomposition rates, availability and losses of nutrients in the soil profile. Sauerbeck (1980) found that the addition of nitrogen to the soil in the fall had little effect on decomposition rates. He also observed that a combination of straw and inter-cropping are likely to approach the effect of farmyard manure alone. Both Sauerbeck (1980) and Davis (1980) concluded that despite different soil treatments and cropping systems, soil humus content will likely approach an equilibrium value. Sauerbeck (1980) suggests that humus conservation should not be an objective of farming systems unless it is proven that a particular system drastically decreases soil organic matter over a long period. Sauerbeck (1982) concludes that erosion of soil organic matter and humus (decomposed organic matter) on steep slopes probably has a larger effect on soil humus levels than crop rotations or manurial treatments.

Kafoed (1982) stresses the importance of soil humus in retaining water and plant nutrients and for buffering changes. Sauerbeck (1982) also speculates that the value of the highly degradable fraction of manure is more important than previously thought. He points out that the benefits include intermediate products of decomposition and microbial turnover.

Aggregate size distribution and water stability were measured by Katcheson et al (1979). They observed that soil aggregates less than 5 mm in size favored corn growth on a well-drained silt loam soil. Fall moldboard plus four spring tillage operations resulted in higher corn yields than either full chisel or no-till. They attributed tillage advantages to the lower penetration resistance of the moldboard system.

Romkens et al (1973) compared the nutrient control effectiveness of various tillage methods. He concludes that most of the nutrient losses from cropland are associated with enriched colloidal particles and the tillage system which controls this fraction will be the most effective control practice.

THE EFFECT OF TILLAGE ON SOIL PROPERTIES AND NUTRIENT LOSSES

Many investigators have studied the influence of manure amendments and tillage on soil structure. Unlike organic matter levels, soil structure is changing constantly under the influence of mechanical forces and water flux induced by precipitation, evaporation, freezing, thawing, stage of crop growth, and farming methods (Kafoed, 1980).

Fawcett (1978) related changes in water accumulation to cone penetrometer measurements. He derived a linear relationship between the log of available water and the force required for cone penetration. Marston and Herd (1978) relate that clay content may be more critical than organic matter in maintaining aggregate stability in heavy clay soils. Osborne et al (1970) reported that bulk density of the surface 0-10 cm was significantly increased by all cultivation treatments. They relate that the permeability of the soils they tested was strongly correlated to the degree of aggregation. In turn the bulk density was significantly related to penetrometer readings. Russell (1978) stresses the importance of roots on soil structure. He also observed that pore size decreased with increasing bulk density.

Pidgeon and Soane (1978) demonstrated that bulk density responses to tillage systems varied with soil type while cone resistance measurements did not. Over a ten-year period, Pidgeon and Soane (1978) monitored the following tillage practices:

- deep moldboard plow (30-35 cm)
- normal moldboard (18-23 cm)
- chisel plow (3 passes, variable depth, 15-25 cm)
- zero tillage.

Cone resistance was found to be more closely linked to tillage and traffic than cropping systems. In addition, they noted that bulk density measurements alone do not correlate well with crop performance. Finally Pidgeon and Soane (1978) observed no significant increase in bulk density with zero tillage at any depth below 6 cm. In later work Soane (1980) documents soil degradation attributable to compaction under wheels and suggests control options.

Boels (1980) describes how density profiles reflect a certain equilibrium state between soil manipulation and bulk density. Boels (1980) relates work done by others which define a critical bulk density profile. This profile is an equilibrium state between bulk density and the average loading by farm machinery on non-cemented soils. This concept also suggests that loosening of soils with densities less than the critical value have to be repeated to keep the soil friable.

Herbert (1982) has described several types of soil degradation related to the organic matter level of soils. Soil compaction and elasticity appear closely related to organic matter levels. VanDyk (1980) and Sochtig and Sauerbeck (1980) have attempted to model the buildup and degradation of soil organic matter for different farming systems. Canarache (1979) developed an agrophysical index to reflect changes in soil structure. The index represents the arithmetic mean of ten individual physical properties.

Utomo and Dexter (1981a, 1981b, 1981c, 1981d) have studied several aspects of soil structure which provide insight into the possible consequences of different manure-tillage systems. On a sandy loam, Utomo and Dexter (1981a) observed that the amplitude of soil water content fluctuation increased with tillage. As a consequence, a decrease in clod strength, termed 'tilth mellowing' was noted. In another set of experiments on a sandy loam, Utomo and Dexter (1981b) found that variations in soil friability (soil structures) are closely related to soil water content. They confirmed that sandy loams are most friable at water contents approximately equal to their casagrande plastic limits. Utomo and Dexter (1981c) increased friability through wetting and drying cycles, freeze/thaw cycles and phosphoric acid treatments. Utomo and Dexter (1981d) also investigated the 'age hardening' of top soils. The term 'age hardening' is used to characterize the change in the strength of a remolded soil sample at a constant water content. They observed that water stable aggregates increased with aging after tillage disturbances. The degree of decomposition and organic matter levels strongly influenced aggregate formation.

The effect of tillage on nutrient losses from manured cropland was studied by Mueller (1979). The manure application rates he used varied from 22-56 MT/ha. Mueller (1979) concluded that the soluble phosphorus load in surface runoff increased with no-till systems while sediment bound phosphorus decreased.

Mueller (1979) also investigated some of the changes in soil characteristics and moisture retention for conventional, chisel and no-till plots both with and without manure. His work indicates that infiltration increased initially with all tillage systems. This effect diminished over time with no-till systems eventually showing better hydrologic characteristics. Mueller (1979) also points out that the chisel plow systems increased surface storage significantly more than the other tillage systems studied. Over the entire period of study Mueller (1979) concluded that no-till is more effective in reducing runoff on well-drained soils than any of the tillage systems investigated.

In Mueller's (1979) study the volume of runoff collected from early spring events on plots where manure had been spread on the surface did not result in the high runoff rates reported by some investigators. Converse et al (1974), Young and Mutchler (1975), and Baker et al (1981) have shown snowmelt runoff, soil losses and TP losses were lower for manure amended soils than for plots not treated with manure. These researchers explain some of their findings by suggesting that manure protects the surface as a mulch cover.

Although Mueller (1979) concludes that TP losses were reduced substantially from manured plots, losses of soluble phosphorus increased significantly. For reduced tillage systems to be effective in controlling soil loss, Mueller (1979) concludes that there must be some residue left on the surface and field operations must be performed across the slope.

SUMMARY

There have been few investigations which have studied the effect of tillage systems on phosphorus losses from manured cropland directly. However, pertinent and helpful information was obtained from two types of studies:

- the influence of livestock manure applications on the hydrologic and nutrient properties of agricultural soils.
- the effect of tillage on nutrient availability and losses.

Some general conclusions can be drawn from the above literature review:

- An accumulation of phosphorus at the soil surface has been observed for no-till cropland.
- Elevated losses of water soluble nutrients have been observed for no-till fields.
- The availability of phosphorus for loss in surface runoff is strongly influenced by organic matter content of the soil, pH and soil structure.
- Relatively high losses of phosphorus from manure-spread cropland are typically associated with surface applications.
- In most cases, manure which is applied to the soil is incorporated into a relatively large pool of organic matter. Soil treatments and cropping systems are likely to have little effect on the equilibrium organic matter level of most agricultural soils.
- The organic matter status of soil appears to reach a long-term equilibrium which is a function of climate and soil texture. Thus, manure applications are only one variable, in most instances having only a subtle effect on long-term equilibrium.
- Tillage complements manure amendments in the short-term by increasing porosity, decreasing bulk density and resistance and redistributing organic matter in the soil profile.
- The benefits of soil tillage are typically followed by soil consolidation and compaction with an associated negative impact on soil hydrologic properties and

nutrient availability potential. Soil compaction is a penalty associated with many tillage systems.

- Since most phosphorus lost from cropland is sediment bound, plant residues are an effective method of reducing total phosphorus load.

SECTION II
MATERIALS AND METHODS

LEVELS OF RESEARCH

Three important questions posed by the project objectives were the extent to which manure application rate, incorporation depth and time of application affected TP and TSP loads in surface runoff. In order to establish experimental control and comparison of the rate/depth/time variables, a series of laboratory (level 1) and field experiments (level 2) were undertaken. The results of level 1 and 2 experiments were then used to evaluate the effectiveness of various tillage - manure systems to decrease phosphorus losses (level 3). In all cases, the design of laboratory experiments were intended to provide more controlled observations of the rate/depth/time effects. Field plots allowed a more realistic comparison of the twelve manure rate and depth combinations on cropland. Farm runs (level 3) provided both general and practical applications of level 1 and level 2 findings in the context of a farm manure spreading program. Table 2.1 provides an overview of the three levels of investigation.

Experimental Design

Twelve cases (three manure application rates and four depths of incorporation) were established for series LG1-LG4. The range of application rate (22-135 MT/ha) and incorporation depth (0-15 cm) were intended to reflect realistic combinations of rate and depth which could be achieved by various tillage systems. One control trough was maintained.

The time interval between runs was chosen to reflect differences in runoff potential due to drying of the soil-manure pack. The initial run, LG1, was conducted on the untreated silt loam while run LG2 was completed two days later, immediately after manure application. The troughs were then covered for 44 days to allow a slow but complete drying of the soil-manure pack before the next run, LG3. By covering the troughs with a plywood foam rubber lid, cracking and separation of the soil-manure mixture from the side walls of the trough was avoided. A shorter period of time, 10 days, elapsed between LG3 and LG4 runs. The purpose of LG4 was to observe runoff volume and TP, TSP concentrations after the soil manure mixture had dried and had been rewetted.

Treatment Preparations

A Genesee silt loam soil was chosen for the first set of laboratory runs. It is a well drained, medium textured alluvial soil derived from glacial drift that is high to medium in lime content. There is typically a 4-6% accumulation of organic matter in the surface layer. The Genesee silt loam exhibits good water holding capacity, is well aerated and usually has a good supply of phosphorus and potassium (Soil Survey, 1981). The silt loam soil was air dried and sieved through a No. 4 standard sieve to eliminate large stones and aggregates.

Thirteen troughs (20 cm x 15 cm x 100 cm) were constructed of 10 gauge stainless steel. Each trough was fitted with one inch angle iron frames and 22 cm x 17 cm sheet metal end plates. Rubber gaskets and silicon caulk were used to provide a watertight seal at each trough end.

Each trough was equipped with a 1.90 cm tygon drainage tube placed at the center bottom of one side. A 60 mesh screen was placed over the tube to prevent the washing of sand. The end plates provided sufficient flange width for a dolly to be inserted under the trough for transport between rainfall simulation runs, weighing operations and storage.

Five centimeters of No. 3 coarse sand was added to the bottom of each trough. Fifteen centimeters of air dried soil were then added to each trough. Weights were recorded at each stage using a 112 kg How top loading scale.

Following one half hour rainfall simulation runs manure treatments were completed. Troughs 1, 2 and 3 had a mixing depth of 15 cm. Troughs 4, 5 and 6 had a mixing depth of 10 cm. Manure was mixed to a depth of 3 cm for troughs 7, 8 and 9. For troughs 10, 11 and 12 manure was applied to the surface. Three application rates were used corresponding to 135., 67. and 22. Mt/ha. Troughs 1, 4, 7 and 10 received heavy applications. Troughs 2, 5, 8, and 11 received the moderate rates while 3, 6, 9, and 12 received low rates. Trough 13 remained untreated.

The mixing of the manure with the soil was accomplished outside of the troughs. Manure quantities were weighed on a Pennsylvania 5 kg. triple beam scale. Soil was excavated with a trowel to the required depth. Manure and soil were then thoroughly mixed with a trowel on a sheet of plastic and refilled into the trough. There was no attempt to pack the trough to achieve a specific bulk density.

Runoff was collected continuously from the plot surface by means of the perforated copper collection tee under a vacuum pressure which typically varied between 60 and 90 mm of Hg. Samples were collected from this flow through a sampling shunt at specific time intervals, predetermined for each run. Each sample was collected in a 490 ml plastic bottle.

Analytical Procedures

pH and suspended solids analyses (SS) were conducted in the soil and water laboratory at Cornell University. An Orion model 407A pH meter was used for the pH analyses. The method of analysis (150.1) is described in EPA (1979). Suspended solids determinations were made by the filtration of 100 mL of sample through tared 4.5 cm glass fibre Whatman filter followed by drying at 105°C in a Thelco Model 18 oven. A Mettler P1000 analytical balance was used for all SS weight determinations.

Unfiltered and filtered samples of runoff were allocated to 125-mL Nalgene containers which had been acidified with 5N H_2SO_4. Filtrations through 0.45μ Millipore filters under a vacuum pressure of 10 psi or less were used to define the soluble phosphorus fraction. All samples were frozen and sent air freight in iced coolers to the Center for Laboratories and Research (CLR), New York State Department of Health where the TP, TSP analyses were performed. The CLR procedures for TP and TSP determination utilize a persulfate digestion in acid medium procedure (365.2), described in EPA (1979).

Rainfall Simulator Unit

An important element of the methods used for investigation was the choice of a technique which would eliminate much of the variability between precipitation events. This variability often masks differences in loading between treatments. In addition, the myriad of manure-tillage systems possible made it advantageous to look for a mobile unit capable of short-term field evaluations. To accomplish project objectives and collect both laboratory and field data a rainfall simulator was utilized.

Advantages in using the simulator were:

- controlled laboratory conditions could be established to formulate more precise treatments
- a greater number of rate-depth options could be investigated in the field
- consistency between field and laboratory observations could be achieved allowing more valid comparisons
- precipitation characteristics are more precisely defined and therefore can be varied as needed for sensitivity analyses.

TABLE 2.1

OVERVIEW OF LEVEL 1, 2, AND 3 INVESTIGATIONS

Series	Level	Description
LG1-LG4	1	Application rate, incorporation depth variables for extreme wet/dry cycles (laboratory)
LB1-LB6	1	Application rate, incorporation depth variables for specific time intervals (laboratory)
LBD1-LBD4	1	Surface applications, drying variables for specific time intervals (laboratory)
LRB1-LRB6	1	Residue cover and manure application rate variables for specific time intervals (laboratory)
FB1-FG3	2	Application rate, incorporation depth variables for field conditions (field)
WB1-WB5	2	Passive winter collection of runoff for silt loam soil. Application rate, incorporation depth, residue cover, soil type, crop, and tillage method as variables (field)
TX1-TX2D	3	Farm runs with different manure application rates, residue cover, tillage method and crop (Oswego County)
AX1-AX28	3	Farm runs with different manure application rates, residue cover, tillage method, crop and soil type (Wayne County)

A literature review was conducted to compare the types of rainfall simulators available. A summary of this review is presented in Appendix A. The principle criteria in choosing a simulator were:

- mobility - A simulator which could be transported from the soil and water laboratory at Cornell University to various farm locations within about a 100 mile radius
- rainfall characteristics - Intensity, drop size, drop velocity, uniformity of application and kinetic energy characteristics should be comparable to natural rainfall
- documented field experience - Utilization of the simulator by other investigators would provide valuable information with respect to other field applications and the comparison of results of similar studies.

A modified Purdue Sprinkling Infiltrometer (PWSI) (Bertrand and Parr, 1961) was used for precipitation simulation runs. Since the principal modifications were made by Dixon and Peterson (1964, 1968) at the University of Wisconsin, the rainfall simulation unit will be referenced as a Purdue Wisconsin Sprinkling Infiltrometer in this report.

The PWSI unit was used to generate and collect both laboratory and field runoff samples for the manure treatments cited earlier. A schematic representation of the PWSI unit is given in Figure 2.1. Component details and operating procedures are provided in Appendix B.

The Spraying Systems 7LA nozzle was selected by Bertrand and Parr (1963) because the range of droplet sizes were comparable to those reported by Laws and Parsons (1943) for a natural rainfall event. In addition, the uniformity of application over the 1.35 m^2 field plot area was the best of the more than 20 nozzles evaluated. Finally, the desired intensity of application could be achieved with relatively low operating line pressures (5-10 psi). A more complete description of the PWSI unit, operating characteristics and procedures are provided in Appendix B.

Since over 300 runs were completed using the PWSI unit, an excellent opportunity existed to evaluate its design and operating characteristics as a result of this extensive experience. Possible modifications and improvements were documented. This information is included in Appendix A.

Laboratory Runs LG1-LG4

The first series of laboratory runs consisted of a 30-minute pre-treatment (series LG1) followed by three 60-minute runs with the manure treated soil. Appendix B summarizes the procedures used during simulated precipitation events in the laboratory.

Laboratory Runs LB1-LB6

Laboratory series LB1-LB6 utilized the channery Bath soils of field series FB1-FB2. Unlike series LG1-LG4, coarse aggregates and stones were not sieved. The experimental design of series LB1-LB6 provides more frequent observations of TP and TSP losses for high manure application rates at incorporation depths of 15, 10, 3 and 0 cm, respectively. A trough with a low application rate to the surface and an untreated trough were maintained during series LB1-LB6. Series LB1-LB6 provided additional details

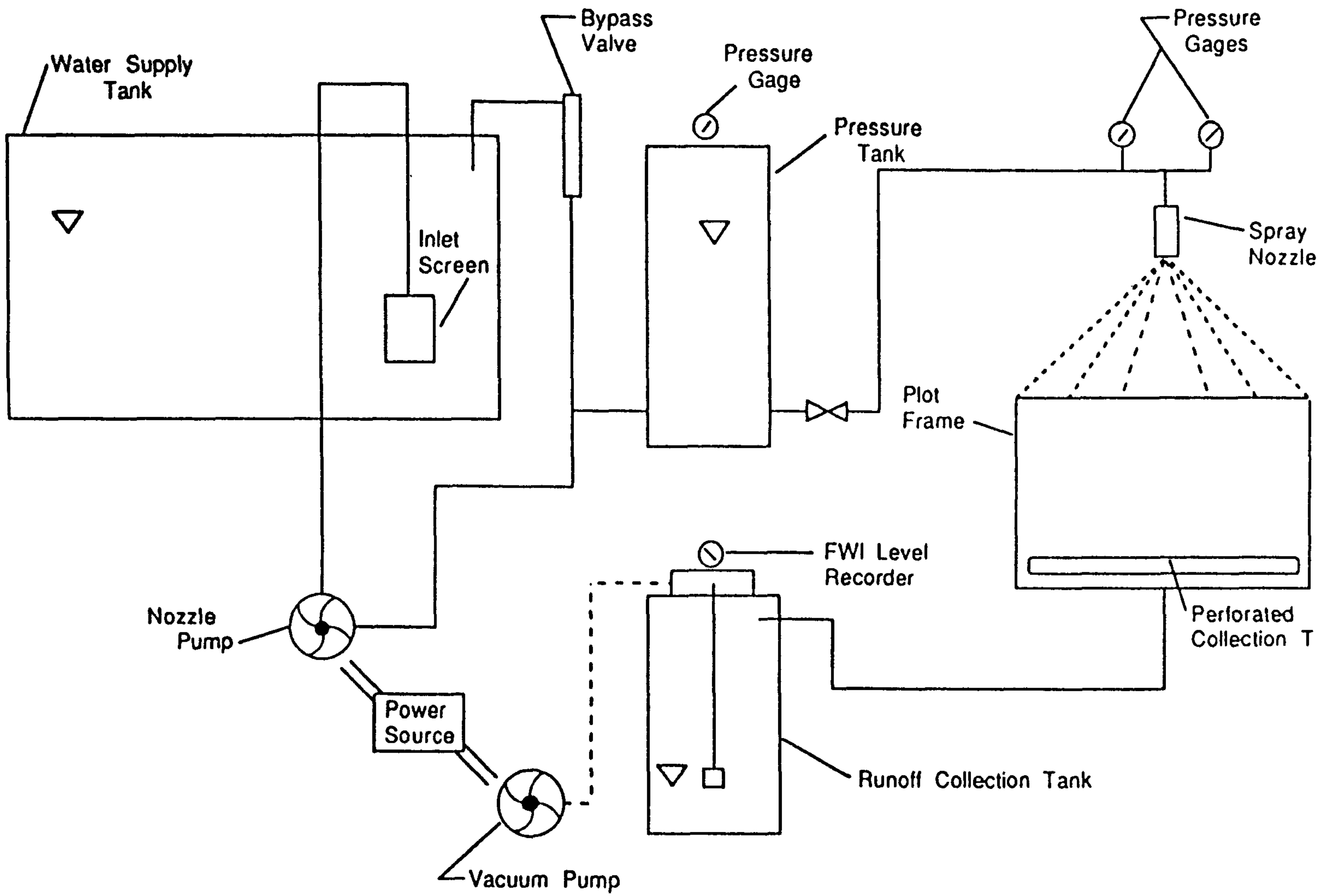

Figure 2.1

Schematic of PWSI Unit

defining TP, TSP load changes occurring as a result of more frequent wetting of the soil-manure mixture.

The second series of laboratory runs was conducted with a channery Bath silt loam. This soil was collected from an area adjacent to the field plots (FB series). The well drained Bath soil is typically acidic. The top 20-30 cm tend to be a dark-grayish brown silt loam containing many flat stone fragments. The plow layer is generally very porous and well aerated allowing for good root development. The organic matter content of the plow layer is commonly between 3-6% (Soil Survey, 1971).

Series LB1-LB6 involved high application rates at different incorporation depths. One trough was added to observe the special case of a relatively low application rate to the surface while one trough remained untreated.

The procedure for laboratory rainfall simulation runs for series LB1-LB6 is the same as series LG1-LG4 and is described in Appendix B.

Laboratory Runs LBD1-LBD4

The purpose of series LBD1-LBD4 was to provide data further specifying how runoff volume changes with drying conditions for the special case of surface-applied manure. This series was designed to provide information for the potentially high TP, TSP losses associated with surface applications. In particular, the storage conditions of the troughs were changed to allow for a relatively high drying rate compared with series LG1-LG4 and LB1-LB6 in which drying rates were purposely kept low. Thus, extremes in drying rate and its likely influence on TP, TSP loading could be investigated, particularly for the special case of surface applied manure.

The LBD1-LBD4 series all used heavy rate applications (135 MT/ha) to the surface of an air dried Bath silt loam. No lid was placed over the troughs during storage as in series LB1-LB6. The surface applied manure was allowed to dry for 2 days, 5 days, 10 days and 20 days before a standard precipitation run using the PWSI unit was completed. Replicate troughs were prepared in each case and after the initial wetting each trough was rewetted during the next run period.

The procedure for laboratory rainfall simulation runs for series LBD1-LBD4 was the same as previous laboratory series runs and is described in Appendix B.

Residue Series Runs

TP and TSP loads were estimated for both residue cover and manure applications over residue. The sequence of experiments is described in Table 2.2. An initial series of runs (R1) was conducted with an air-dried soil with no residue or manure cover. Two runs with surface cover rates of 0, 1, and 3 Mt/ha equivalent of dry corn stover on a Bath soil were then completed. The final three runs reflect TP, TSP loading for manure applied over the residue cover. Manure application rates for these simulated precipitation events were 0, 22 and 135 Mt/ha.

FIELD EXPERIMENTS (Level 2)

Cornell's EIDS project farm located 16 miles north of Ithaca, New York was chosen for the field level of study. The watershed draining the farm flows to Fall Creek and through the Finger Lakes tributary system ultimately discharging to Lake Ontario.

Table 2.2 - Residue Series Runs

Trough	Runs***					
	R1	R2	R3	R4	R5	R6
1	Res. 0*	Res. 1	Res. 1	Man. 1**	Man. 1	Man. 1
2	Res. 0	Res. 2	Res. 2	Man. 2	Man. 2	Man. 2
3	Res. 0	Res. 1	Res. 1	Man. 1	Man. 1	Man. 1
4	Res. 0	Res. 0	Res. 0	Man. 0	Man. 0	Man. 0
5	Res. 0	Res. 1	Res. 1	Man. 2	Man. 2	Man. 2
6	Res. 0	Res. 0	Res. 0	Man. 0	Man. 0	Man. 0
Time	0 d	2 d	7 d	11 d	13 d	20 d
Applications	No	Res.	No	Man.	No	No

*Residue levels	Res 0 = 0 g Res 1 = 41 g (dry) Res 2 = 23 g (dry)
**Manure application levels	Man. 0 = 0 kg Man . 1 = 0.41 kg Man . 2 = 2.48 kg
***Sample protocol	- Time interval 5 min., 15 min., and 25 min. - All composite samples - All subsurfaces flow collected and 1 composite sample created

The purpose of the field series was twofold. First, validation of the high TP, TSP loads associated with precipitation events which immediately followed manure application was desired for the field case. Second, the likely changes in infiltration and runoff for the undisturbed field soil as opposed to the disturbed trough samples required further investigation.

Eighteen permanently staked plots were established on a cornfield consisting primarily of a Bath channery silt loam. The eighteen plots were established on the lower slope of EIDS field #27. In addition to the 13 rate depth treatments used in the laboratory series, five untreated plots were staked to establish control plots and an indication of the heterogeneity of the soils in the area of the field where the runs were being made.

A 1.35 m^2 steel frame was driven to a depth of 20 cm on each plot. Soil was excavated to treatment depth and placed on sheets of plastic adjacent to the plot. Manure and soil were then mixed within the plot area in layers such that a uniform distribution of manure was achieved.

Series FB1-FB2

The first series of precipitation events (FB1) took place immediately after site and treatment preparation. The second series (FB2) were completed approximately 24 hours after FB1. Incorporation depths were the same with the exception of the maximum depth which increased from 15 cm to 20 cm for the field series. This change was made to more closely approximate depths of moldboard plowing and deep chiseling. A plywood lid was placed over the plot frame during the 24 hours between simulated precipitation events FB1 and FB2. A third set of simulation runs (FB3) were made the following spring to observe long term changes in flow volume and TP, TSP concentration in surface runoff.

The procedure for each run was similar to the laboratory procedures described in Appendix B with a few exceptions:

- instead of transporting the troughs to the PWSI unit, the canopy/frame/nozzle unit was erected over each plot
- an MF65 tractor was used to transport all equipment and the water supply tanks
- unlike the laboratory troughs, the field plots were exposed to natural precipitation events after the FB2 runs.

FARM EXPERMENTS (Level 3)

The objectives of level 2 studies were to look more closely at the special problems associated with tillage-manure system design during the winter period. The sub-objectives directly related to this question include:

- the effects of surface residue on TP, TSP losses, particularly during the winter period
- field and farm observation of TP, TSP loads for different tillage, residue, crop and soil type conditions
- characterization of tillage-manure systems to decrease phosphorus losses during the winter period.

SUMMER FARM RUNS

Summer Farm Runs TX1-TX25, AX1-AX28

The purpose of the summer farm runs was to extend initial laboratory and field experiments to operating farms where the manure had been incorporated by tillage implements. Two farms (one in Wayne County and one in Oswego County, New York) cooperated for these runs. Specific phosphorus control options investigated were:

- incorporation with moldboard, chisel and no-till planting
- a wide range of residue levels
- a wide range of manure applications rates
- inclusion of hayland
- a wide range of soil types, including poorer drained soils.

Table 2.3 summarizes the specific tillage soil-treatment variables evaluated by the simulated precipitation farm runs.

The hydrologic response and TP, TSP loading characteristics of manure amended soils are greatly influenced by drying of the manure pack. This effect had been observed in both laboratory and field experiments. The time and drying conditions between initial manure application and the first precipitation event are particularly important.

Table 2.3 - Farm Series Runs, 1986

Series	Field Treatments	Soil	Variables
TX1-TX7	no-till	silt loam	3 manure application rates
TX8-TX15	no-till	silt loam	3 residue levels
TX16-TX17	no-till	silt loam	fresh manure applications to surface
TX18-TX21	conventional	silt loam	fall manure applications
TX22-TX23	conventional	silt loam	alfalfa cover
AX24-AX28	chisel	sandy loam	3 residue levels
AX29-AX34	no-till	sandy loam	3 residue levels

Series	Field Treatments	Soil	Variables
AX35-AX36	no-till	clay loam	alfalfa cover
AX37-AX41	conventional	clay loam	fall manure applications
AX42-AX48	chisel	sandy loam	fresh manure applications to surface

Table 2.4 - Laboratory and Farm Drying Runs

Series	Plots	Time
LBD	135 mt/ha surface	t = 2, 5, 10, 20 d
	135 mt/ha surface	t = 5, 10, 20 d
	135 mt/ha surface	t = 10, 20, d

	135 mt/ha surface	t = 20 d
TX	135 mt/ha surface	t = 4 d
AX	225 mt/ha surface	t = 4 d
	135 mt/ha surface	t = 4 d
	67 mt/ha surface	t = 4 d
	22 mt/ha surface	t = 4 d

The LBD series specifically looked at flow volume, TP and TSP concentration under controlled laboratory conditions. These experiments were repeated on farms A and B in June, 1986. For these farm trials a period of four days between manure application and simulated precipitation was allowed. Table 2.4 summarizes all laboratory and field treatments.

The Purdue Wisconsin Sprinkling Infiltrometer (PWSI) was winterized to allow for cold weather and spring thaw runs. These modifications included the following: all pipe networks were provided with a sump and drain system. All piping was insulated and wrapped in heat tape. Finally, all valves and flow control devices were protected from freezing by insulation and drain sump systems.

Sampling and Runoff Analysis Procedures

- Each runoff collection period is run for 60 minutes, with t 0 being the time at which precipitation is first applied to the plot.
- One composite sample was collected for each run at intervals of 5 min., 20 min., 35 min., and 50 min. after runoff began.
- Each sample was immediately refrigerated at 4°C.
- pH, suspended solids and volatile solids were performed on each sample as described in the quality assurance update.
- Three composite samples (0-20 min., 20-40 min., and 40-60 min.) were collected for a small sample of runs.
- Approximately 50mL of sample was filtered through a 0.45µ filter for TSP analysis at the Health Department Labs. Whole and reserve samples were dispensed and sent to the Health Department Labs for TP analysis.

Procedure for Rainfall Simulation and Runoff Collection

- The sprinkling infiltrometer was prepared for operation by filling supply reservoirs and connecting runoff collection tubes to vacuum tank.
- The channels were covered with sheet metal lids during calibration runs
- The infiltrometer was allowed to operate for five minutes before precipitation calibration data is collected. During this period all valves and gauges were checked to be sure system is in full operation.
- Following the initial five minute period, a ten minute calibration run was made where the nozzle discharge was directed through a 7.6 cm pipe to a collection tank where the volume change over time was recorded.
- After the calibration run the nozzle is allowed to discharge fully over the plot area and the channel lids were removed for runoff collection runs.

- Initial time of precipitation was recorded.
- Time to ponding was recorded.
- Time to initial runoff collection was recorded.
- Samples were collected at specific time intervals (varies with series, can be individual or composite).
- Sample bottle number and time were recorded.
- At the end of the run, the supply valve was closed
- Vacuum pump was allowed to collect remaining runoff.
- Surface and subsurface samples were immediately refrigerated for later preservation.
- Trough was transported to storage (with lid cover).
- After 24 hours trough was re-weighed.
- Periodic re-weighing of trough and soil samples collected.
- Level recorder strip charts reduced for flow rates and flow volumes.

SECTION III
RESULTS

LABORATORY SERIES LG1-LG4

The purpose of laboratory series LG1-LG4 was to observe changes in runoff volume and phosphorus concentration for different application rates and depths of incorporation. The time interval between simulated precipitation events was chosen to represent differences in runoff potential and drying of the soil-manure mixtures. The results of laboratory series LG1-LG4 were used to more precisely define the experimental design of laboratory series LB1-LB6.

Flow Volume

Figures 3.1 and 3.2 indicate flow volume for three manure application rates and four depths of incorporation (15, 10, 3, 0 cm) and one untreated trough for four precipitation events over a 56-day period. Each observation represents the mean value for the respective incorporation depth or application rate treatments of a specified rainfall simulation event. As indicated in Figure 3.1, when precipitation occurred immediately after manure application (series LG2,) surface flow volume was greater for the manure treated soils compared with the untreated case. The application of manure to the soil surface increased surface runoff by as much as 81% above the untreated case (Figure 3.2) when a 12 cm simulated rainfall event immediately followed manure application. The largest surface runoff volume for an individual trough occurred for the high (135 MT/ha) application rate to the surface.

After drying of the manure soil mixture, a third precipitation event was run (series LG3). Surface runoff volumes (Figure 3.1 and 3.2) were reduced by as much as 89% for the manure treated soils with the highest reduction for the trough with the 135 MT/ha surface application.

The three manure application rates (135, 67 and 22 MT/ha) did not cause significant differences in surface flow volume. However, when surface flow volumes are compared by incorporation depth, the troughs having surface applications (0 depth of incorporation) indicate significantly lower surface runoff volume for series LG3. This surface runoff volume is less than 40% of the flow volume observed for the other incorporation depths. For series LG3, incorporation depths of 15, 10 and 3 cm did not result in significantly different surface flow volumes.

Precipitation to Initiate Runoff

Precipitation to initiate runoff (PIR) is the quantity of rainfall measured from the beginning of the precipitation event until the first surface flow is collected. Generally, the manure treatments caused PIR to increase relative to untreated trough levels (Figures 3.3 and 3.4) for series LG2-LG4. Series LG3 (dry) indicated increased PIR relative to the control trough with the surface applied case (0 depth of incorporation) showing the largest increase. For the surface applied case, mean PIR (series LG3) was over four times the control value. Analysis of variance of PIR for the three application rates and four depths of incorporation indicated that incorporation depth explained about 70% of the PIR variation for series LG3 while application rate accounted for less than 10% of the variation.

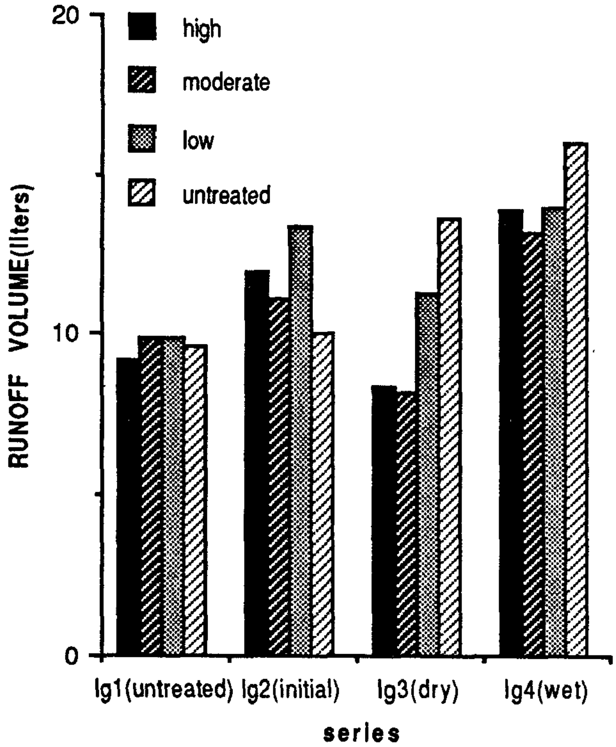

Figure 3.1
Runoff Volume, by rate, series lg1-lg4

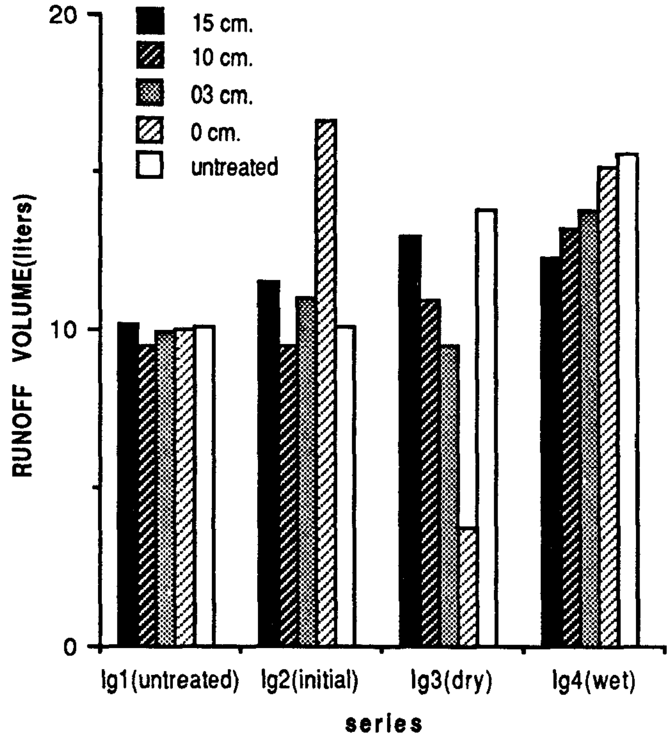

Figure 3.2
Runoff Volume, by depth, series lg1-lg4

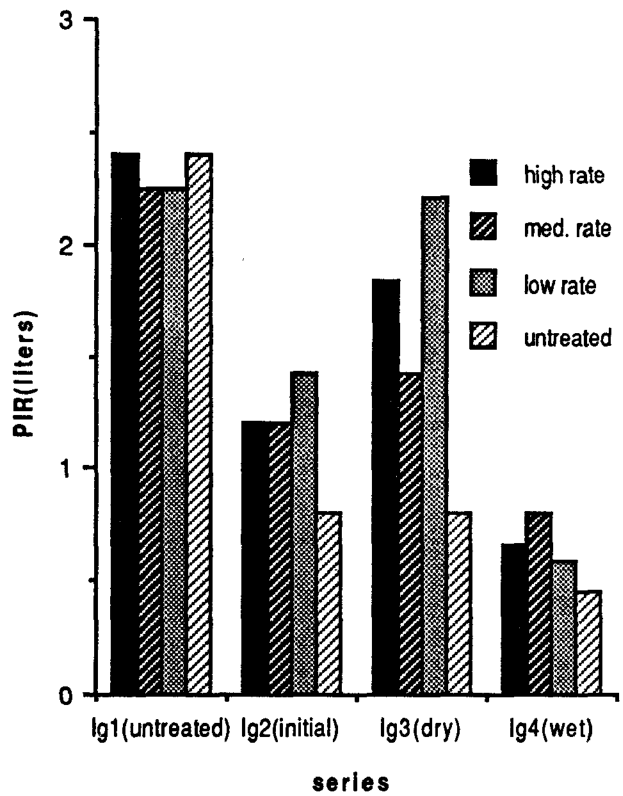

Figure 3.3
Precipitation to Initiate Runoff, by rate, lg1-lg4

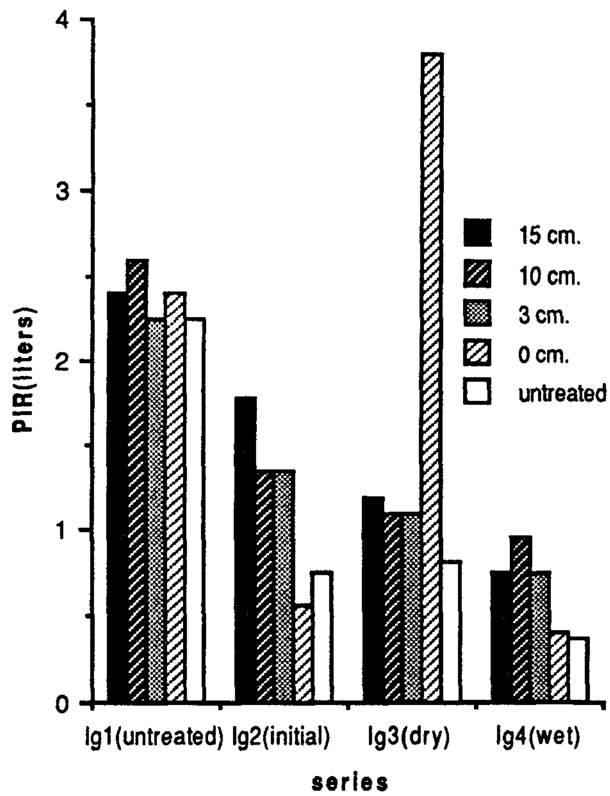

Figure 3.4
Precipitation to Initiate Runoff, by depth, lg1-lg4

TP, TSP Concentration in Surface Runoff

Manure applications to the soil surface resulted in relatively high TP and TSP concentrations in surface runoff when precipitation immediately followed manure application. Concentrations were as high as 23 mg/L and 8.5 mg/L of TP and TSP, respectively, for individual troughs. These concentrations were 19 times the TP value of the untreated trough and 65 times the untreated TSP level. The associated TP load for this event was 375 mg.

TP concentrations in surface runoff (Figures 3.5 and 3.6) were higher than the control case for all manure application rates and depths of incorporation when precipitation immediately followed manure application (series LG2). After drying of the soil-manure mixture (series LG3), the TP concentration in surface runoff for all rate and depth cases approached untreated levels.

Similar to the TP concentration trends, TSP concentration for all rates of application and incorporation depths were greater than untreated levels for series LG2 (Figures 3.7 and 3.8). Subsequent precipitation events (LG3 and LG4) indicate that TSP concentration in surface runoff approaches untreated levels for the treated silt loam soil used in this laboratory series.

There was no significant difference in TP concentration among application rates. TP concentration in surface runoff by depth of incorporation was significantly higher for series LG2 compared with the untreated (LG1) and subsequent precipitation events LG3 and LG4. In addition, the surface application case (0 depth of incorporation) resulted in a significantly higher TP concentration during the LG2 series compared with the three other depths of incorporation.

The influence of incorporation depth is even more evident on TSP concentration in surface runoff. While the application rate did not result in significantly different TSP concentrations, the surface applied case resulted in a TSP concentration over eight times the value recorded for the 3, 10 and 15 cm incorporation depths during LG2. TSP concentration in surface runoff for all incorporated depths was also significantly higher for series LG2 than series LG3 and LG4.

Much of the variability of TP and TSP concentration in surface runoff can be explained by incorporation depth. Analysis of variance indicated that incorporation depth explained about 80% of the TSP concentration for the first precipitation event following manure incorporation. Generally, incorporation depth explained considerably more of both the TP and the TSP variation than application rate.

TP, TSP Load

The total load of TP and TSP in surface runoff reflect both changes in runoff volume and TP, TSP concentrations as a result of the manure treatments (Figures 3.9-3.12). TP load as a function of both application rate (Figure 3.9) and depth of incorporation (Figure 3.10) indicate high losses in surface runoff when precipitation immediately follows manure application (series LG2). Subsequent precipitation events (series LG3 and LG4) indicate that TP load values decrease appreciably after the first precipitation event.

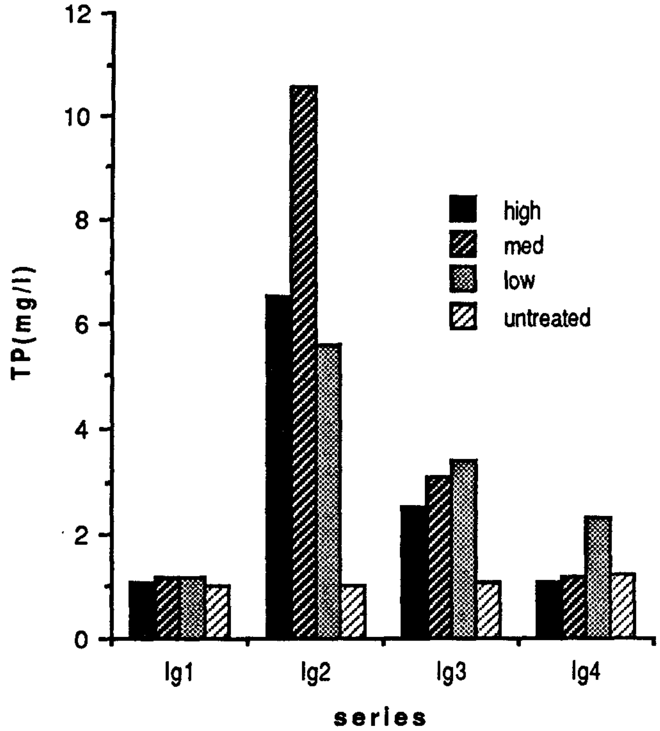

Figure 3.5
TP Concentration, by rate, series lg1-lg4

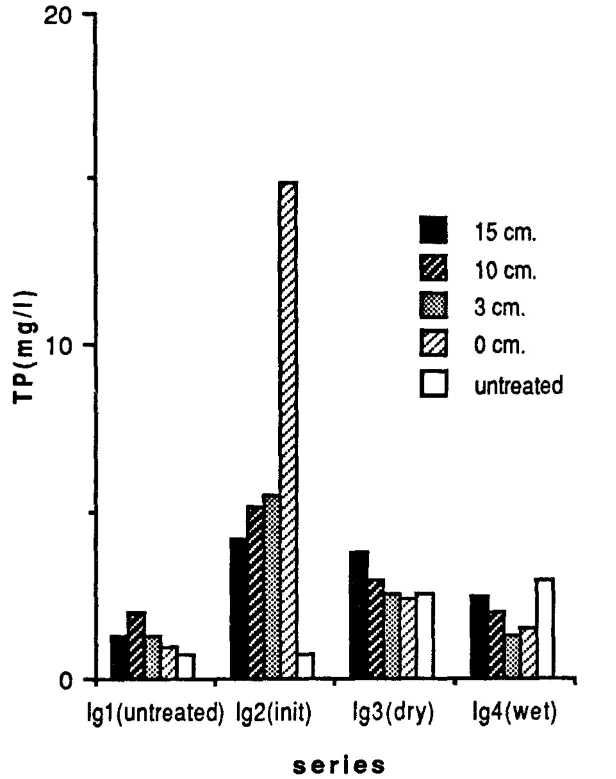

Figure 3.6
TP Concentration, by depth, series lg1-lg4

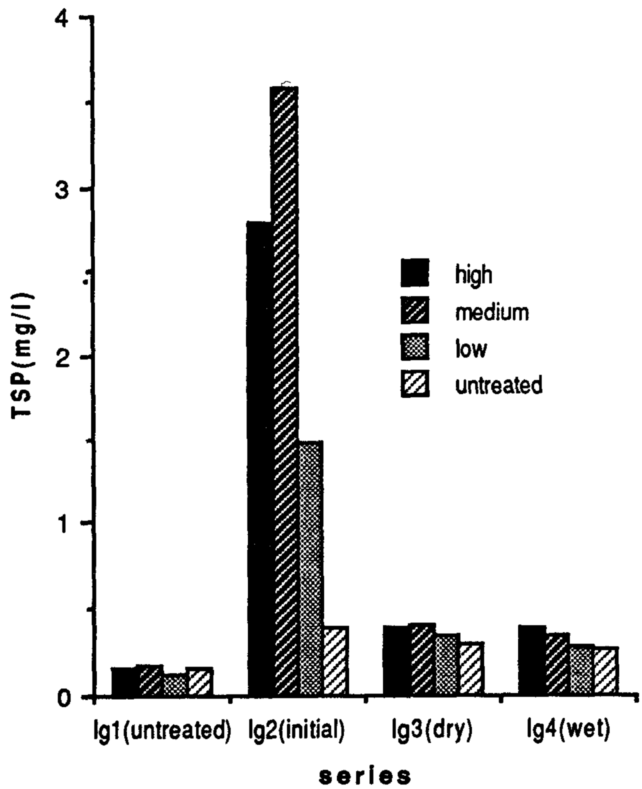

Figure 3.7
TSP Concentration, by rate, lg1-lg4

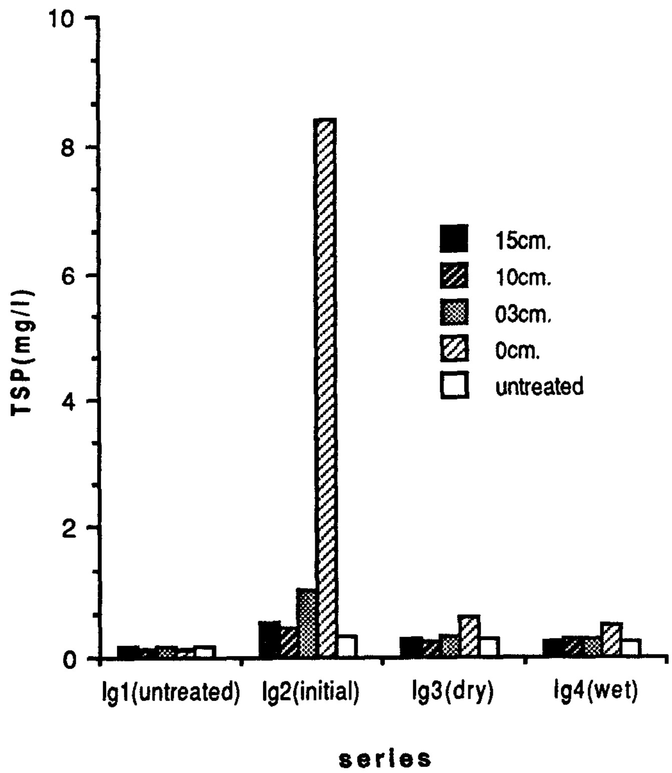

Figure 3.8
TSP Concentration, by depth, lg1-lg4

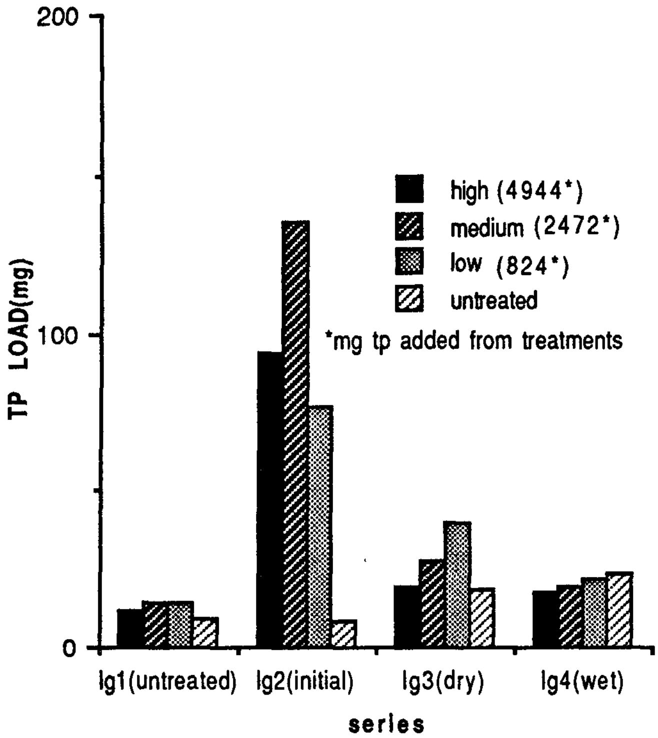

Figure 3.9
TP Load(mg), by rate, lg1-lg4

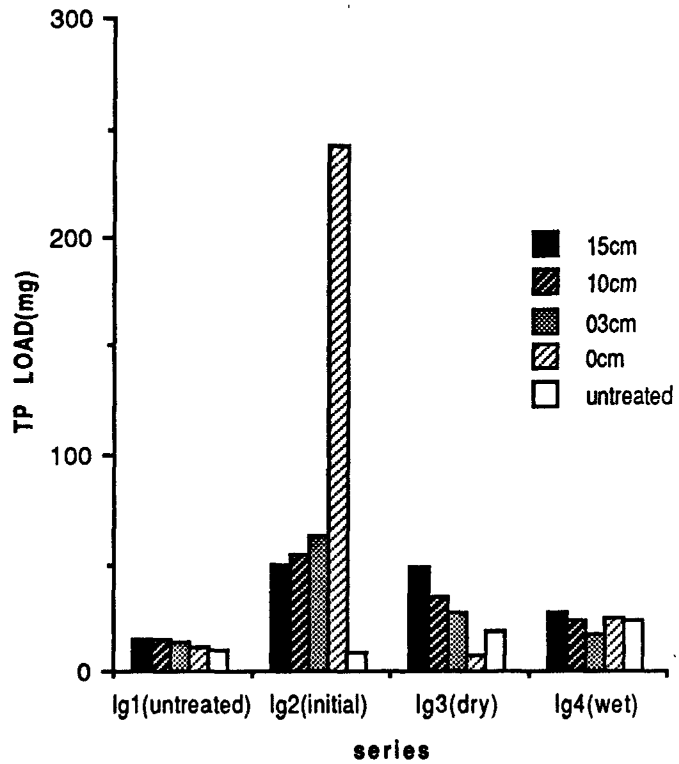

Figure 3.10
TP Load(mg), by depth, lg1-lg4

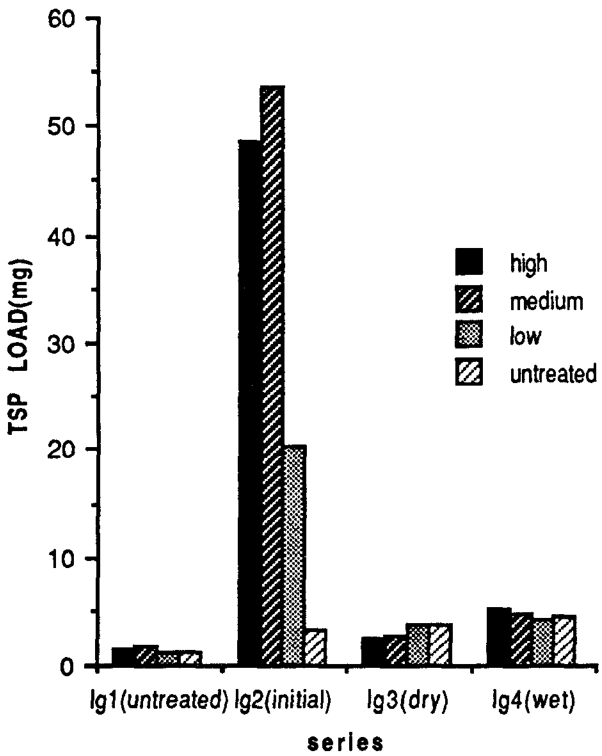

Figure 3.11
TSP Load(mg), by rate, lg1-lg4

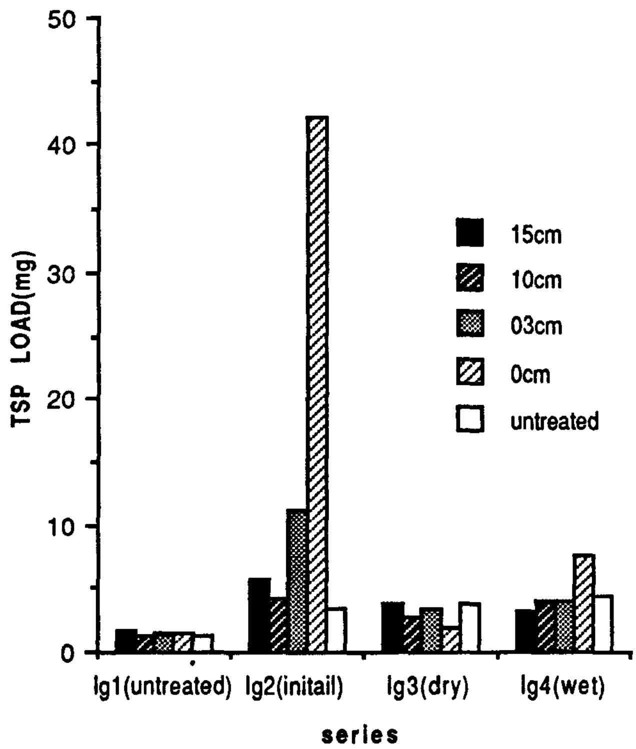

Figure 3.12
TSP Load(mg), by depth, lg1-lg4

TSP load in surface runoff is relatively high when precipitation immediately follows manure application. For the extreme case, the TSP load in runoff for all surface applications in series LG2 is 101 mg, or more than 31 times the untreated value. As with TP load, TSP load in surface runoff approaches the untreated case after three precipitation events.

Application rate was not associated with a significant difference in TP load. However, surface application of manure did result in a significantly higher TP load in surface runoff for series LG2. After the soil-manure mixture dried, the TP load from the surface-applied troughs was significantly lower than the 15 cm incorporation depth as well as the 3 and 10 cm depth.

TSP loads in surface runoff from the surface application for series LG2 and LG4 were significantly higher than other depths of incorporation.

Analysis of variance of the TP and TSP load indicated that incorporation depth accounted for 66% and 75% of the variation in TP and TSP load, respectively, for the three precipitation events following manure application (LG2-LG4). As with flow volume and TP, TSP concentration, incorporation depth explained appreciably more of the variance than application rate for the TP, TSP load results.

FIELD SERIES FB1-FB2

The purpose of field series FB1-FB2 was to compare laboratory results with field data for the same application rates and incorporation depth treatments used in series LG1-LG4. In addition, five control plots were added to the experimental design to more accurately compare flow volume, concentration and loading results from the manure amended silt loam to the untreated case.

Series FB1-FB2 involved two precipitation events on each plot. The timing of manure applications and precipitation events provided an opportunity for characterizing the initial high loading period in the field. In series LB1-LB6 and LBD1-LBD4 (discussed later), which complement series FB1-FB2, load changes were observed over a longer period of time and under various drying conditions for the same soil.

Flow Volume

When the twelve rate-depth treatments were applied in the field, the volume of surface flow (Figures 3.13-3.14) increased significantly above control levels. As with series LG1-LG4 the highest individual runoff volume occurred with the 135 MT/ha application rate to the surface (0 depth of incorporation). The runoff volumes for the plots where surface application occurred were more than five times the surface runoff volumes observed for the control plots during series FB1.

Series FB2 followed FB1 by 24 hours. All runoff volumes from treated plots were significantly greater than the control plots. Typically, runoff volume increased by 20-30% over series FB1 (Figures 3.13-3.14).

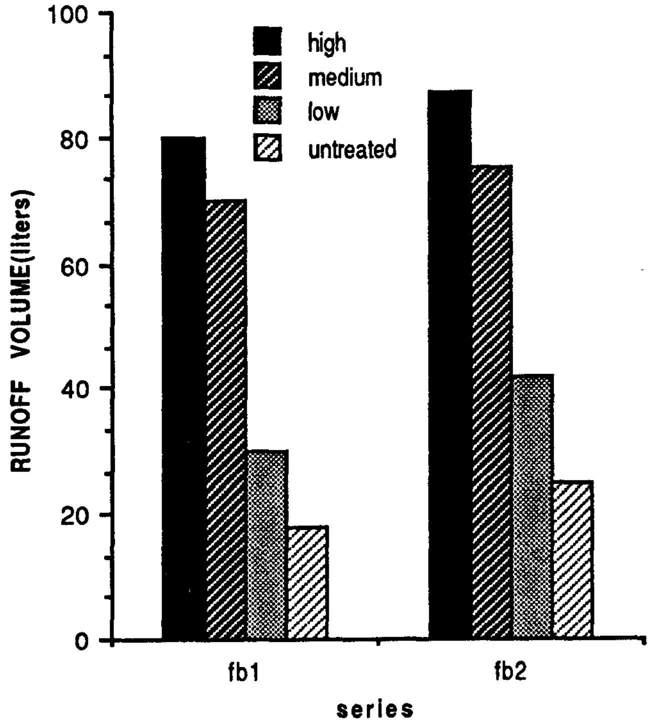

Figure 3.13
Runoff Volume, by rate, fb1-fb2

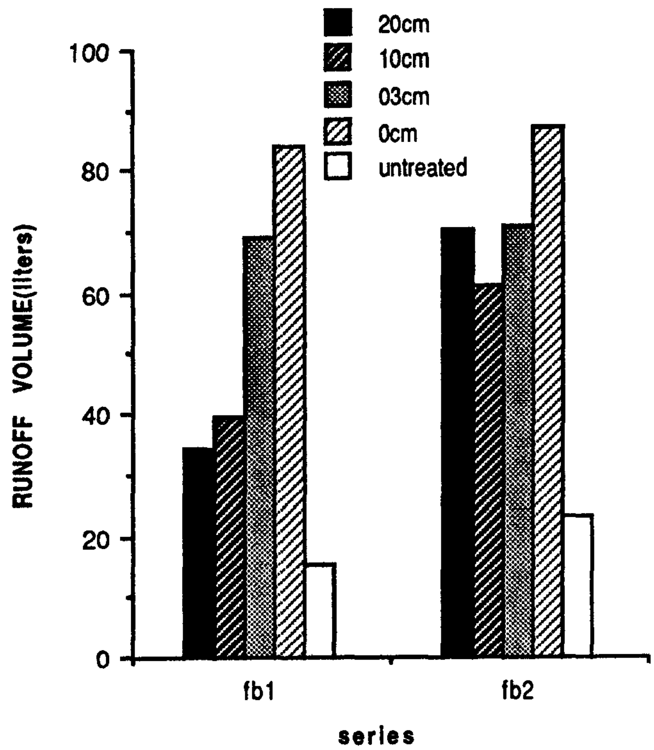

Figure 3.14
Runoff Volume, by depth, fb1-fb2

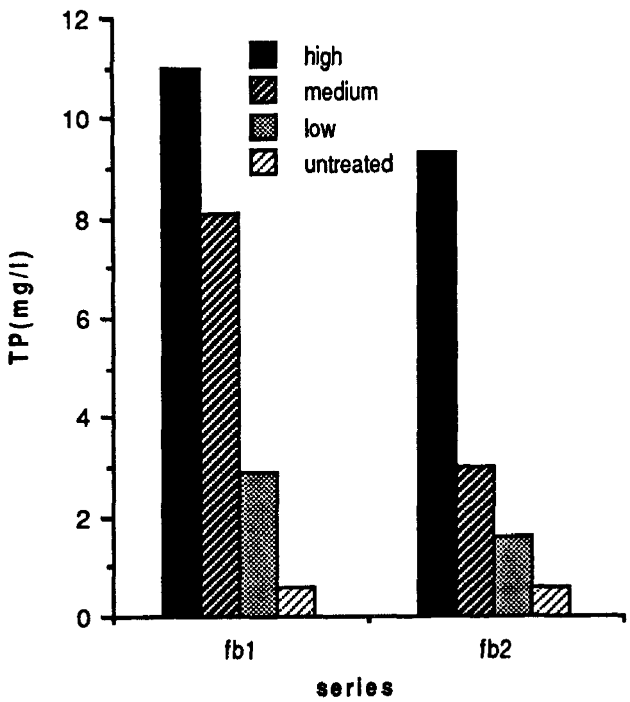

Figure 3.15
TP Concentration, by rate, fb1-fb2

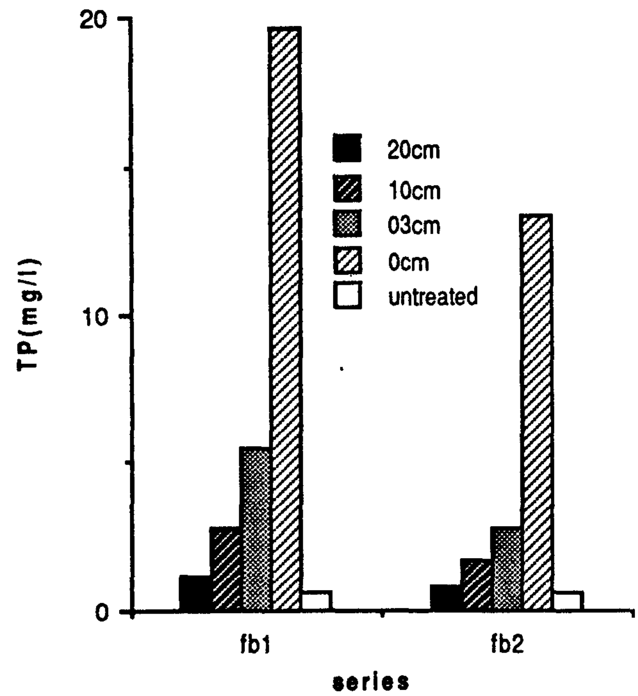

Figure 3.16
TP Concentration, by depth, fb1-fb2

There was no significant difference in surface runoff volume due to rate of application. However, manure incorporation did result in significant differences in flow volume with respect to depth and time. As indicated, incorporation depths of 0 cm and 3 cm resulted in significantly higher runoff volumes than the 10 cm and 20 cm depths for series FB1. These differences between rates were not observed for series FB2. When flow volumes are compared over a 24-hour period, runoff from the 10 cm and 20 cm incorporation depths increase significantly while the 3 cm and 0 cm plots changed very little.

TP, TSP Concentration Surface Runoff

With the exception of the low application rate (22 MT/ha), the concentration of TP in surface runoff (Figures 3.15 and 3.16) was significantly higher than control levels in series FB1 and FB2. TP concentration was typically an order of magnitude higher than the controls. The extreme case of surface application (0 depth of incorporation) at 135 MT/ha resulted in a TP concentration over 30 times control levels.

TP concentration in surface runoff exhibited significant differences by depth of incorporation for series FB1 and FB2. In each case, surface application (0 depth of incorporation) resulted in significantly higher TP concentrations than the 3 cm, 10 cm and 20 cm depths. Similarly, the 3 cm depth for series FB1 and the 3 cm and 10 cm depths for series FB2 resulted in TP concentrations in surface runoff which were greater than the TP concentration associated with the 20 cm incorporation depths.

For series FB1 and FB2, TSP concentrations in surface runoff (Figures 3.17-3.18) were significantly greater than control concentrations for all rates of application and the 0 cm and 3 cm incorporation depths. Incorporation depths of 10 cm and 20 cm resulted in TSP concentrations which were not significantly different from control levels. For the cases of 0 cm and 3 cm incorporation depths, 4.4 mg/L and 1.6 mg/L TSP were observed for series FB1 against a mean control level of 0.14 mg/L TSP in surface runoff. As with TP concentration in surface runoff, TSP concentration from the 0 cm incorporation depth was significantly greater than concentrations from the other depths for series FB1 and FB2. Similarly, the TSP concentration in surface runoff for the 3 cm depth case was significantly greater than the 20 cm and 10 cm depths for series FB1.

TP, TSP Load in Surface Runoff

The cumulative effect of changes in surface flow volume and concentration can be expressed as a mass load. Figures 3.19 and 3.20 depict mass TP and TSP loads by application rate and depth of incorporation, respectively. The load associated with the high application rate is 995 mg TP (Figure 3.19) which is 142 times the control level. Similarly, the surface application of manure resulted in a loss of 1926 mg TP (Figure 3.20). TSP load (Figures 3.21 and 3.22) in surface runoff followed trends similar to TP with relatively high losses occurring for surface applications (0 depth of incorporation).

Flow volume measurements taken the following spring indicated that the manure-treated plots yielded relatively less runoff than the control plots. The influence of surface applications was less after 300 days than during the FB1-FB2 series. The greatest decreases in runoff were associated with the 3 cm incorporation depth while flow volumes from the 20 cm depth plots were only 15% less than the volumes measured during the FB1-FB2 series.

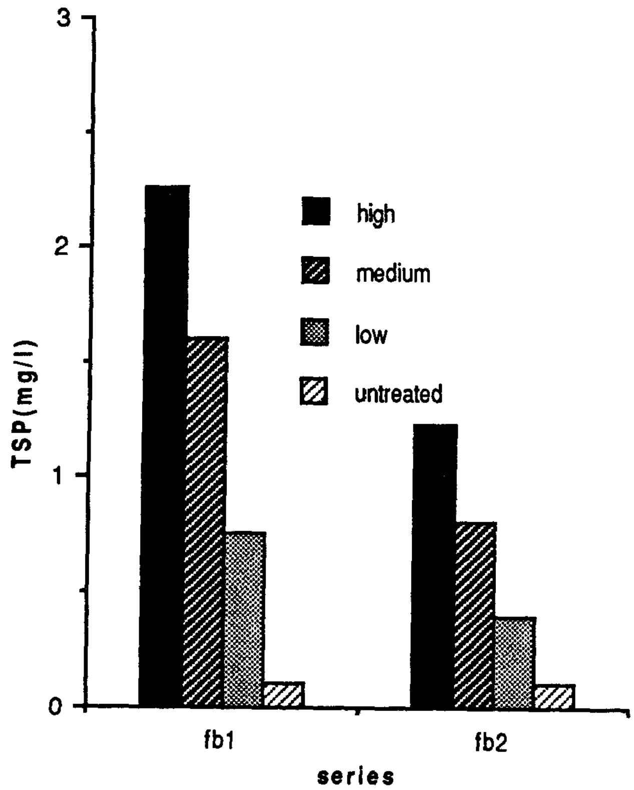

Figure 3.17
TSP Concentration, by rate, fb1-fb2

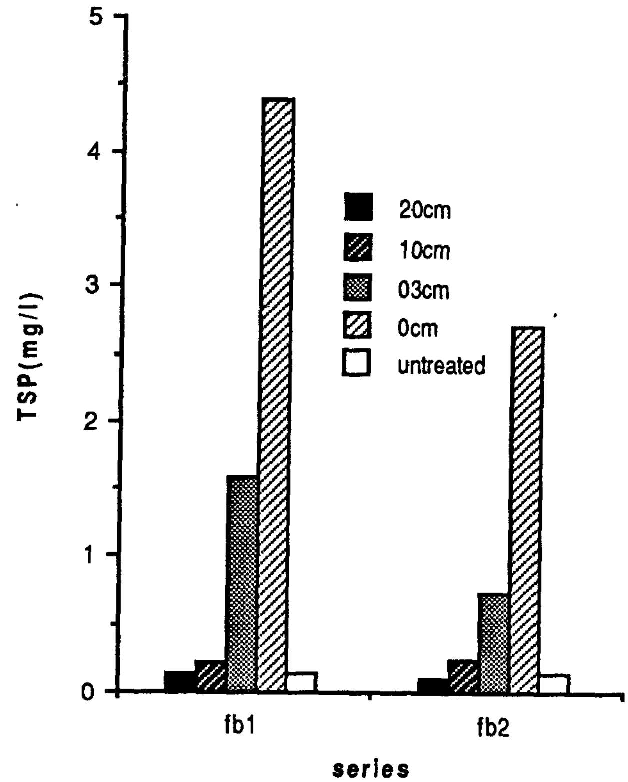

Figure 3.18
TSP Concentration, by depth, fb1-fb2

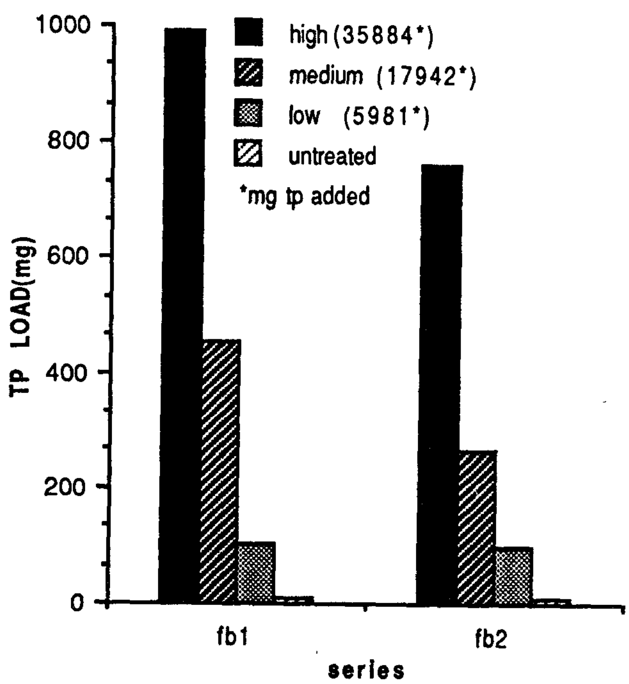

Figure 3.19
TP Load(mg), by rate, fb1-fb2

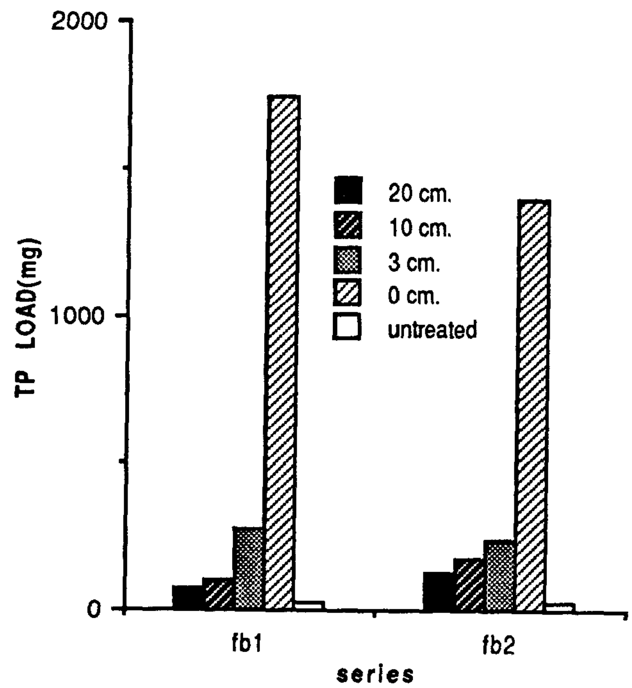

Figure 3.20
TP Load(mg), by depth, fb1-fb2

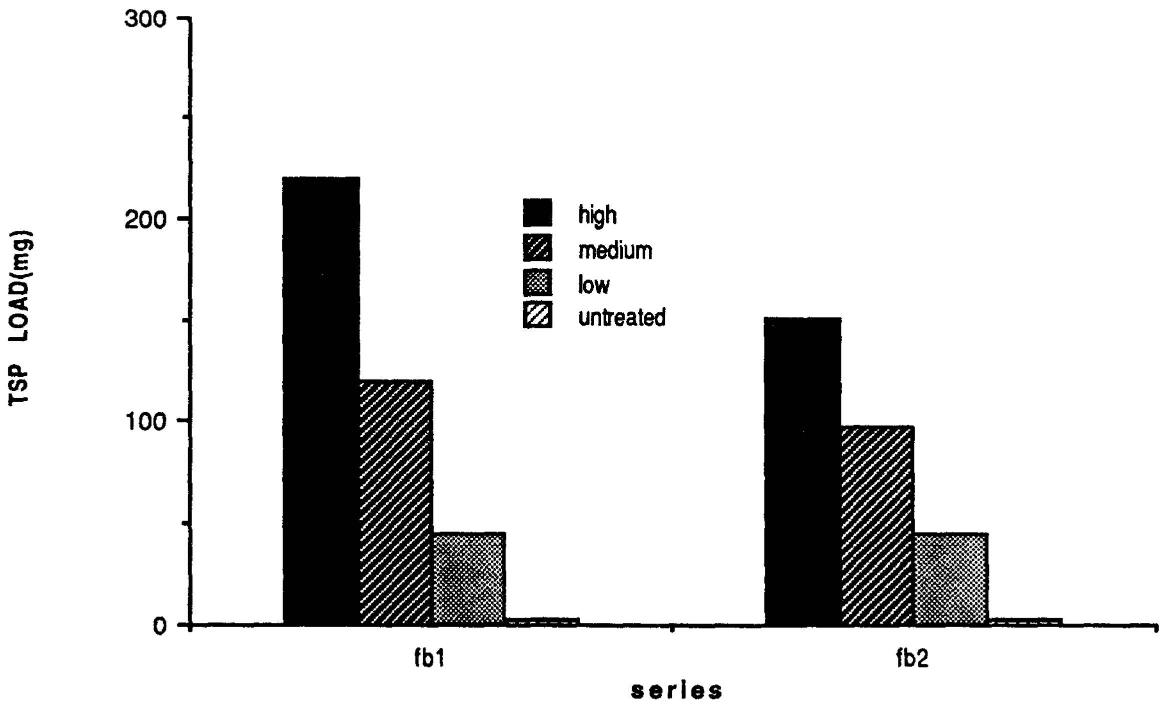

Figure 3.21
TSP Load(mg), by rate, fb1-fb2

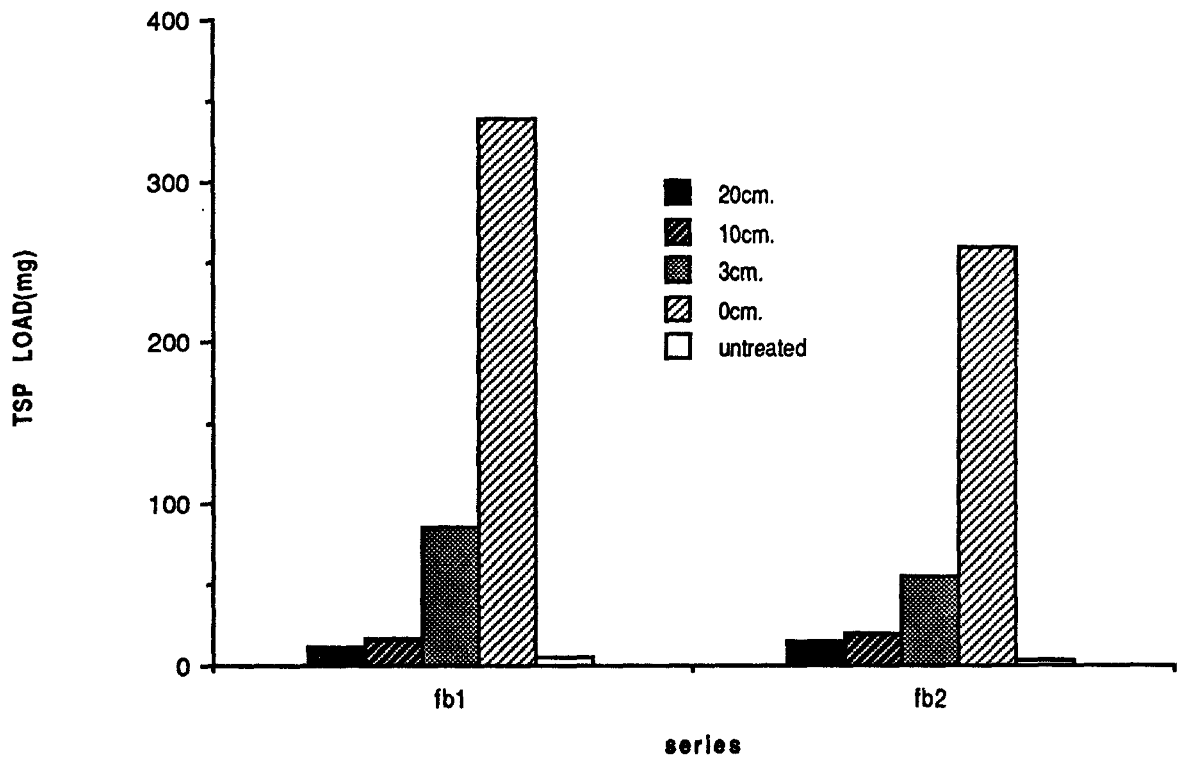

Figure 3.22
TSP Load(mg), by depth, fb1-fb2

Changes in TP concentration over time were greatest for the case of surface applications after 300 days; TP concentration was significantly less than that observed during series FB1 and FB2. Conversely, TP concentration in surface runoff was higher for the 20 cm incorporation depth after 300 days than observed for series FB1 and FB2. TSP concentration decreased significantly in surface runoff for the case of surface application. This trend was also observed for the 3 cm depth. Although differences over time for the 10 cm depth were not significant, an increase in TSP concentration in surface runoff was observed for the 20 cm incorporation depth after 300 days.

TP loads were decreased during the spring runs with losses after 300 days totaling less than 125 mg (9.2 kg/ha) for all application rates and depths of incorporation. Generally, TSP load after 300 days was only 5-10% of FB1 and FB2 series levels. Control losses were significantly less than losses for all application rates and incorporation depths.

LABORATORY SERIES LB1-LB6

Flow Volume

The air-dried soil (7.1% moisture) yielded little runoff (Figure 3.23) during series LB1 (no treatment). As with series LG2 and FB1, surface runoff volume increased for high manure application rates. For series LB2, the troughs treated with 135 Mt/ha of manure exhibited a runoff volume 24% higher than untreated levels. After two and ten days, (respectively series LB3 and LB4, Figure 3.23), troughs treated with a high application rate did not yield a significantly higher surface runoff volume than untreated levels. The following two precipitation events (series LB5 and LB6) produced lower surface runoff volumes for the high-rate troughs. In series LB5 (t=25 days), high application surface runoff volume was only 49% of the untreated volume. Although surface runoff from the high-rate troughs was less than the untreated level after 62 days (series LB6), the difference was smaller than that observed for the 25-day event.

When surface flow volume is categorized by incorporation depth, series LB2 (t=0) and series LB5 (t=25 days) indicate different effects of manure amendments to the soil (Figure 3.24). For series LB2, runoff volume was 10-20% higher than the untreated case. Conversely, for series LB5 manure-treated soil resulted in surface flow volumes 40-60% less than the untreated troughs.

Precipitation to Initiate Runoff (PIR)

The initial wetting of the air-dried soil (series LB1) resulted in PIR values which were relatively high (Figure 3.25). Conversely, precipitation event LB2 immediately after manure application resulted in PIR values which were 5-10% of LB1 (the untreated series). Subsequent series LB3-LB6 indicated that PIR generally increased with each series relative to the values recorded during series LB2. After 62 days (series LB6), PIR values were more than three times those of series LB2.

TP and TSP Concentrations in Surface Runoff

Similar to other series runs, LB2 and FB1, surface runoff collected immediately after the application of manure contained a relatively high TP concentration compared to the untreated case. Approximately an order of magnitude increase in TP concentration was observed at t=0d. After two days (series LB3), the concentration of TP in surface runoff

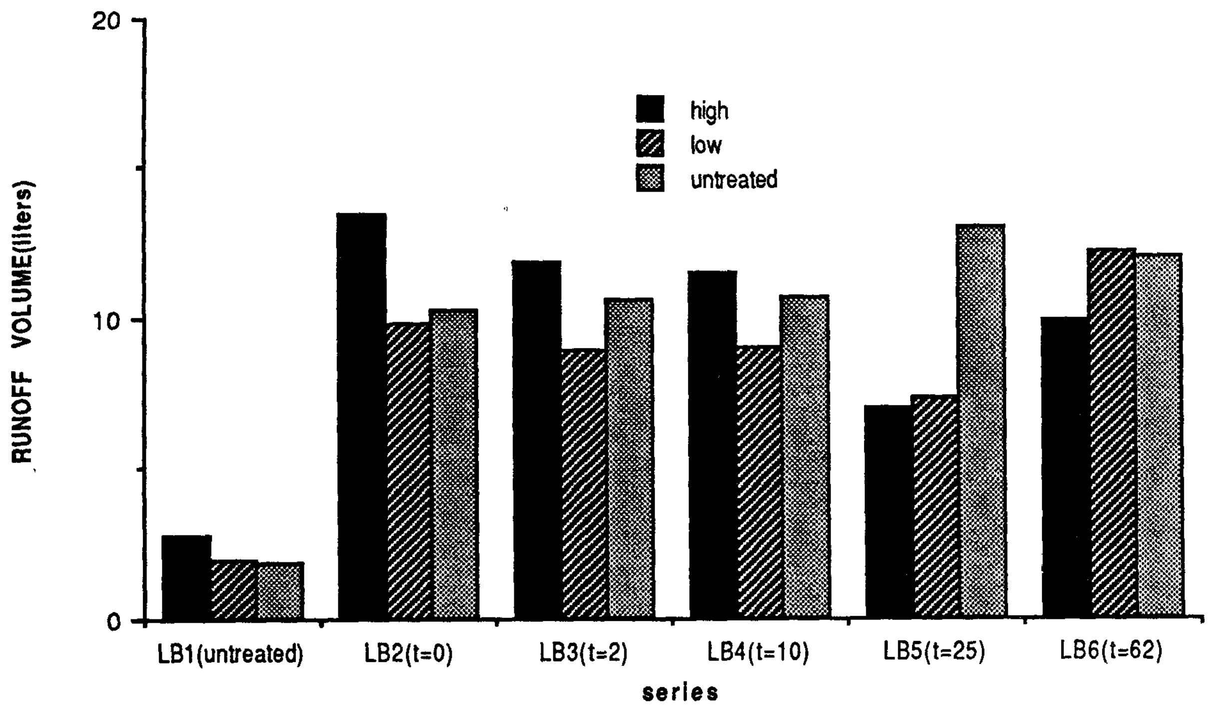

Figure 3.23
Runoff Volume, by rate, lb1-lb6

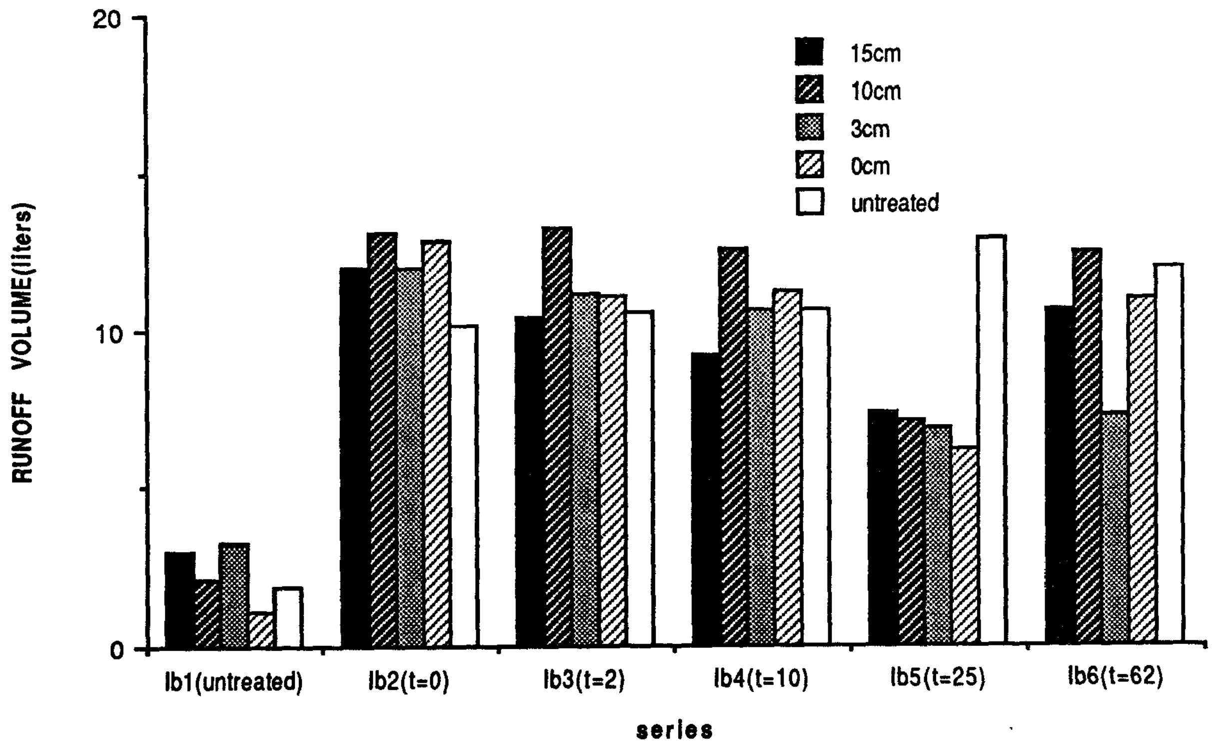

Figure 3.24
Runoff Volume, by depth, lb1-lb6

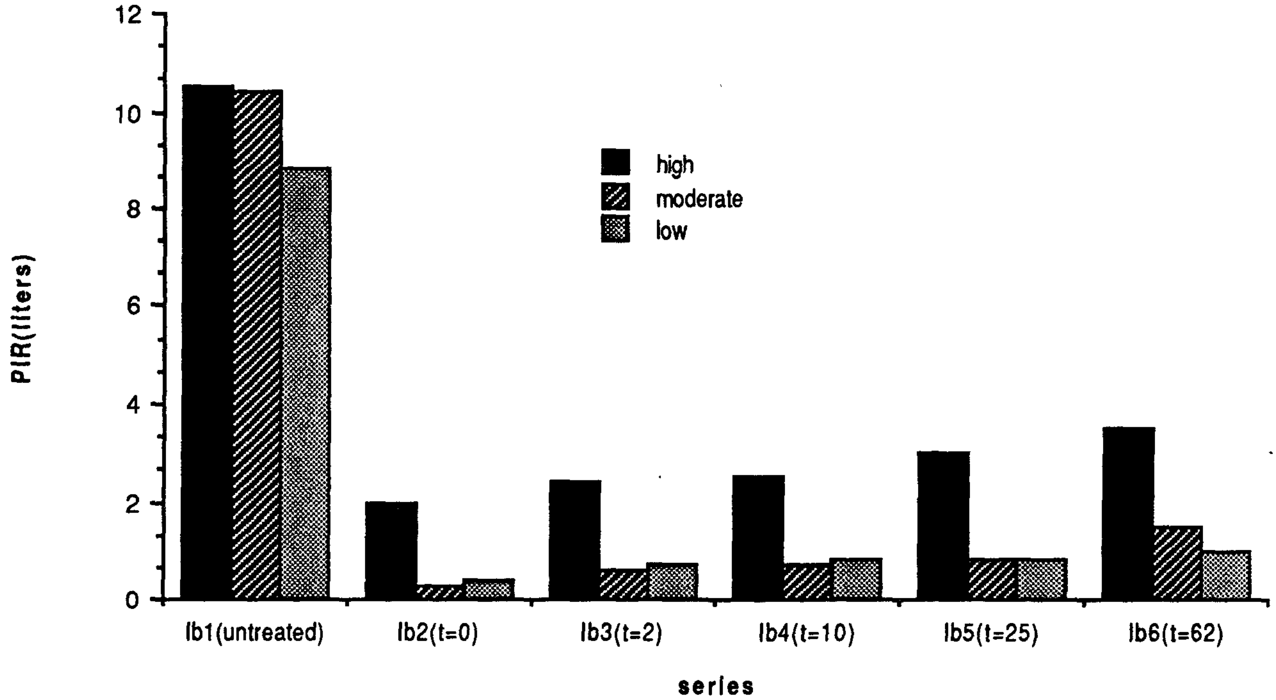

Figure 3.25
Precipitation to Initiate Runoff, series Ib1-Ib6

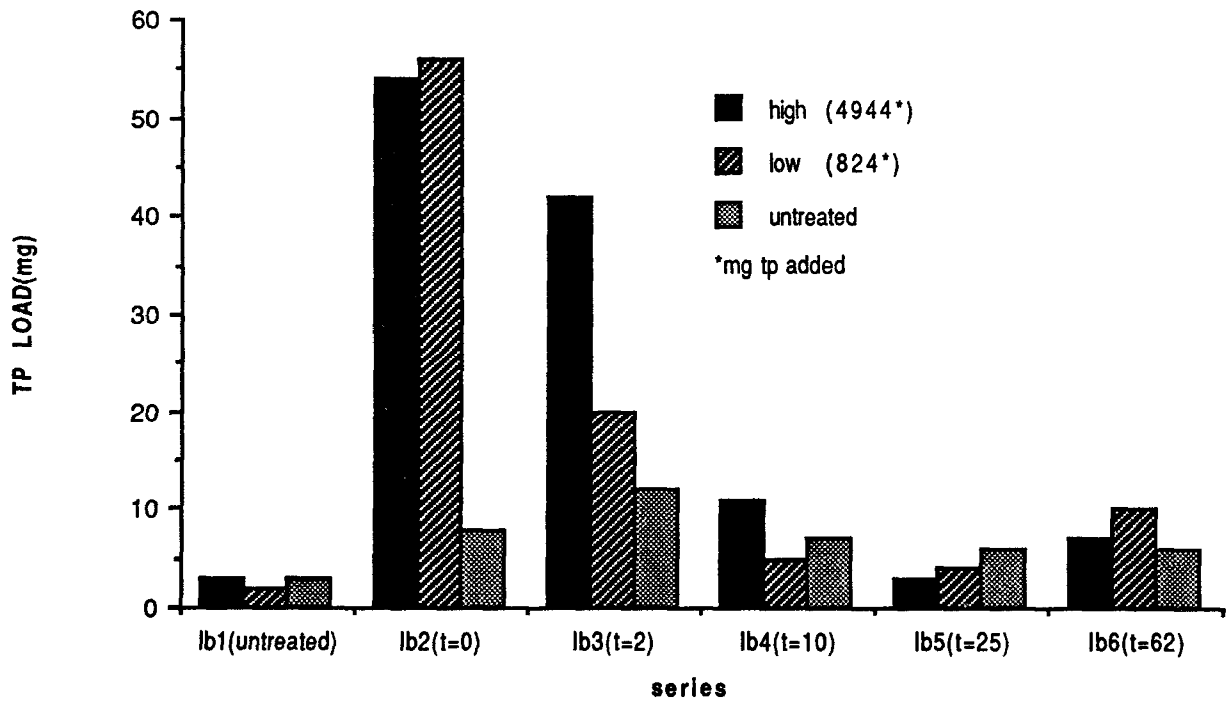

Figure 3.26
TP Load, by rate, series Ib1-Ib6

was approximately two to three times the control level. The following three precipitation events indicated that TP concentration was not significantly different than untreated levels. Thus after three precipitation events the impact of manure amendments to the soil was relatively small.

When TP concentration in surface runoff is examined by depth of incorporation treatments, results vary appreciably. In particular, surface applications (0 depth of incorporation) result in TP concentrations almost 40 times higher than untreated levels when precipitation immediately follows surface application. This difference is considerably less after two days with TP concentration in surface runoff approximately five times control levels for series LB3. Similarly an incorporation depth of 3 cm produced significantly higher TP concentrations for series LB2 and LB3.

Incorporation depths of 10 cm and 15 cm resulted in TP concentrations which were similar to untreated levels for all series runs. In addition, after 10 days (series LB4) surface application and the 3 cm incorporation depth indicated that TP concentration in surface runoff approached untreated levels.

The effect of the rate and depth manure treatments on TSP concentration was apparent during series LB2 and LB3, the two precipitation events immediately following manure application. High concentrations of TSP in surface runoff were observed during series LB2 with almost a 30-fold increase above control values. An incorporation depth of 3 cm resulted in TSP concentration significantly less than those observed in surface applications yet still over eight times higher than the untreated values.

As with TP concentration in surface runoff, incorporation depths of 10 and 15 cm resulted in TSP levels which were comparable to untreated values for all series runs. In addition, after four precipitation events TSP concentration associated with 0 and 3 cm incorporation depths were not significantly different than the untreated soil.

TP and TSP Load

The combined effect of flow volume and TP, TSP concentration result in loadings which vary widely over time both with respect to application rate and depth of incorporation (Figures 3.26-3.29).

The application of manure to the soil resulted in a mass load in surface runoff as high as 391 mg TP for the surface applied case (t=0d). This load was almost 50 times the untreated load and if the simulated precipitation event were extrapolated to an annual quantity of 100 cm, would be equivalent to an annual TP load of 183 kg/ha. After two days (series LB3), the TP load in surface runoff from surface applied case was about six times the untreated level.

Although differences between manure treatments and the untreated soils were less for series LB4 (t=10d) it was series LB5 which, similar to series LG3, exhibited decreased loading in surface runoff for treated soils. This effect was observed for both TP and TSP loads for all application rates and depths of incorporation (Figures 3.26-3.29).

TSP mass load in surface runoff followed similar trends to TP load. For surface applications and precipitation events immediately following manure application, TSP load

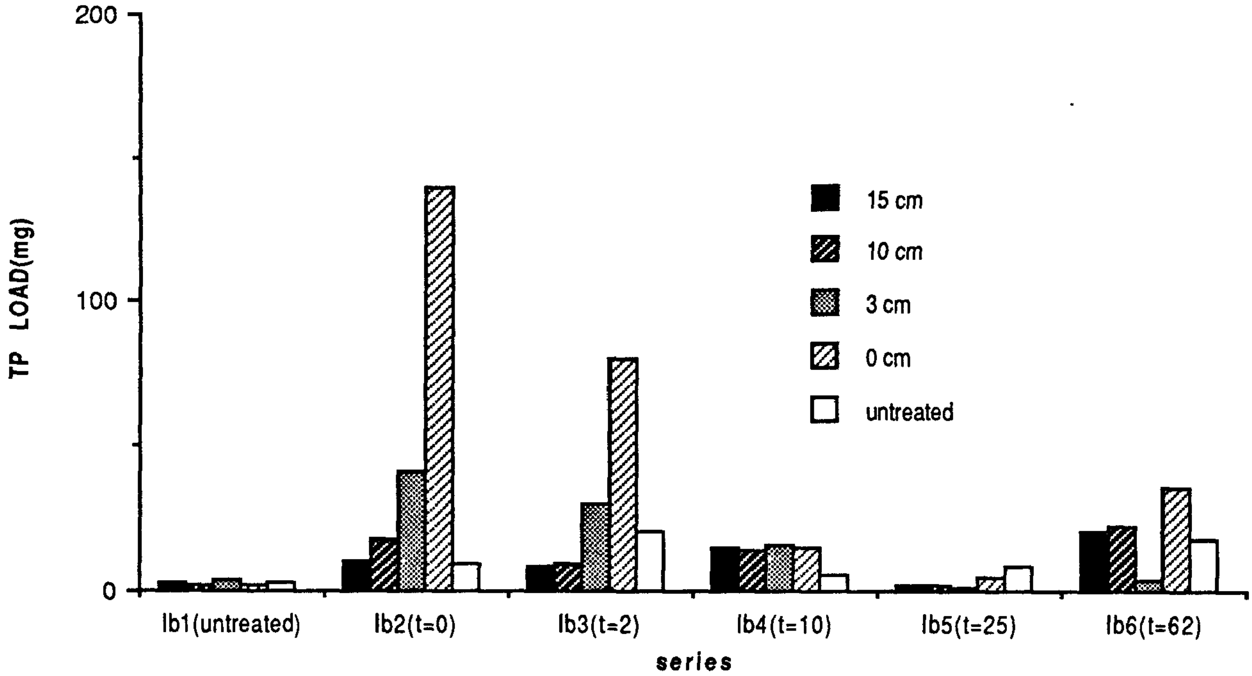

Figure 3.27
TP Load (mg), by depth, series Ib1-Ib6

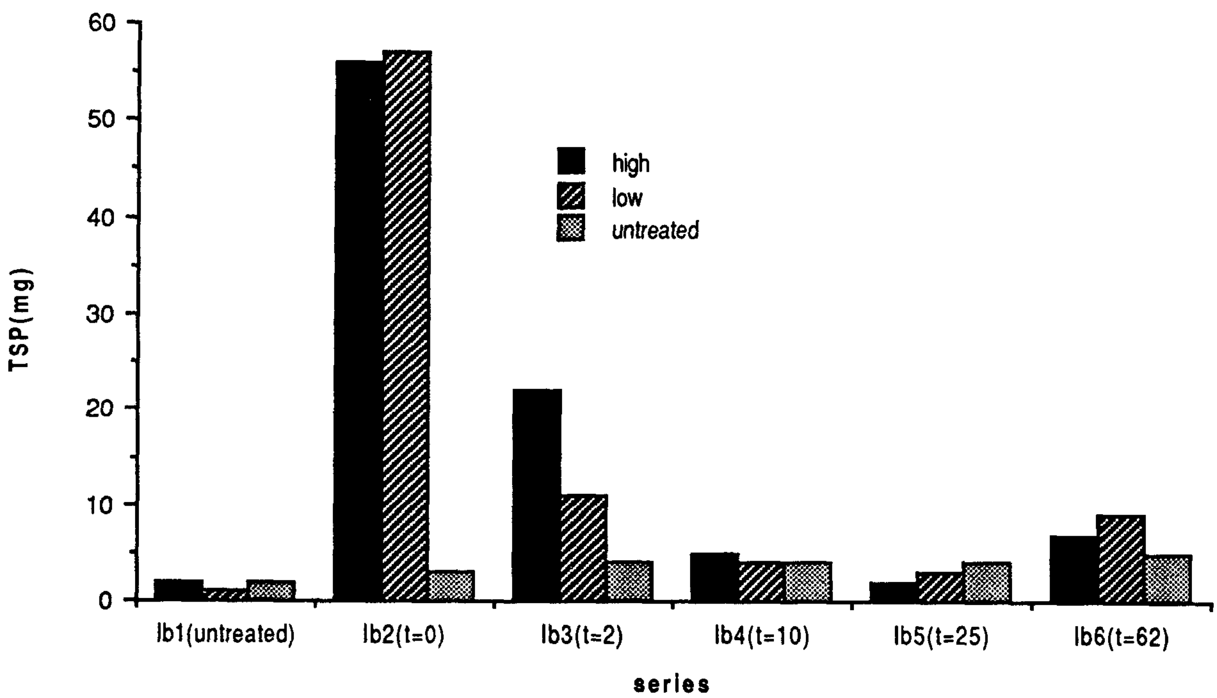

Figure 3.28
TSP Load, by rate, series Ib1-Ib6

was as high as 35 times untreated levels. After 10 days (series LB4) there was no significant difference in TSP load in surface runoff between manure treated soils and the untreated soils (Figures 3.28 and 3.29).

LABORATORY SERIES LBD1-LBD4

The laboratory troughs used for series LG1-LG4 and LB1-LB6 were covered between precipitation events. The effect of this cover was to reduce surface evaporation, slow the drying process and minimize cracking of the soil manure mixture. Following analysis of all LG, LB and FB series runs, the importance of the first few wet-dry cycles was evident.

The results of series LBD1-LBD4 confirm the importance of the initial drying cycle when manure is applied to the surface. Figure 3.30 indicates changes in runoff volume for drying times (time between simulation runs) of two, five, and ten days. After two days, mean flow volume associated with rainfall simulation events decreased to approximately 53% of the flow volumes observed for precipitation events which immediately followed manure application (runs LG2, LB2). Flow volumes observed after five and 10-day drying periods are also greatly reduced with the volume of the 10-day runs less than 20% of the initial high values reported for series runs LG2 and LB2.

NORMALIZED TP, TSP LOADS IN SURFACE RUNOFF

Series LG1-LG4

When TP load is normalized by application rate, TP loads for the high and medium application rates are less than 40% of the normalized low rate values (Figure 3.31). As indicated in Figure 3.32, the high normalized load in surface runoff associated with surface applications is greatly reduced at the 3 cm incorporation depth in the LG2 series.

Normalized TSP loads indicate high values for the low application rate troughs (Figure 3.33). Increases of as much as six times the high and medium rate values were observed for normalized low rate TP loads in surface runoff. Untreated values are included for reference in Figure 3.33. Incorporation depths of 3, 10 and 15 cm resulted in normalized TSP loads in surface runoff which were less than 40% of the mass TSP load associated with surface applications for series LG2 (t=0). Generally the 3 cm incorporation depth was significantly lower than surface application TSP losses, yet higher than normalized TSP losses observed for the 15 and 10 cm incorporation depths (Figure 3.34).

Series LB1-LB6

The relatively high normalized TP load observed in series LG1-LG4 was also evident in laboratory series LB1-LB6 (Figure 3.35). For series LB2 (t=0), normalized TP load rate for the low application was over six times the load observed for the high application rate (135 MT/ha). For subsequent precipitation events LB3-LB6, normalized TP load in surface runoff was also greater for the low application rate 22 MT/ha. However, the increase in normalized TP load for the low application rate compared with the high application rate varied greatly between series. For series LB4 (t=10d), for example, normalized TP load for the low rate was only 1.8 times the value recorded for the high rate while the low rate was 19 times the high rate for series LB6 (t=62 days).

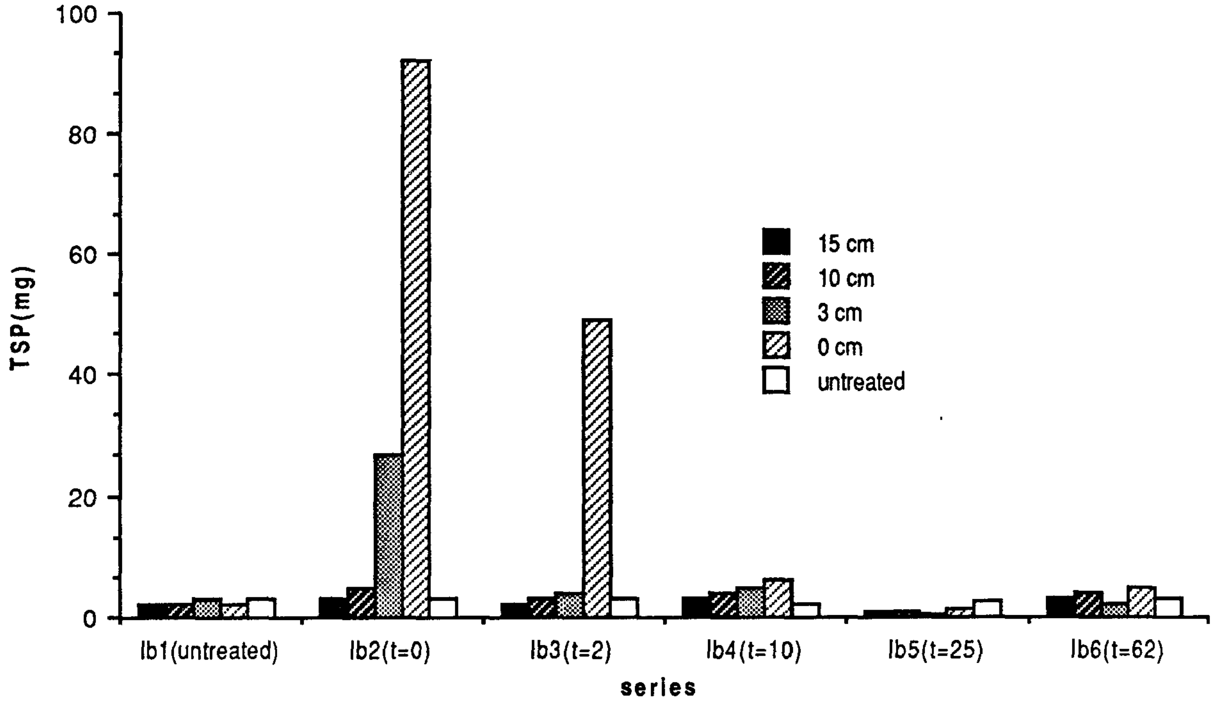

Figure 3.29
TSP Load, by depth, series Ib1-Ib6

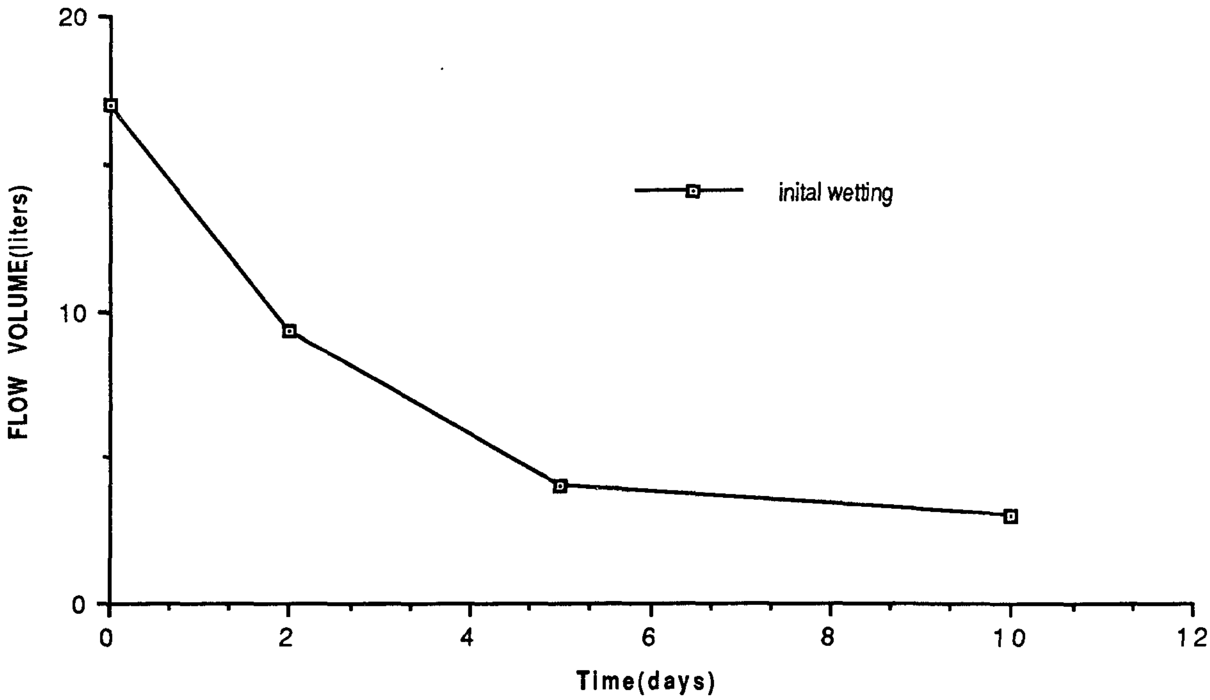

Figure 3.30
Flow Volume for Different Drying Times, Ibd1-Ibd4

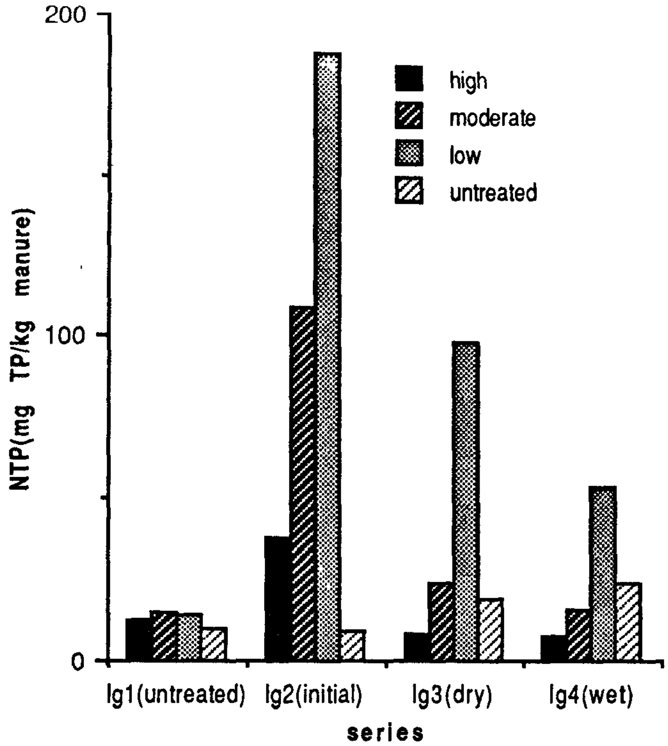

Figure 3.31
Normalized TP Load(mg/kg), by rate, lg1-lg4

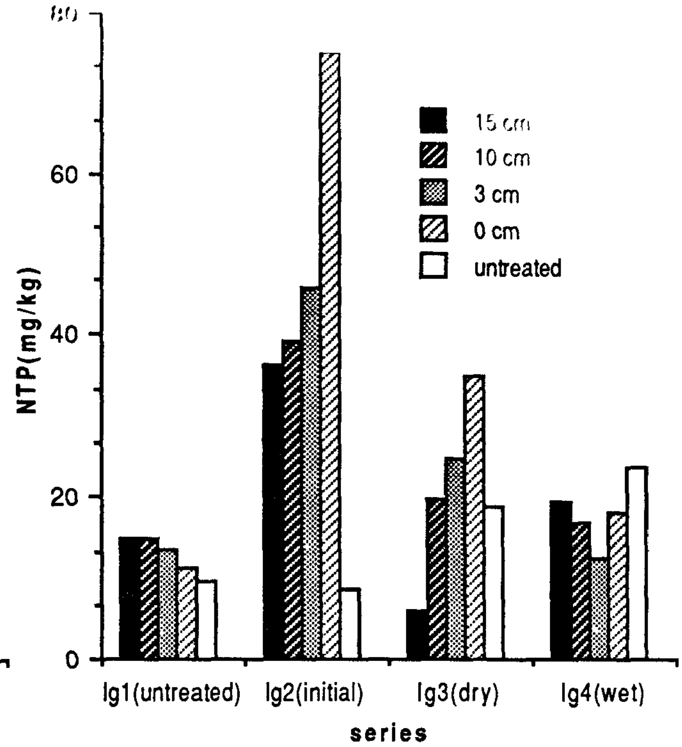

Figure 3.32
Normalized TP Load(mg/kg), by depth, lg1-lg4

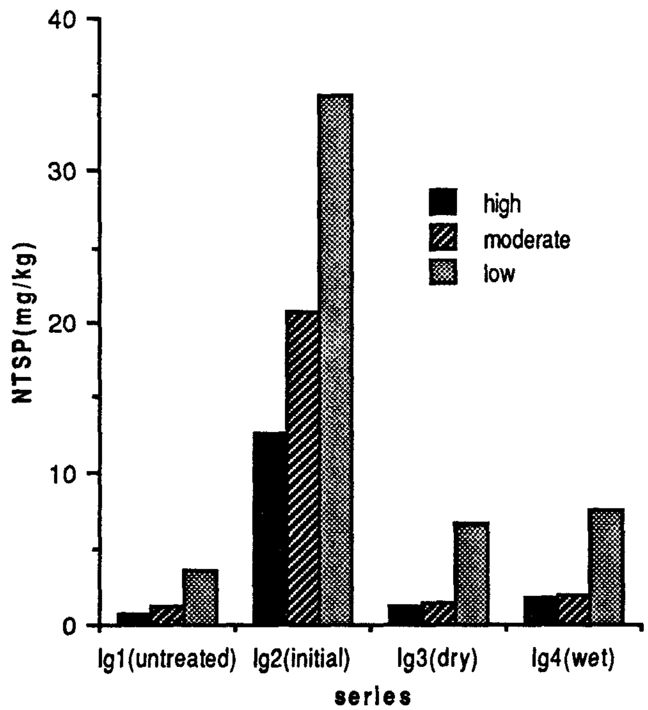

Figure 3.33
Normalized TSP Load(mg/kg), by rate, lg1-lg4

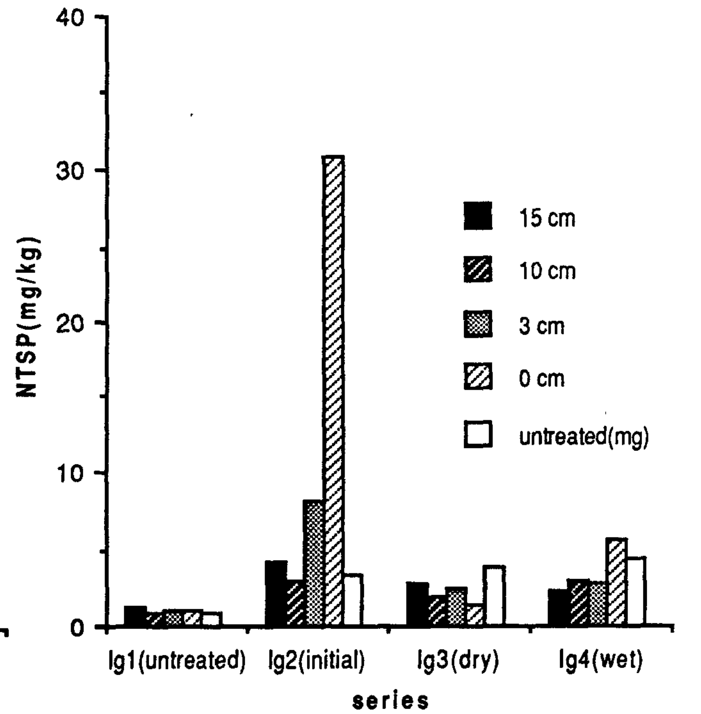

Figure 3.34
Normalized TSP Load (mg/kg), by depth, lg1-lg4

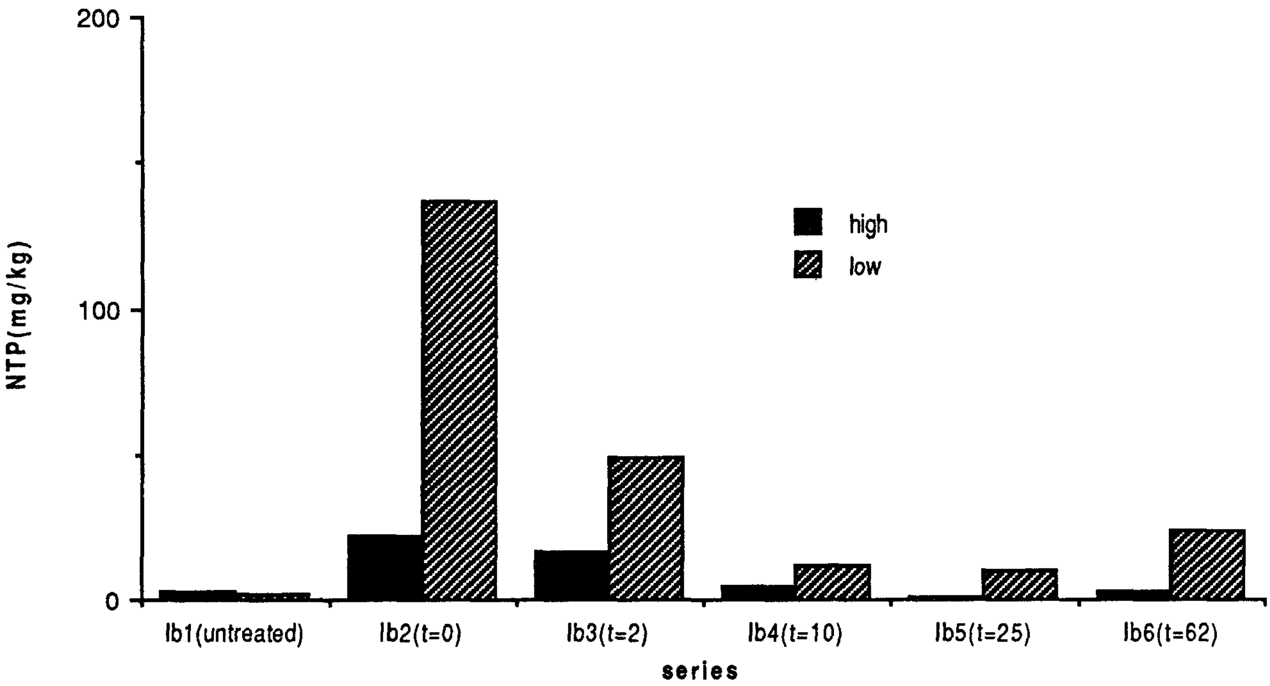

Figure 3.35
Normalized TP Load(mg/kg), by rate, Ib1-Ib6

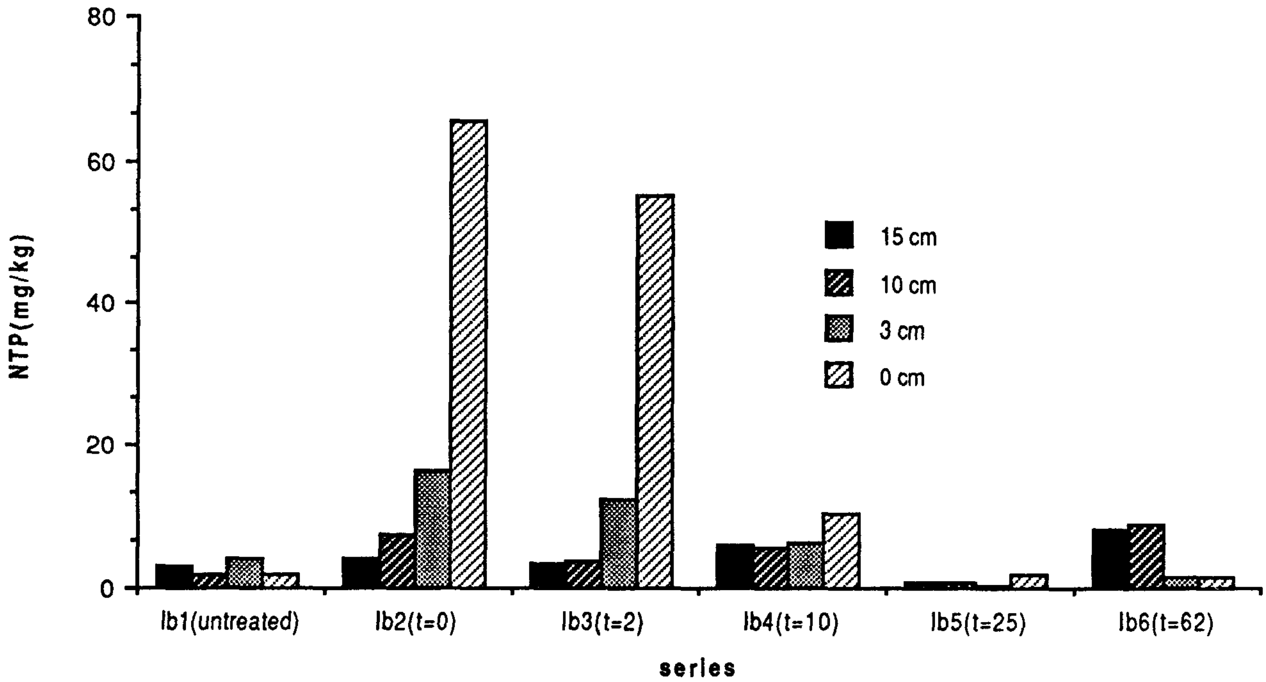

Figure 3.36
Normalized TP Load(mg/kg), by depth, Ib1-Ib6

For series LB1-LB6, normalized TP load by incorporation depth emphasizes the effect of incorporation within the top 3 cm of soil (Figure 3.36). It is evident from Figure 3.36 that mass loading of TP per unit manure input is much less for incorporated manure than the normalized TP load associated with surface application. In addition, differences in normalized load lessened considerably after precipitation event LB3. However, as with variations in normalized TP load by incorporation depth, differences between normalized loads for precipitation events LB3-LB6 vary considerably.

Normalized TSP load in surface runoff (Figure 3.37) indicates high loading per unit of manure applied for the low application rate (22 Mt/ha equivalent). For LB2, the low application rate would yield 152 mg of TSP for each kg of manure applied to the laboratory trough while the high rate yields 18.4 mg/kg of manure applied. This high rate TSP yield is 12% of the low normalized yield. Subsequent precipitation events LB3-LB6 resulted in low rate normalized TSP yields which were 3.8 to 8.2 times the high rate values.

When normalized TSP load in surface runoff is presented by depth of incorporation (Figure 3.38) most values are comparable to the TSP mass load observed for the control troughs. Exceptions to this observation are the mass loads associated with surface applications for precipitation events LB2 and LB3 which were 36 and 14 times the control values, respectively. In addition, normalized TSP load in surface runoff for the 3 cm incorporation depth was four times the control TSP mass load for LB2.

PARAMETER CORRELATIONS

The correlation coefficient between two parameters can help explain variability between observations and aid in the understanding of physical/chemical processes. However, it is important to note that statistical inference does not allow a direct cause-effect statement.

Comparisons between different correlation coefficients were made by grouping series runs according to the time period between manure application and runoff. This grouping was made to attempt comparisons at stages of manure degradation which were roughly similar between series. The various groups are listed below:

Group 1. Control Runs - parameter correlations derived from water samples from untreated plots (LG1, LB1, FB1-FB2)

Group 2. Initial Runs - parameter correlations derived from water samples collected within two days of manure application to the soil (LG2, LB2, LB3, FB1, FB2)

Group 3. Intermediate Runs - parameter correlations derived from water samples collected between three and thirty days after manure application to the soil (LB4, LB5)

Group 4. Long-term Runs - parameter correlations derived from water samples collected between 31 and 90 days of manure application to the soil (LG3, LG4, LB6)

Group 1. (control runs) statistical analysis indicated that TP concentration and suspended solids (SS) had a correlation coefficient of 0.71, while TSP concentration and pH had a coefficient value of 0.79. Similar degrees of correlation were observed for

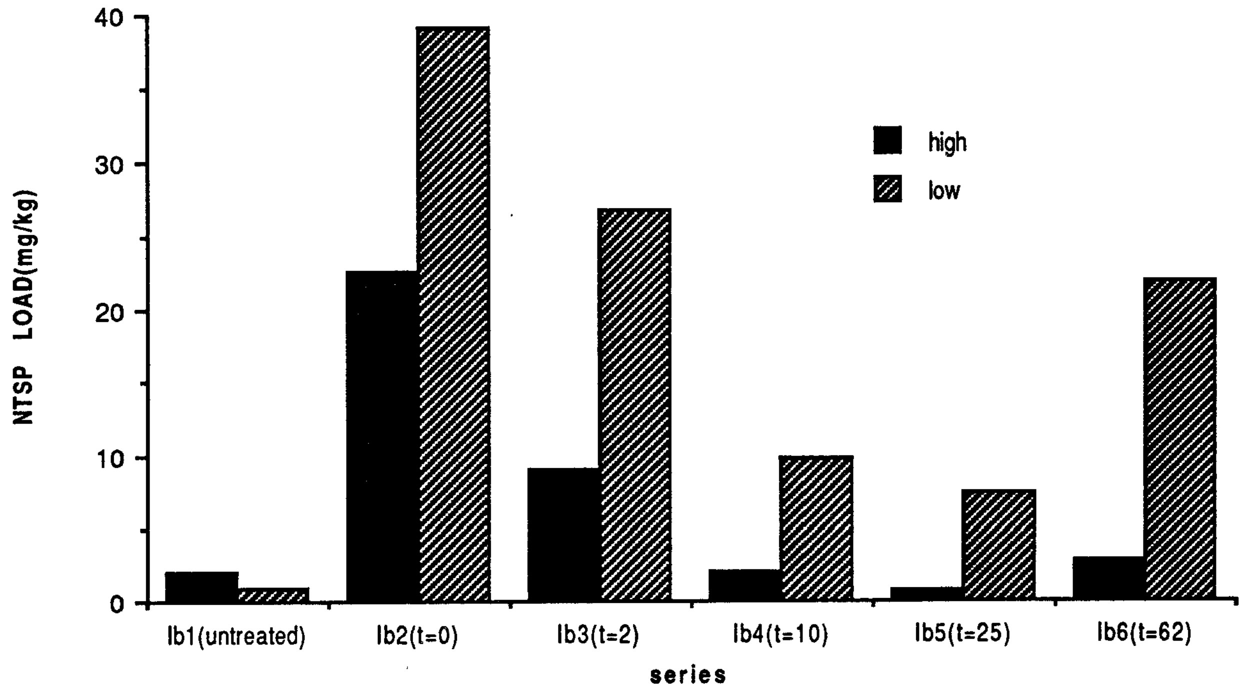

Figure 3.37
Normalized TSP Load(mg/kg), by rate, Ib1-Ib6

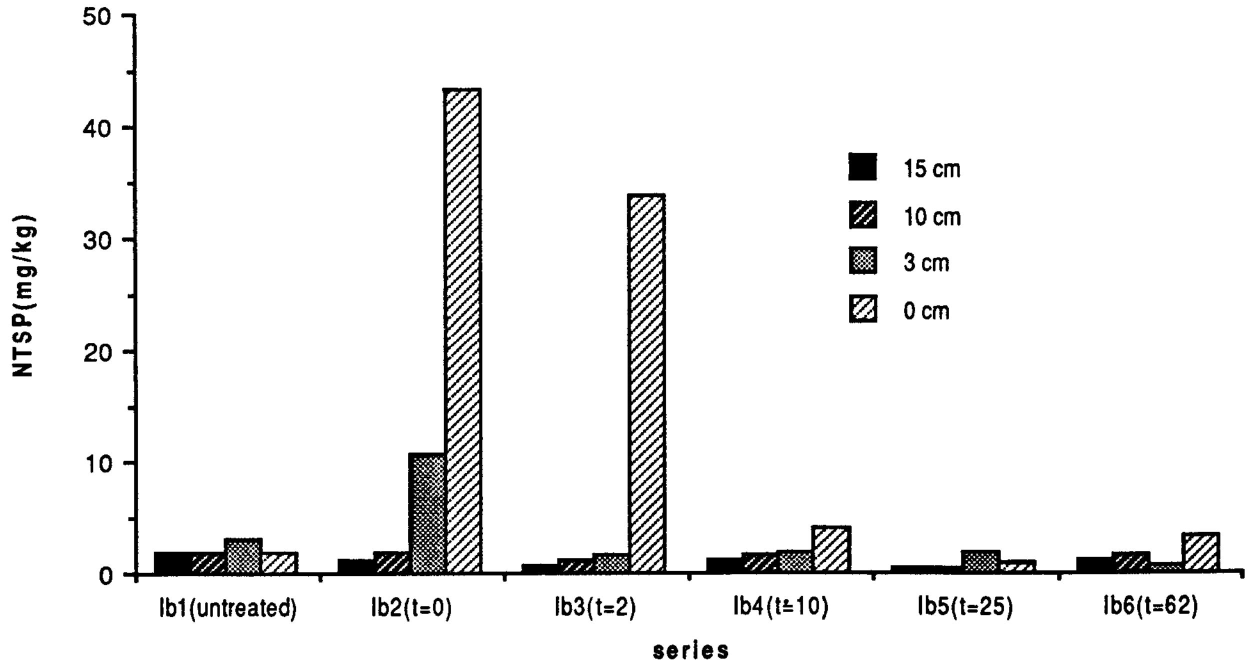

Figure 3.38
Normalized TSP Load(mg/kg), by depth, Ib1-Ib6

Group 2 (initial runs) with the correlation between TP concentration and SS, TSP concentration and pH equal to 0.73 and 0.81, respectively. In addition, Group 2 displayed a high correlation between TP and TKN concentration. The correlation between flow volume and TP, TSP, pH and SS concentration varied between 0.60-0.73. A correlation between flow volume and other parameters was not observed to be greater than 0.50 for the other three Groups. Group 3 correlations again indicated coefficients greater than 0.50 for TP and SS. In addition, the correlation coefficient for TSP and TKN concentration was 0.69 for series runs which took place 2-30 days after manure application. Finally, Group 4 runs indicated correlation coefficients of 0.78 and 0.72, respectively, for TP-SS and TP-TKN. Although not as high as other groups the correlation between pH and TSP was still greater than 0.50 for these longer term series runs.

VARIATIONS IN NUTRIENT CONCENTRATION IN SURFACE RUNOFF WITHIN EVENTS

For many series runs, individual parameter concentration changed in similar patterns. This is important when the results of simulated precipitation events are extrapolated to storms of either a lower or higher intensity.

An example of variations in TP concentration within series FB1-FB2 are given in Figure 3.39. The first sample taken yielded a relatively low TP value while the second sample indicated the highest series value. Subsequent samples over the 24-hour run period were less than 35% of the maximum TP concentration. TP concentration changes for series LB1-LB3 similarly indicate relatively high or peak concentration observed early in the run with later samples indicating a considerably lower TP concentration over a 48-hour period (Figure 3.40).

Although at lower concentrations, TSP in surface runoff (Figure 3.41) followed a similar pattern to TP with a maximum concentration of 2.5 mg/L indicated for the second sample of series FB1 (immediately following manure application). The dilution effect for samples collected over a short time period (Figure 3.42) was observed for series LB1-LB3 with a maximum TSP concentration in surface runoff occurring for the first sample collected in series LB2, 3.6 mg/L.

Considering the high correlation between TP and SS it is not surprising that the suspended solids concentration in surface runoff follows a similar trend to TP (Figure 3.43). Thus, over a 24-hour period and two precipitation events (series FB1-FB2), SS peaked at almost 6000 mg/L while the last sample of series FB2 indicated about 1000 mg/L in surface runoff.

SURFACE RESIDUE SERIES (LRB1 - LRB6)

As Wishmeier (1979) points out, even small quantities of straw mulch increase infiltration and decrease soil erosion. The effect of surface applied manure is consistent with two particularly important aspects of mulch systems which decrease TP, TSP loading;

- After the surface manure pack has dried a residue cover is evident. This residue can result in almost complete surface cover when high rates of woodchip, sawdust or straw bedding have been used.

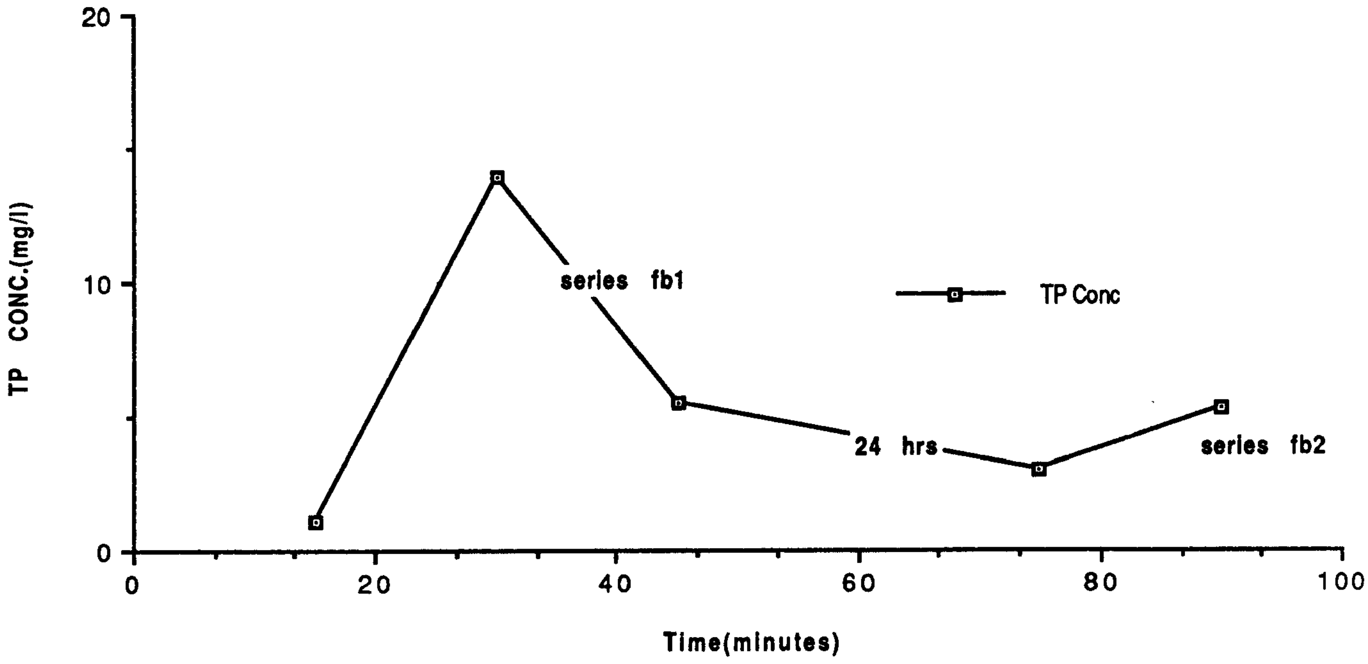

Figure 3.39
TP Concentration, by sequence, series fb1-fb2

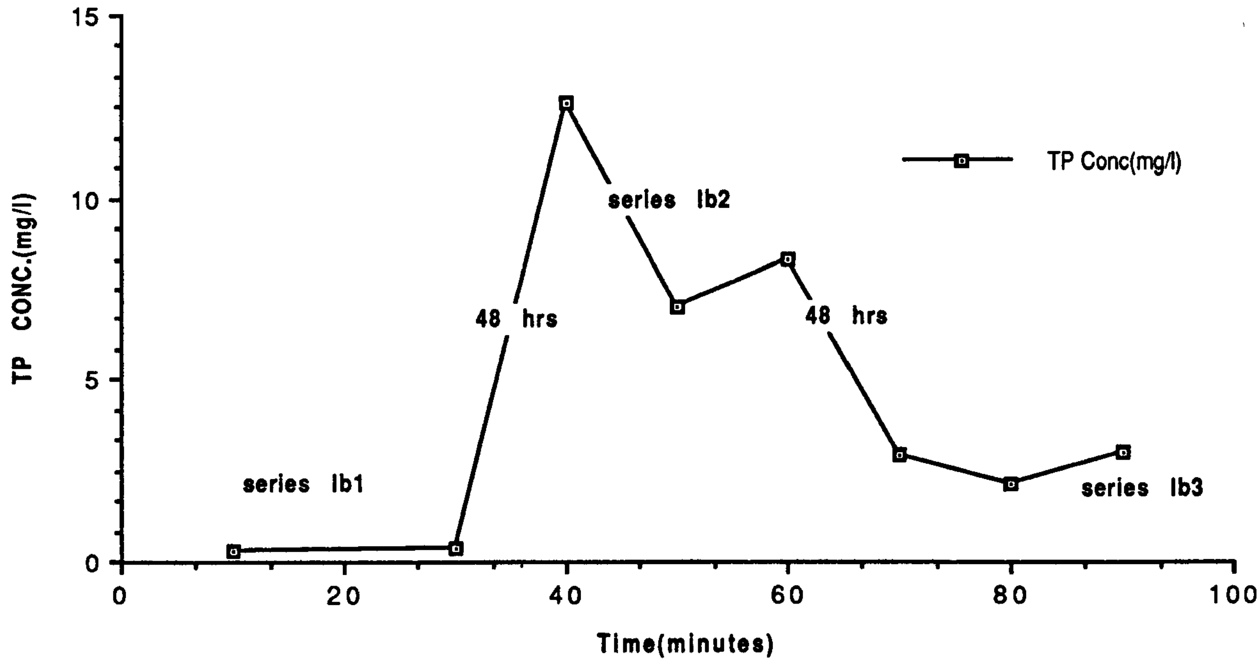

Figure 3.40
TP Concentration, by sequence, series lb1-lb3

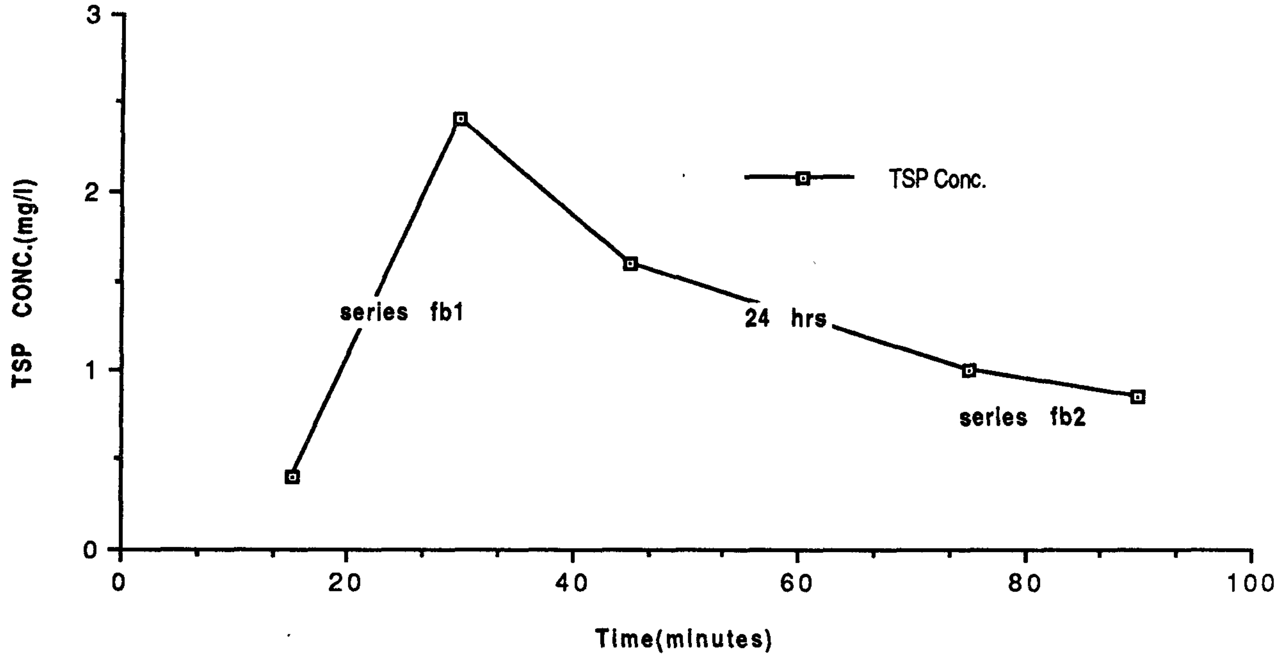

Figure 3.41
TSP Conc.(mg/l), by sequence, series fb1-fb2

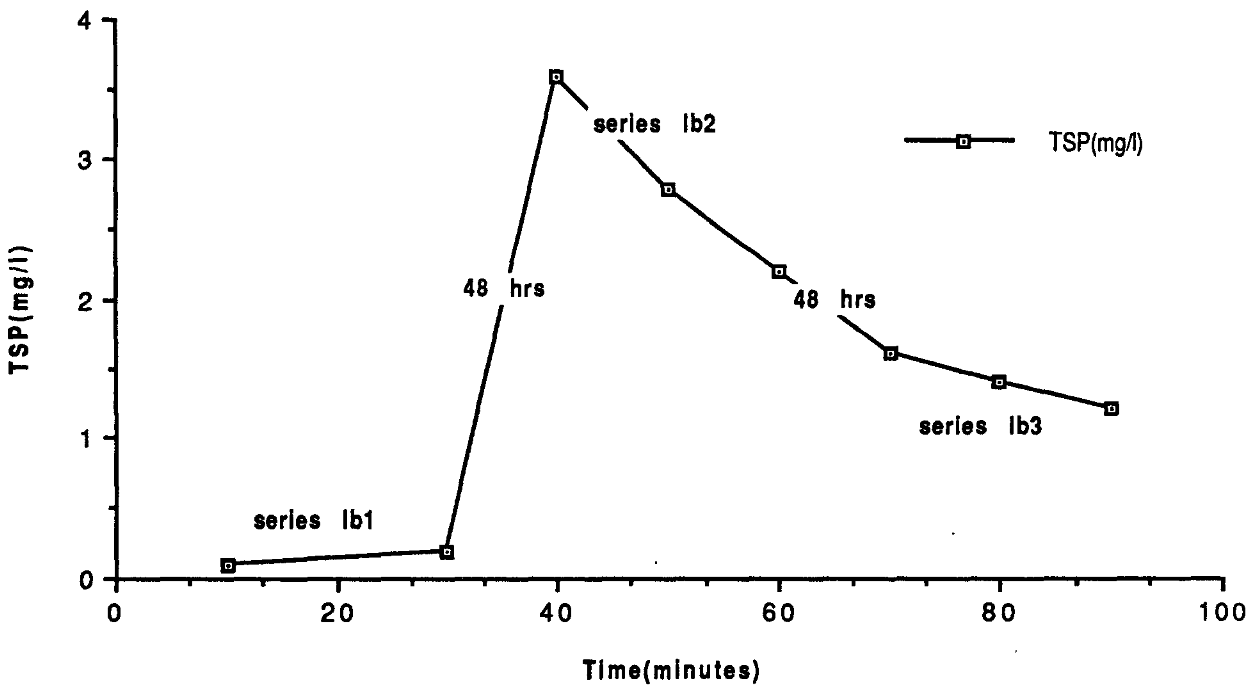

Figure 3.42
TSP Concentration, by sequence, series lb1-lb3

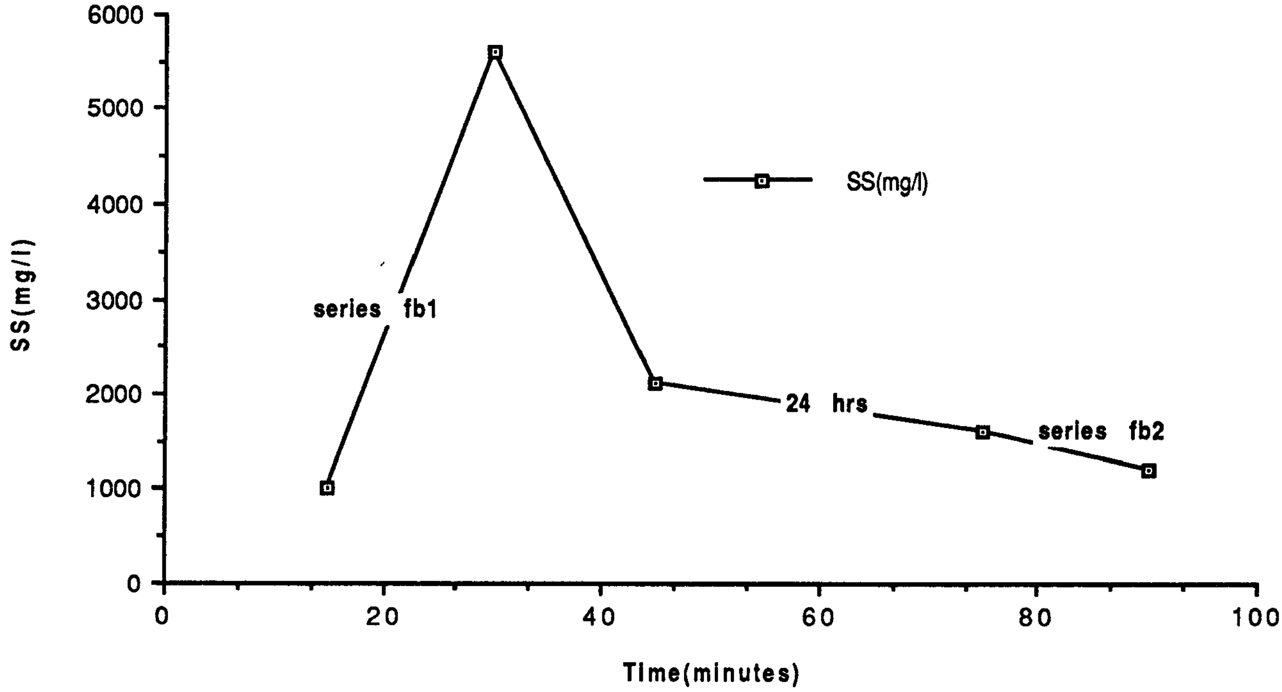

Figure 3.43
SS Concentration, by sequence, series fb1-fb2

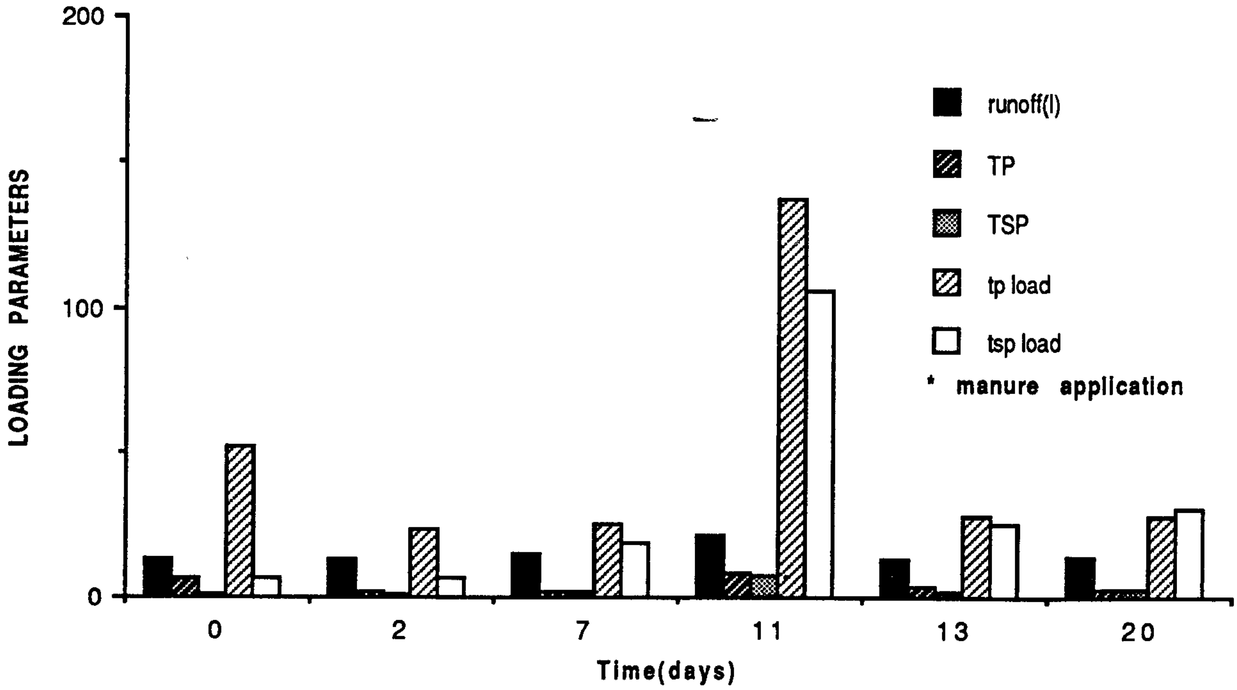

Figure 3.44
Loading Parameter, by Time, residue series

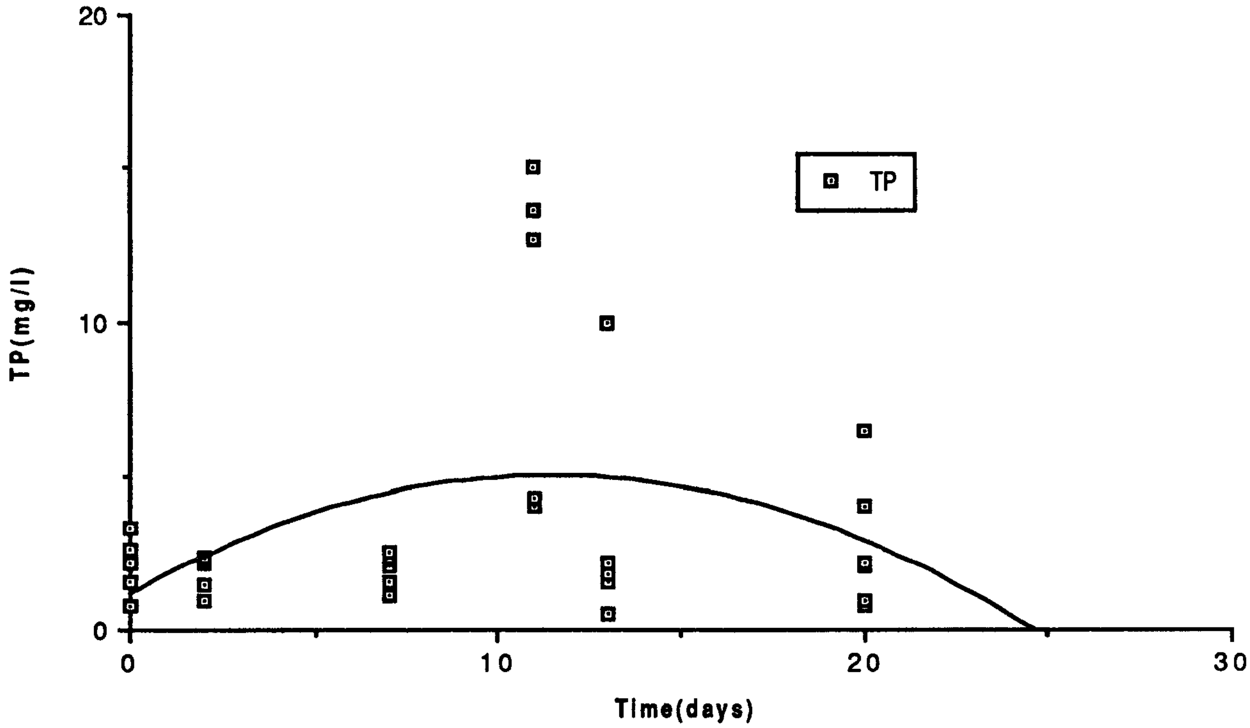

Figure 3.45
TP(mg/l), by Time, residue series

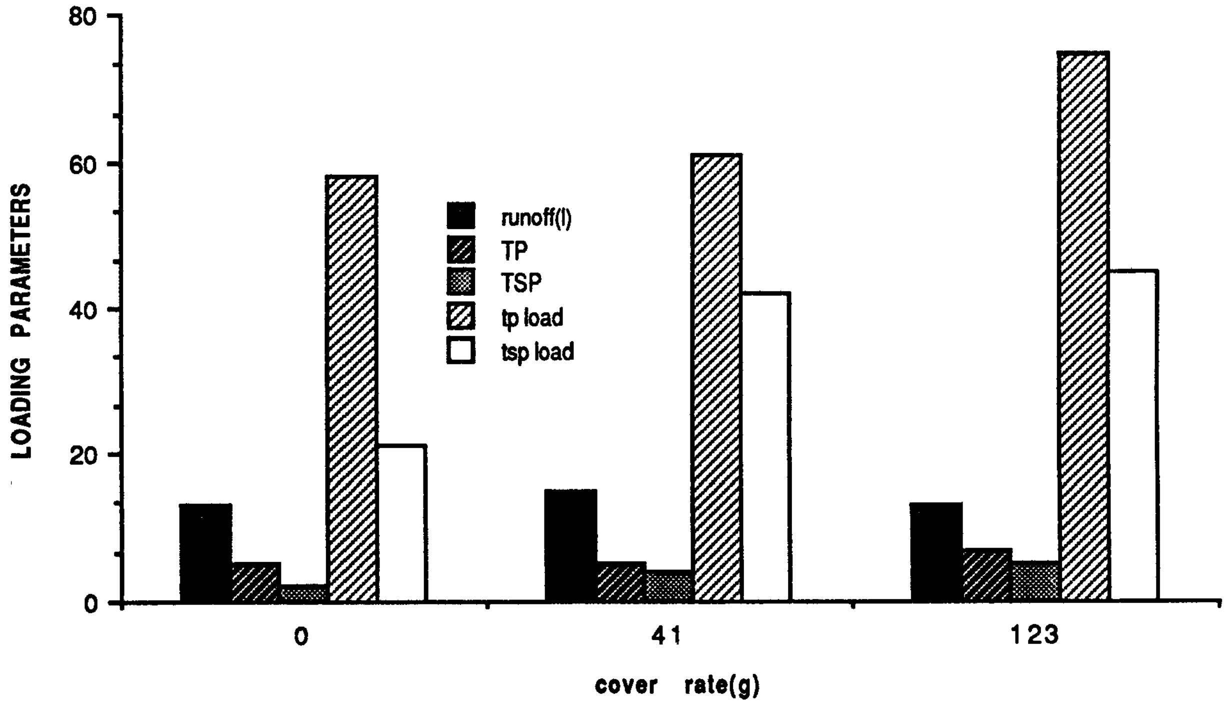

Figure 3.46
Loading Parameters vs. Cover,all

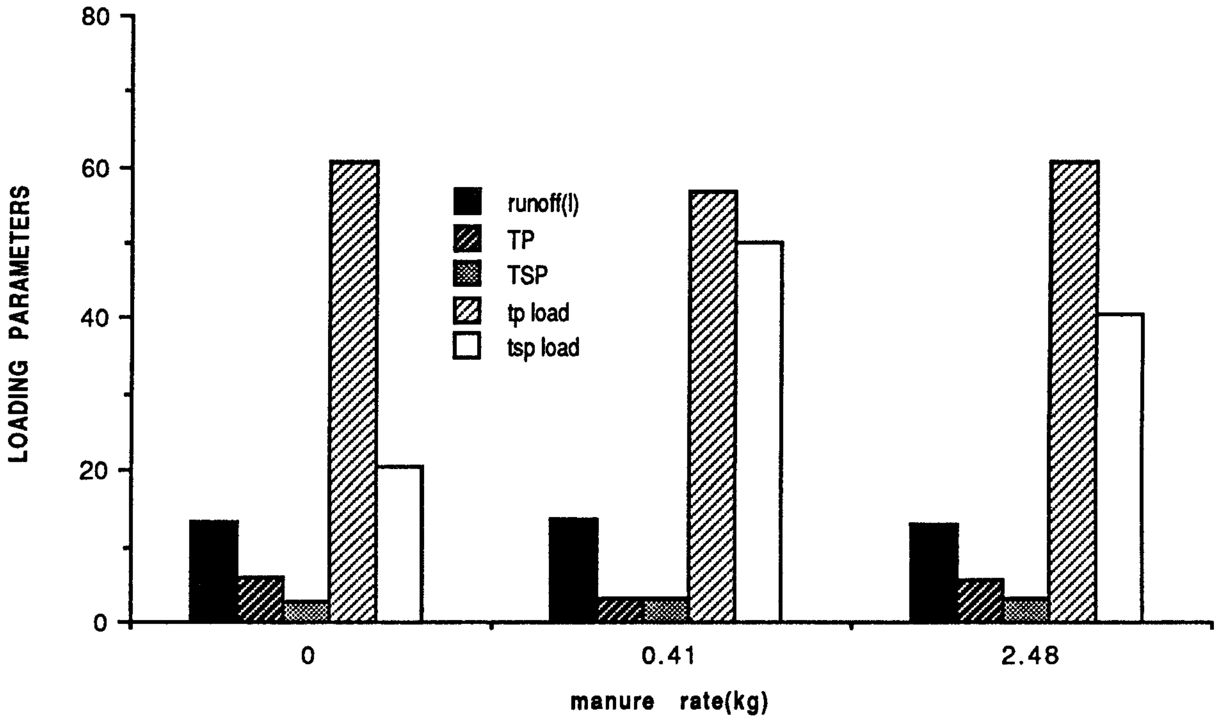

Figure 3.47
TP Loading Parameters vs. Rate

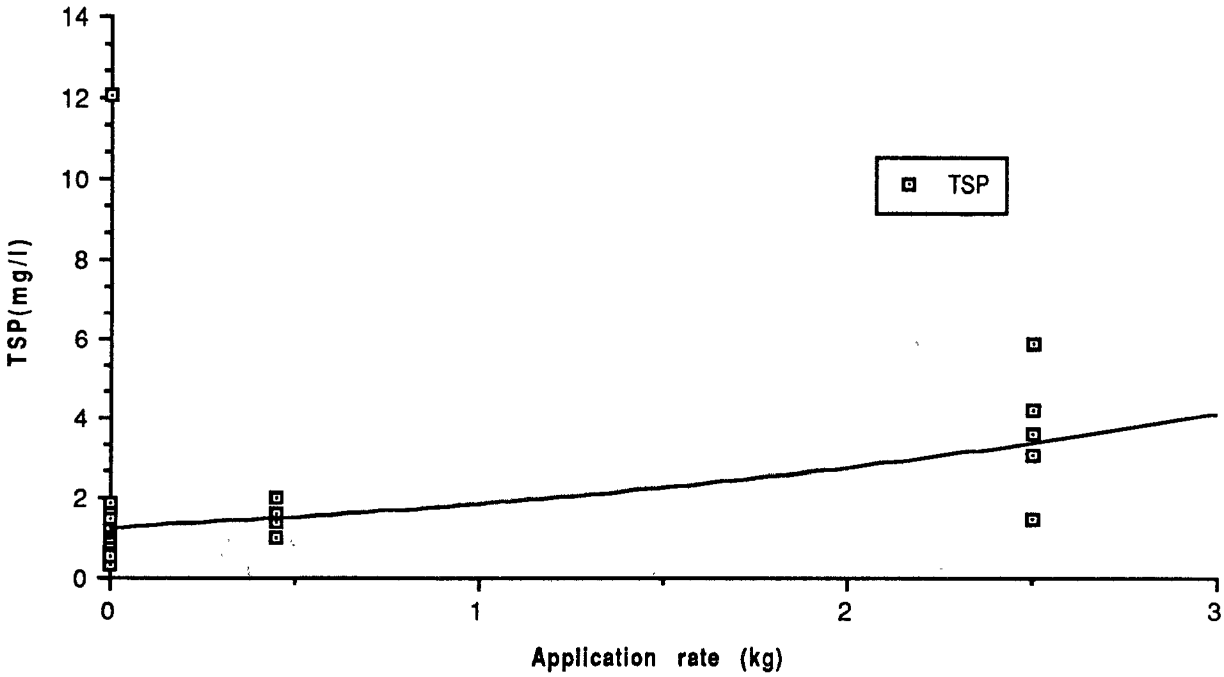

Figure 3.48
TSP(mg/l) vs. Application Rate

- The resulting mulch effect from manure applications to the surface will improve hydrologic properties of the soil and decrease winter frost depths (Benoit 1984, 1985).

Differences in the volume of runoff for the residue series runs (Figure 3.44) are small and showed no trend with time. TP load with a residue cover was reduced by 60% from the untreated case. When manure was applied to the residue, TP and TSP concentration increased significantly. However, the increase in TP and TSP load associated with the higher concentrations were not as great as those observed when manure was applied to the surface of bare soil (series LG1-LG4 and FG1-FG3). On the other hand, the fraction of TP which is soluble was high (60-90%) both when manure applications were made to the surface and over residue.

Figure 3.45 shows the effect of manure applications on TP concentration over time with a concentration spike occurring at 11 days, corresponding to the time when manure was applied over the surface residue. When all series data are pooled (Figure 3.46) TSP load and TP load increase appreciably with residue cover This load increase is likely due to the fact that manure applied over the residue cover is more easily detached and transported in overland flow. The effect of manure application rate (Figure 3.47) also indicates increased TSP load and comparable or decreased TP load with increased application rate.

Changes in TSP concentration and load are particularly important because virtually all of this load is readily available for algae growth. Figures 3.48 and 3.49 indicate that both manure application rate and residue cover increase TSP concentration in runoff. The higher concentrations associated with surface manure applications validate earlier Phase I laboratory and field experiments. However, the clear association of TSP concentration with corn residue rate suggests that the availability of phosphorus is controlled by water movement and that the decreased loads observed when surface manure applications are dried (series LG-LG4, FB1-FB3 and LB1-LB6) are less evident with soil mulch systems.

The quantity of water retained after surface manure treatments is reflected in Figures 3.50 and 3.51. Figure 3.50 indicates the change in moisture after sequential wet-dry cycles. The higher moisture content results in smaller amounts of moisture retained (Figure 3.51) by the soil manure mixtures. As indicated in Figure 3.51 after simulated precipitation at 10 and 20 days the quantity of water retained decreased although the percent soil moisture was relatively high in most cases. This phenomena, in part, explains the high losses of soluble phosphorus since drying and sorption processes are decreased with the wet soil surface conditions under the mulch cover. On the other hand the apparent surface sealing which occurred during precipitation immediately following manure application (series LG1-LG4, FB1-FB3, LB1-LB6) does not appear to inhibit surface infiltration. This later effect is reflected in lower observed runoff and high subsurface flow volumes.

When residue series TP and TSP loads are normalized for manure application rate (Figure 3.52) the higher rates result in lower unit losses. These observations confirm Phase I findings for manure applied to a bare soil.

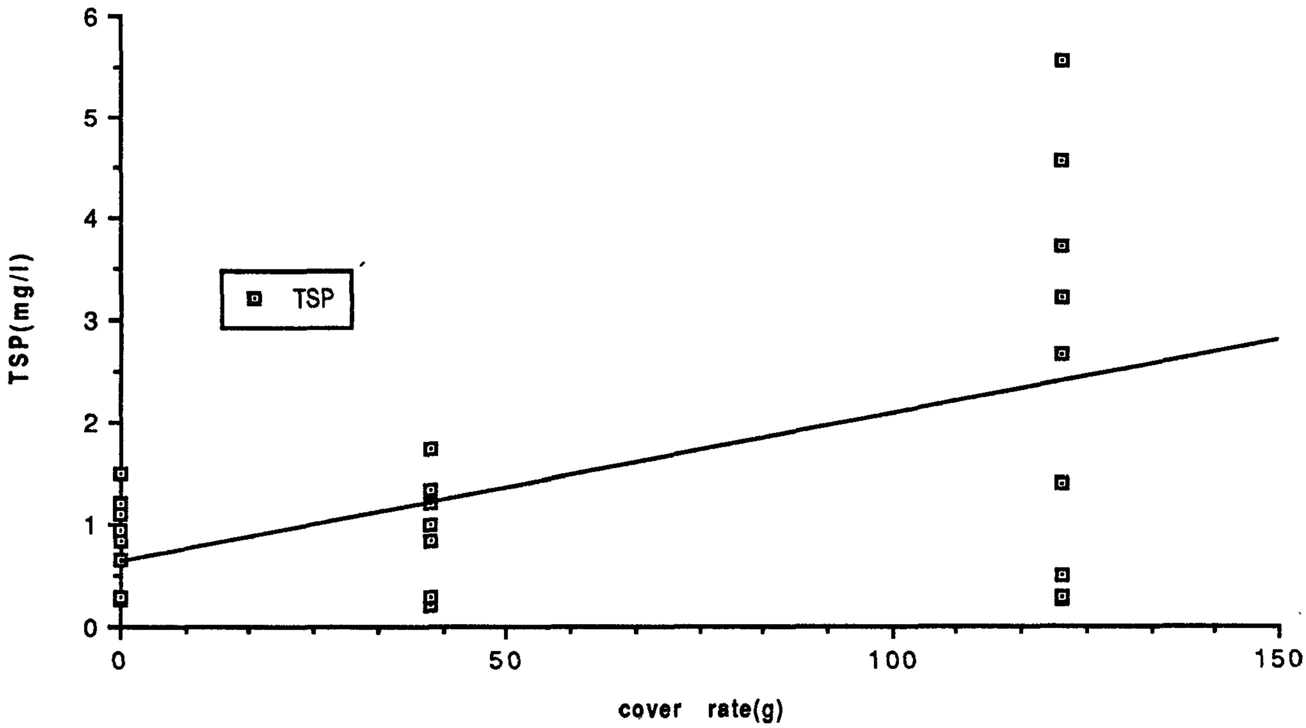

Figure 3.49
TSP(mg/l) vs. Residue Cover

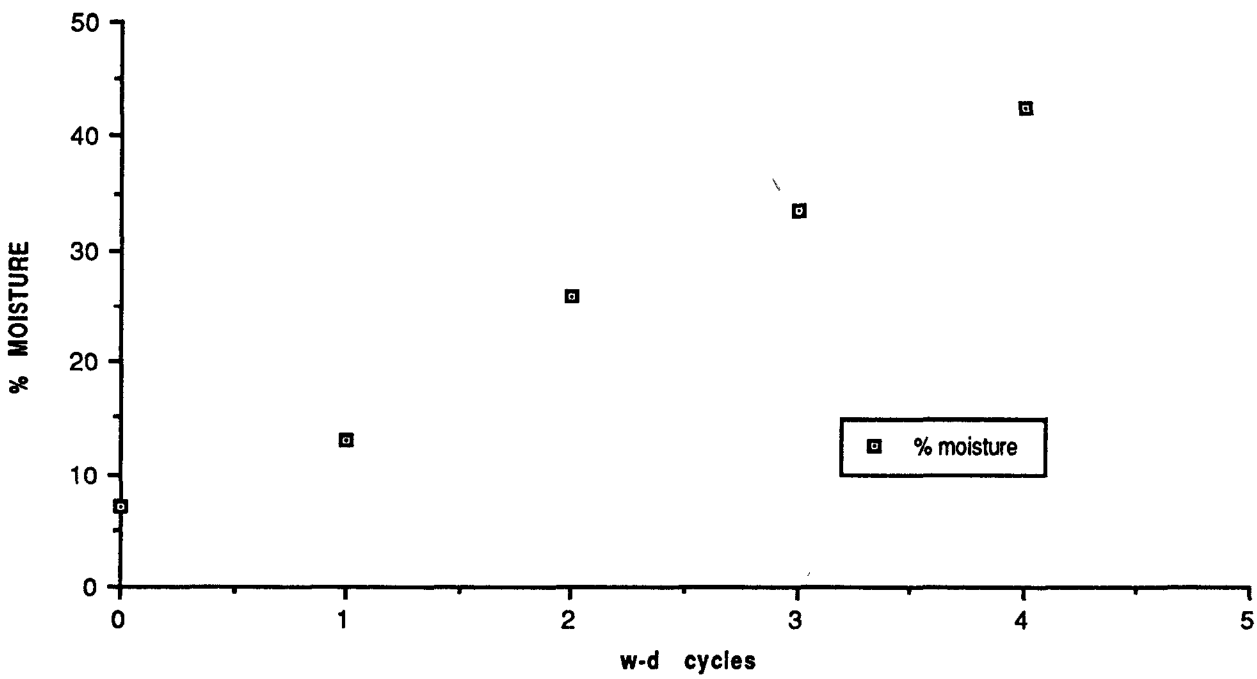

Figure 3.50
Mean Moisture Retention for Wet-Dry Cycles

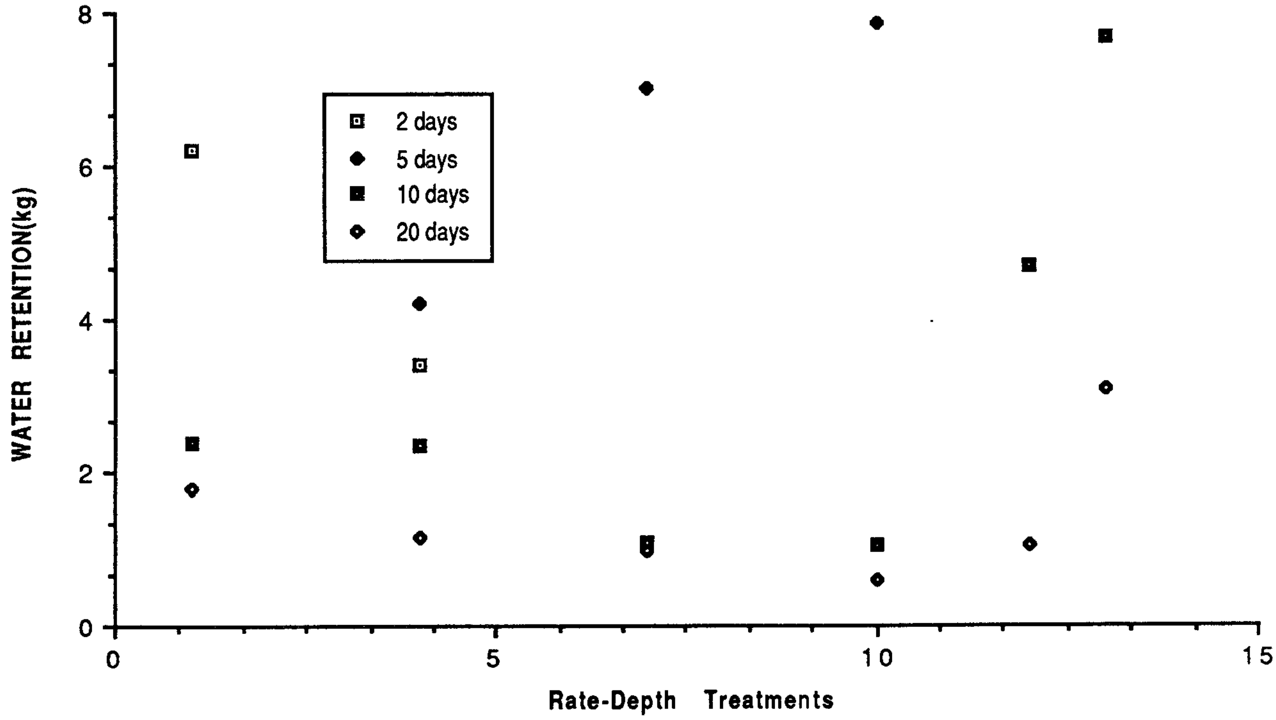

Figure 3.51
Water Retention, series, LBD

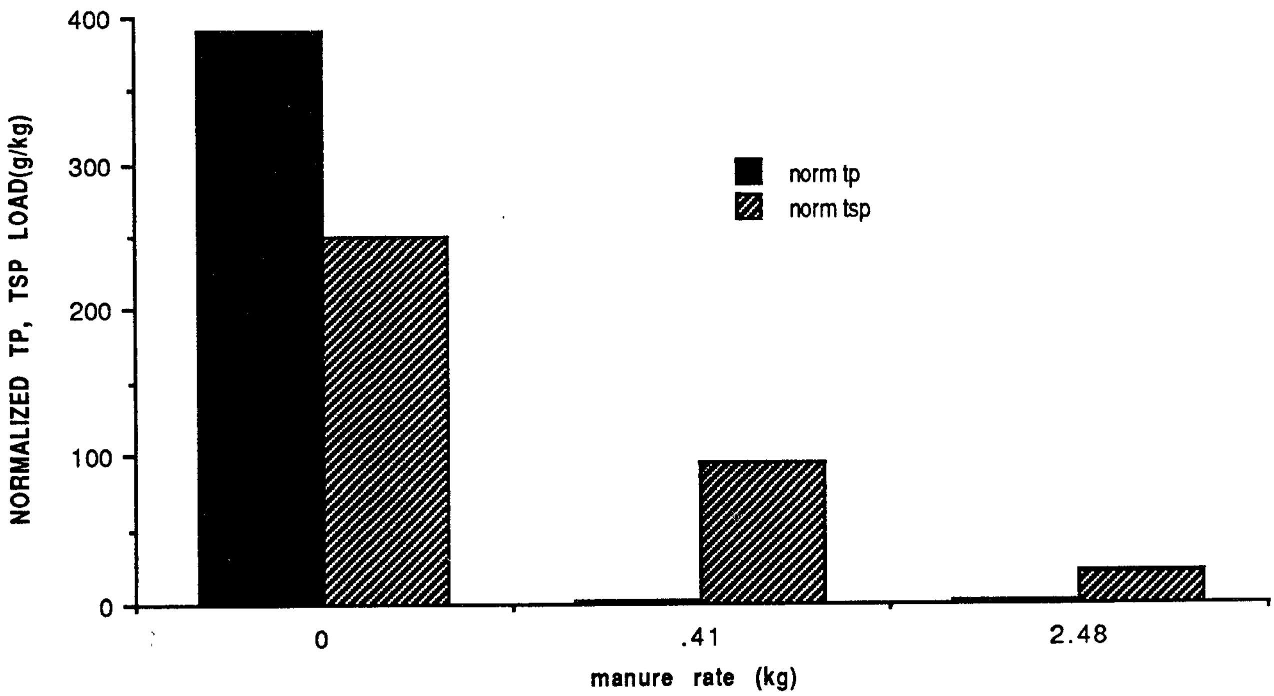

Figure 3.52
Normalized TP, TSP Loads, residue series

SUMMER FARM RUNS

Although in the short-term (two to six months) specific field operations and conditions were known, the history of any field (particularly with respect to manure application rates) was unknown. Therefore a high degree of interaction between residue, application rate, soil type, and crop will buffer and obscure trends observed in more controlled experiments (series LG1-LG4, FB1-FB3, LB1-LB6, LBR1-LBR6). This is particularly evident when all data are pooled to observe TP, TSP concentration and loading for different manure application rates (Figure 3.53). Perhaps the only clear trend is indicated by the increased TSP load where manure applications have occurred. The general lack of cause-effect relationships can be related to three primary factors:

- where manure applications have occurred in previous years the rate of application has varied greatly
- the quantity and quality of residue associated with surface manure application vary greatly
- in performing field evaluations, relatively large differences in data are possible due to spatial variability

The mechanism by which manure treated soils infiltrate water and initiate runoff can be observed in Figure 3.54. Although time to ponding increased with application rate the total time to initiate runoff from simulated precipitation did not indicate a consistent trend. Again, the three factors listed above would typically cause a cumulative convergence of observations despite short-term treatments.

Simulated precipitation from farm series runs indicated lower normalized TP, TSP loads for higher application rates (Figure 3.55). Although the normalized loads for 99 and 67 mt/ha were similar, both TP and TSP losses per kg manure applied were less than the low rate (33 mt/ha) loads.

Growing season differences in runoff volumes and TP, TSP concentration (Figures 3.56 and 3.57) resulted in higher loads for no-till and chisel systems compared with conventional moldboard plowing. It should be noted that this data was collected approximately 45 days after planting. Other investigators (Mueller, 1979, Romkens, 1973) have shown that advantages of infiltration and nutrient retention of conventional tillage are typically short lived. In addition, the period of critical concern to this study is spring runoff when the reverse order of loading parameters is possible.

When all data is pooled and loads are calculated by crop (Figures 3.58 and 3.59) corn losses are significantly higher than alfalfa. It should be pointed out that all simulated precipitation runs were made shortly after the first cutting of alfalfa which resulted in an appreciable area of exposed soil.

Differences in concentration between soil types (Figure 3.60) indicate that the sand and clay soils have a relatively shallow zone of interaction resulting in a significantly reduced TSP concentration.

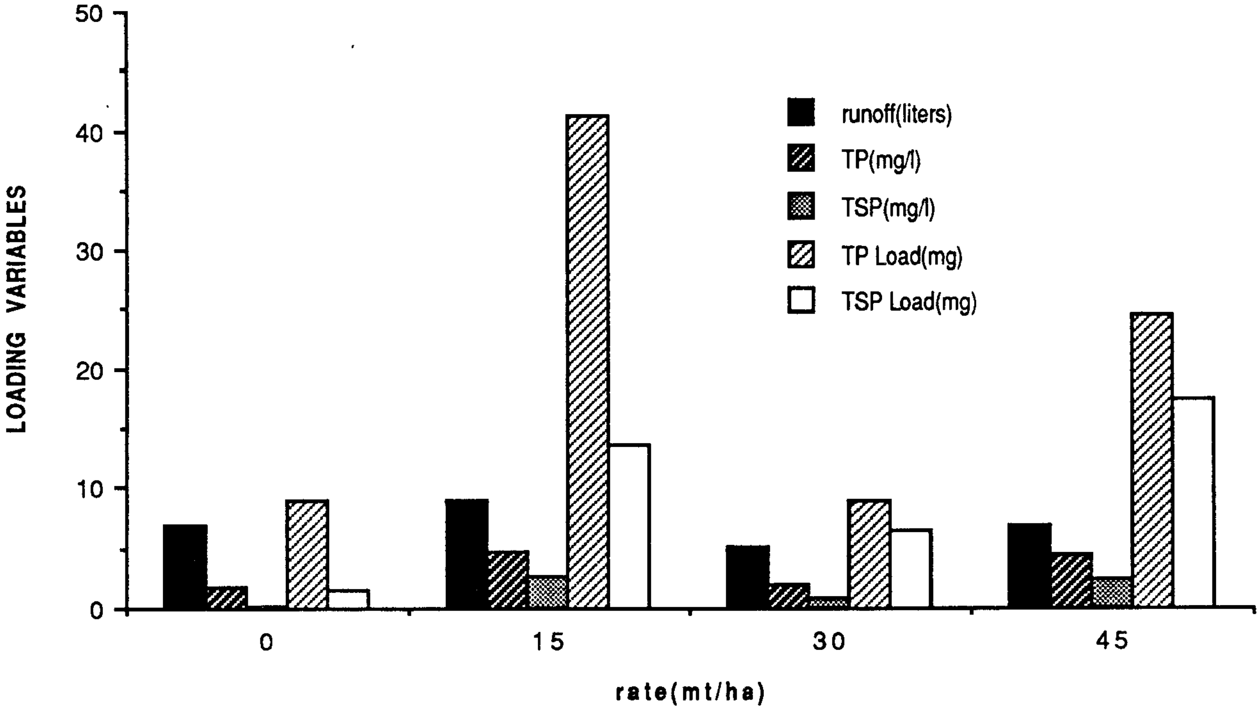

Figure 3.53
Loading Parameters, farm series

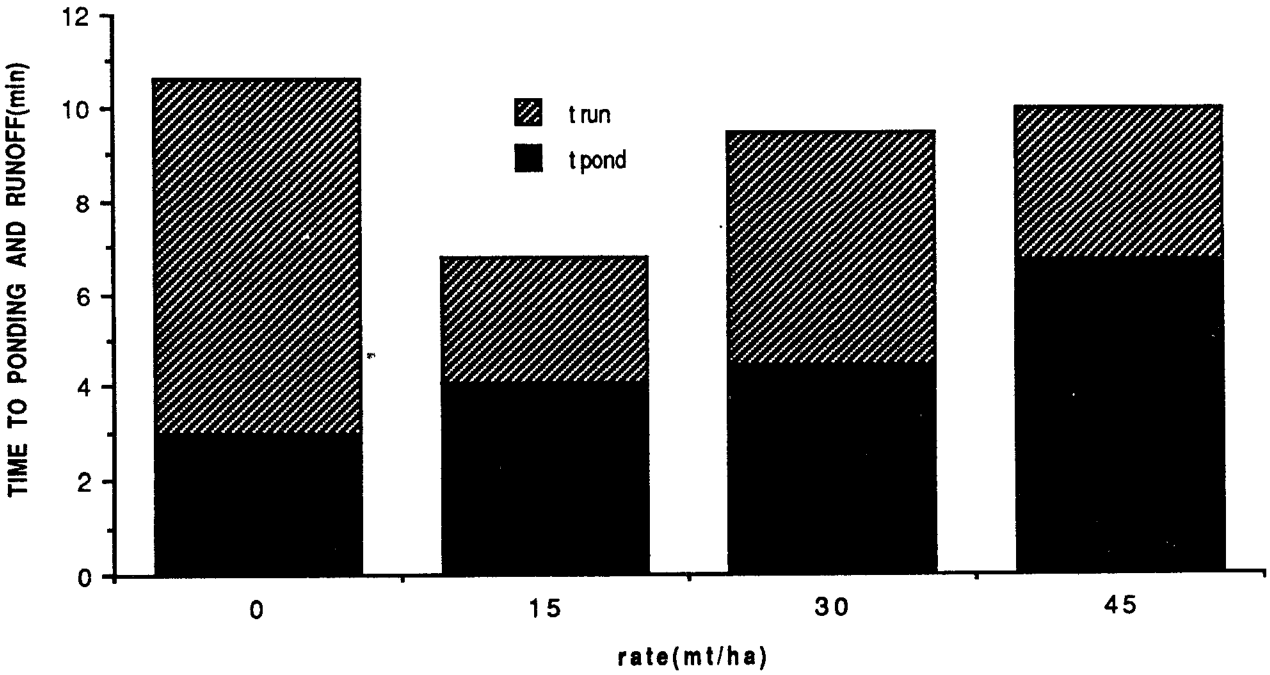

Figure 3.54
PIR, farm series

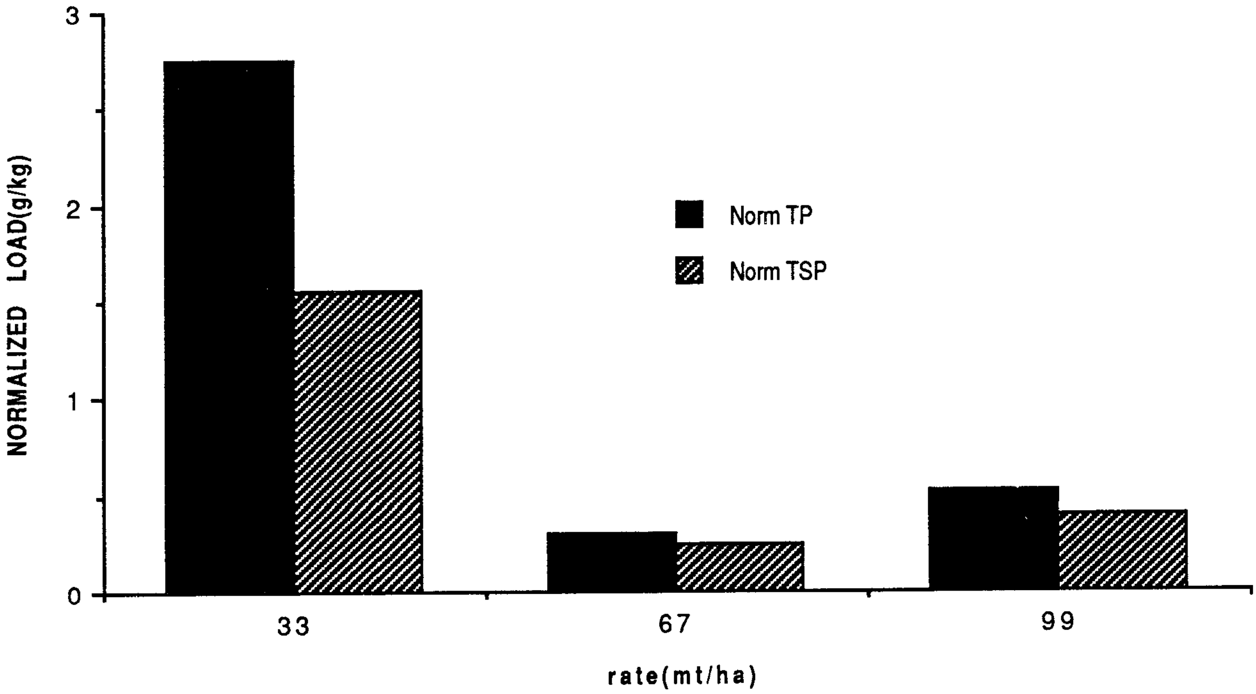

Figure 3.55
Normalized TP, TSP, farm series

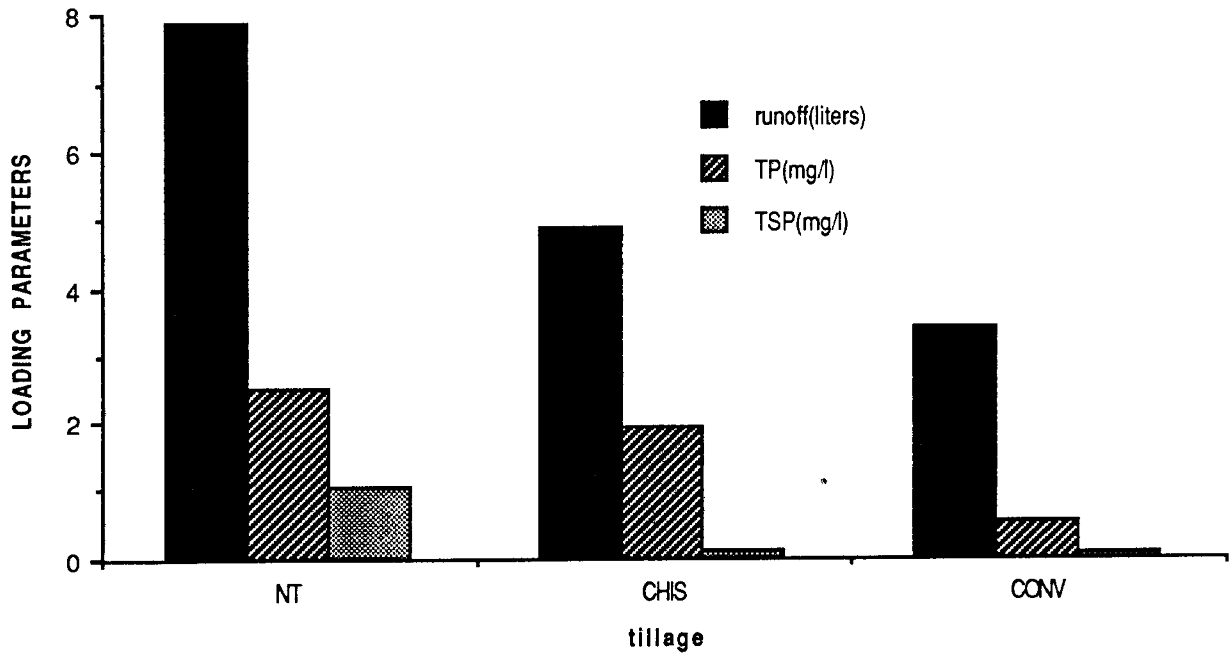

Figure 3.56
Loading Parameters vs. Tillage

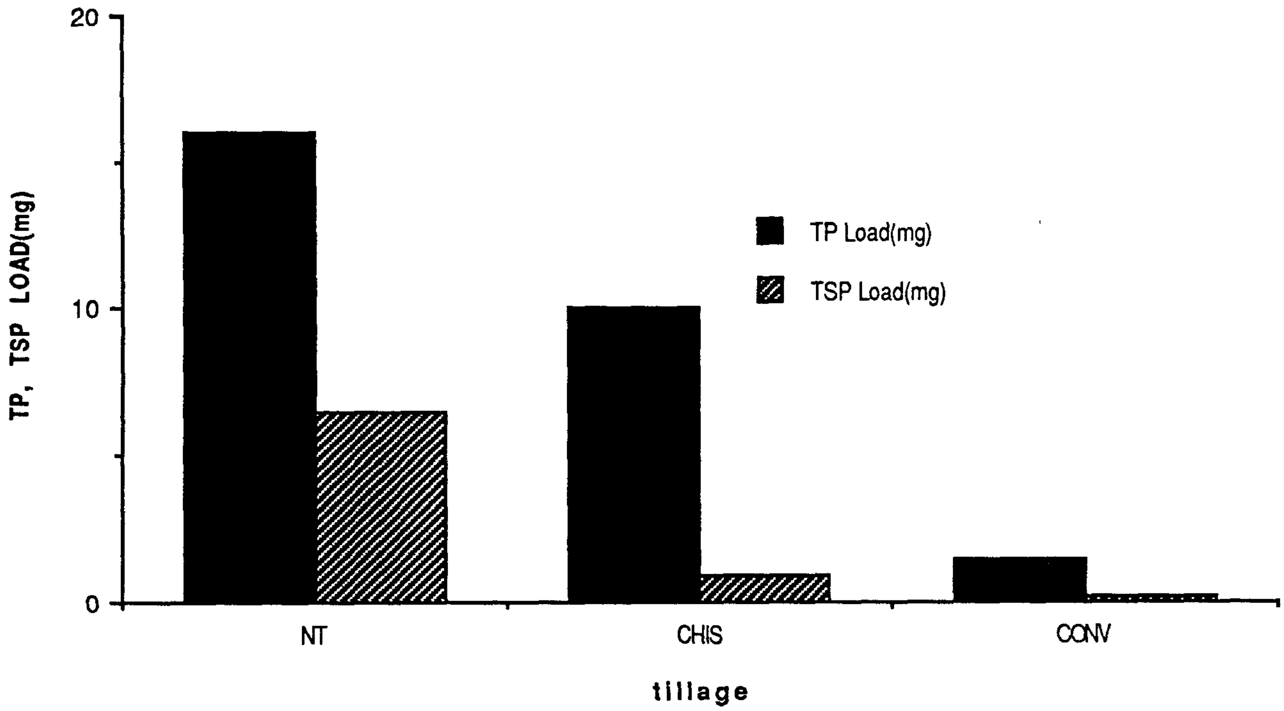

Figure 3.57
TP, TSP Load vs. Tillage

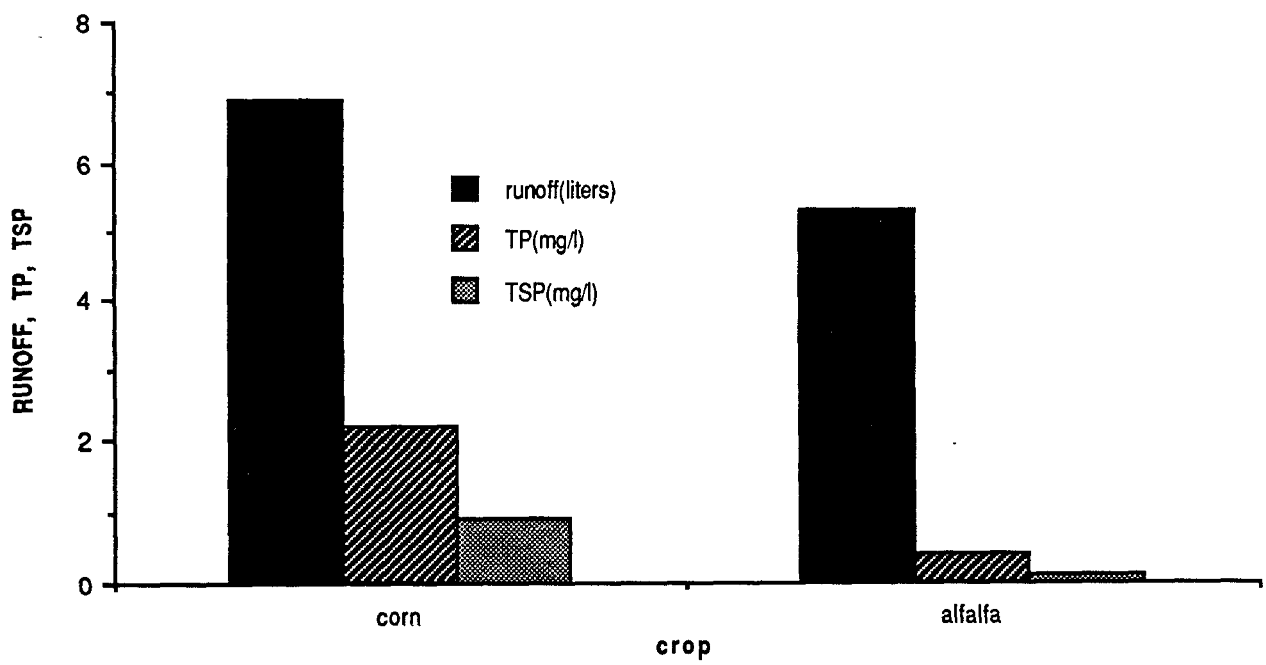

Figure 3.58
Loading Parameters vs. Crop

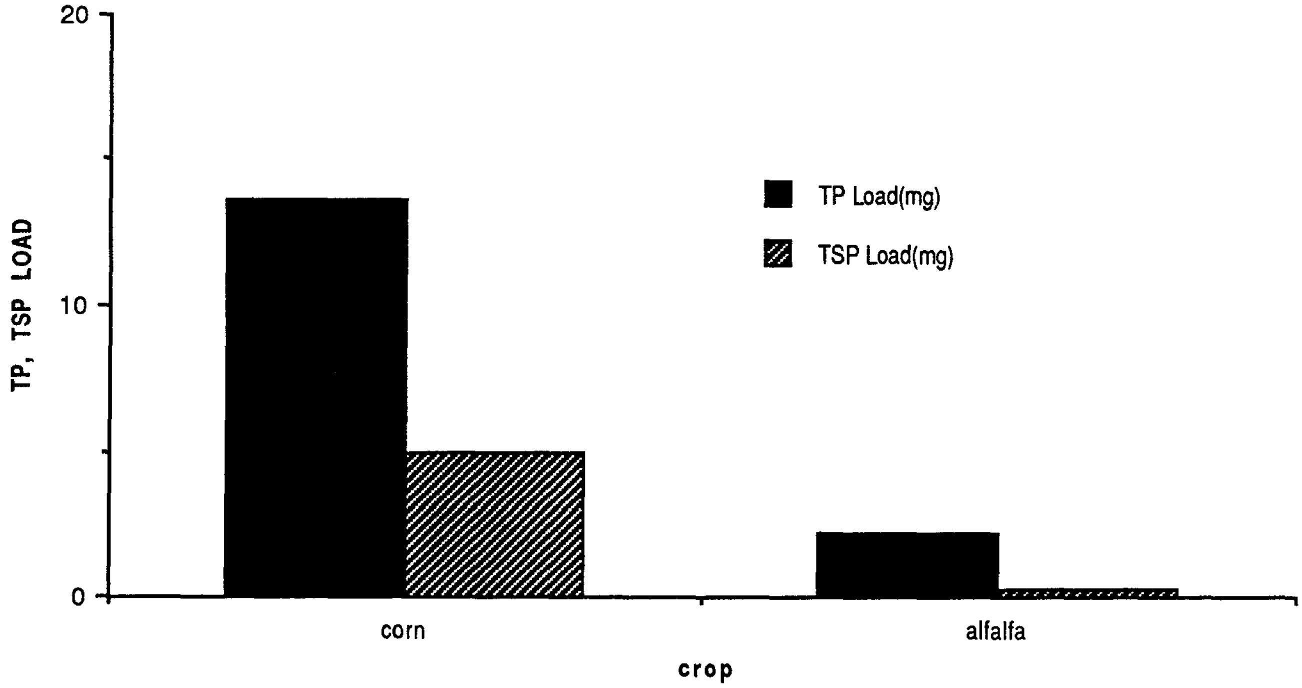

Figure 3.59
TP, TSP Load vs. Crop

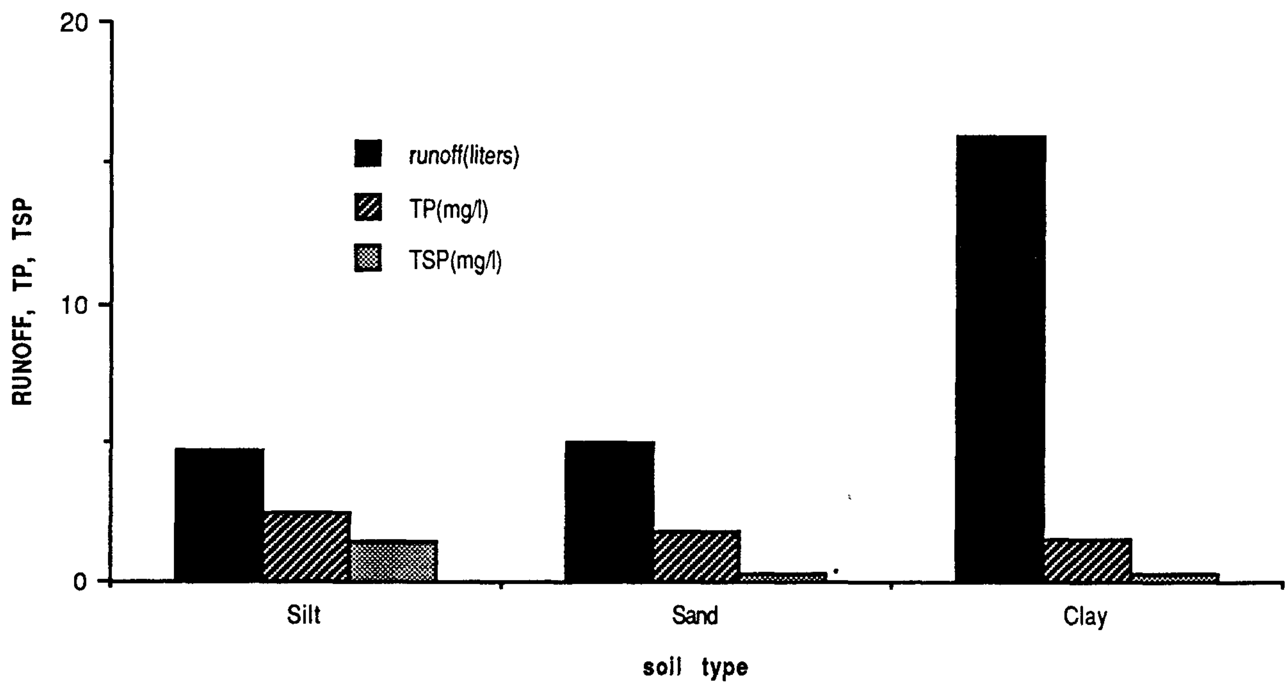

Figure 3.60
Loading Parameters vs. Soil Type

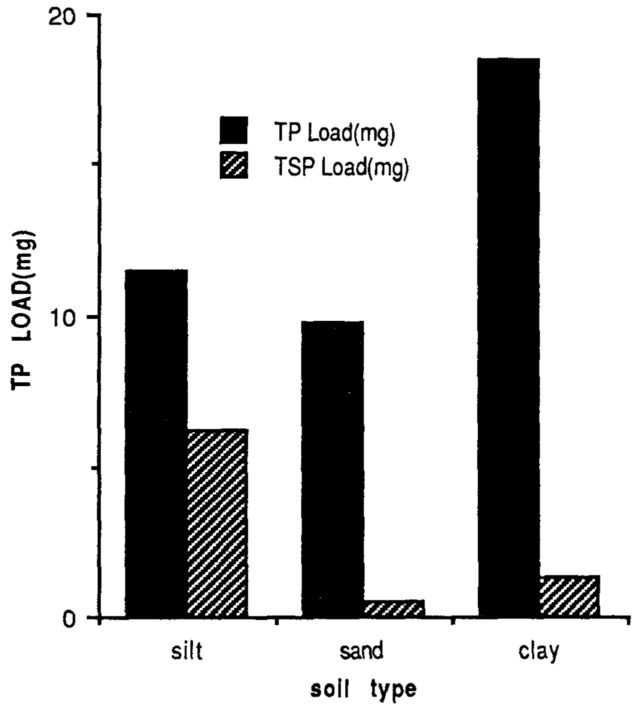

Figure 3.61
TP, TSP Load vs. Soil Type

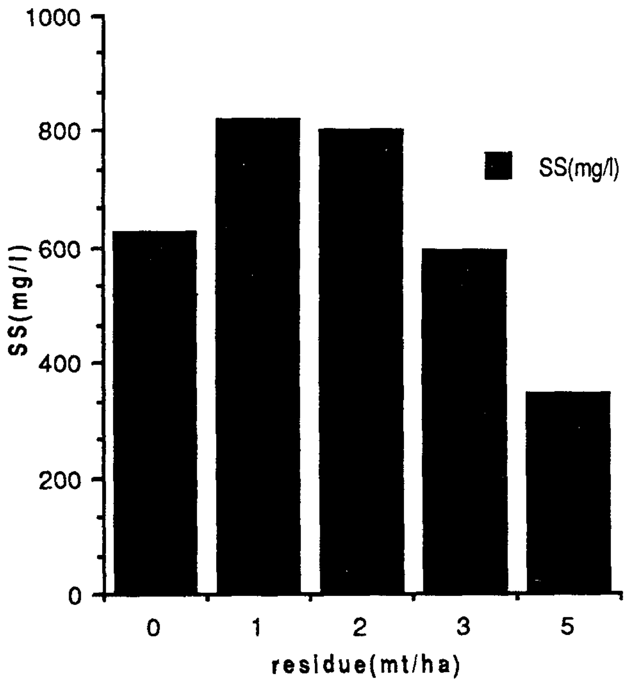

Figure 3.62
Suspended Solids vs. Residue Level

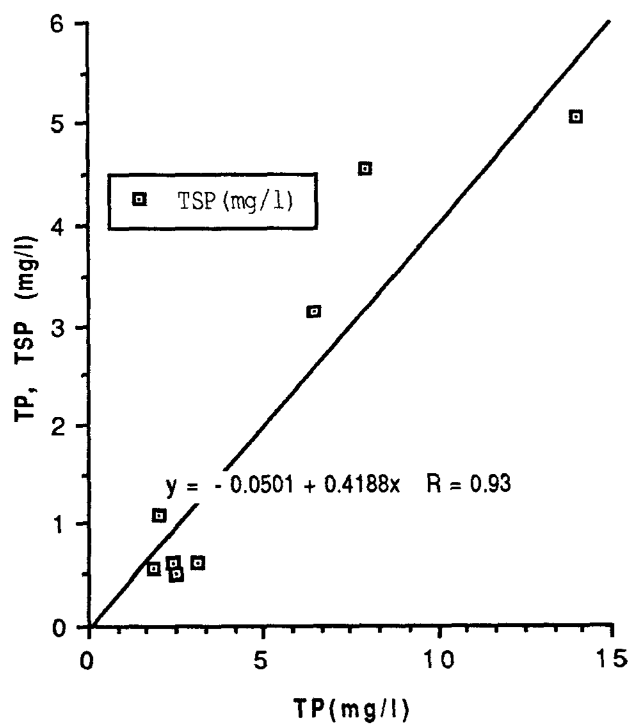

Figure 3.63
TP vs. TSP Concentration, farm series

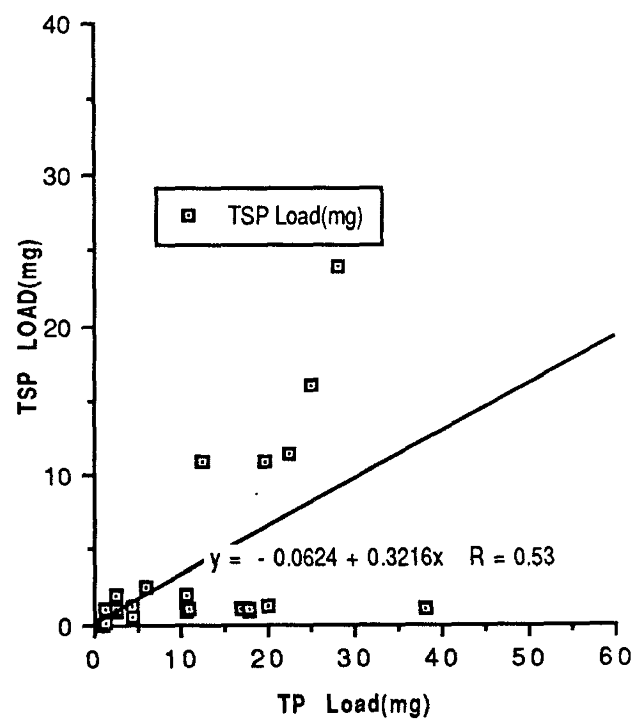

Figure 3.64
TP Load vs. TSP Load, farm series

Figure 3.61 indicates the variation in the hydrologic response of the different soil types. Despite a relatively low concentration of TP in runoff, the total mass TP load is greatest for the clay loam soil.

The residue rate directly influenced suspended solids (SS) concentration (Figure 3.62). However, the quality and coverage of residue indicated that relatively low cover rates (1-3 Mt/ha) resulted in SS concentrations similar to the untreated case. The reasons for these observations likely involve an interaction of the following factors:

- Most of the soils in this study have received long-term treatments of manure. Even where there is no residue cover, soil aggregation and surface infiltration improvements from previous manure applications may decrease suspended solids in runoff.
- The presence of bedding and undigested fiber in certain manures will have a positive effect on suspended solids concentration utilizing the same mechanisms as surface residues.

As indicated in Phase I studies, the correlation between TP and TSP concentration and load on manure treated soils is relatively high. This trend (Figures 3.63 and 3.64) was verified for growing season samples collected on the Wayne and Oswego County farms.

SURFACE CONDITIONS AND THEIR EFFECT ON TP, TSP LOADING

Drying Mechanisms

Sobel (1971) describes three basic mechanisms (mechanical, absorption, and thermal) for moisture removal from manure. These processes all can be accomplished as intensive treatment measures. The two mechanisms which naturally occur in manure disposal systems which can be modified to achieve reduced TP, TSP loading are absorption and drying.

As indicated in Figure 3.65, the moisture absorbing capacity of common bedding materials can be quite high. The use of bedding particularly during periods of high delivery is one practical TP, TSP control measure.

Short-term drying of manure (Figure 3.66) emphasizes the importance of wind effects and thickness of the manure pack. Although the deeper pack (Figure 3.67) indicates an appreciably longer drying time requirement, initial drying rates are high with moisture content dropping to 50% in about three days. The shrinking which would occur in this case would cause appreciable increases in infiltration as demonstrated in all LBD series runs.

Series LBD

An indirect method of observing changes in moisture characteristics of manure treated soils is to note changes in moisture content with wetting and drying cycles. As indicated in Figure 3.68 a pattern appears which indicates a decrease in moisture content associated with the initial drying of the surface applied manure. Once this cycle has occurred manure amendments cause increased absorbance and higher moisture content as expected. As the manure soil mixture undergoes wetting and drying cycles the precipitation to initiate runoff tends to increase as indicated in Figure 3.69.

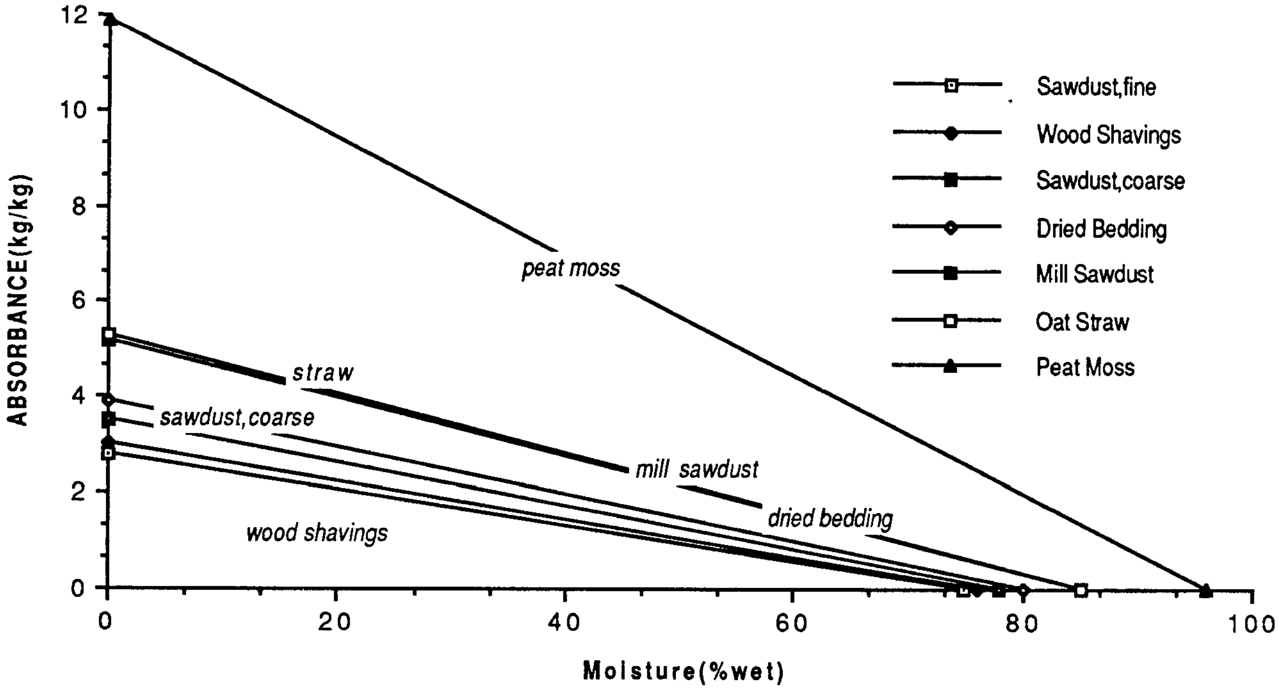

Figure 3.65
Moisture Absorbing Capacities of Bedding Materials (after Sobel,1973)

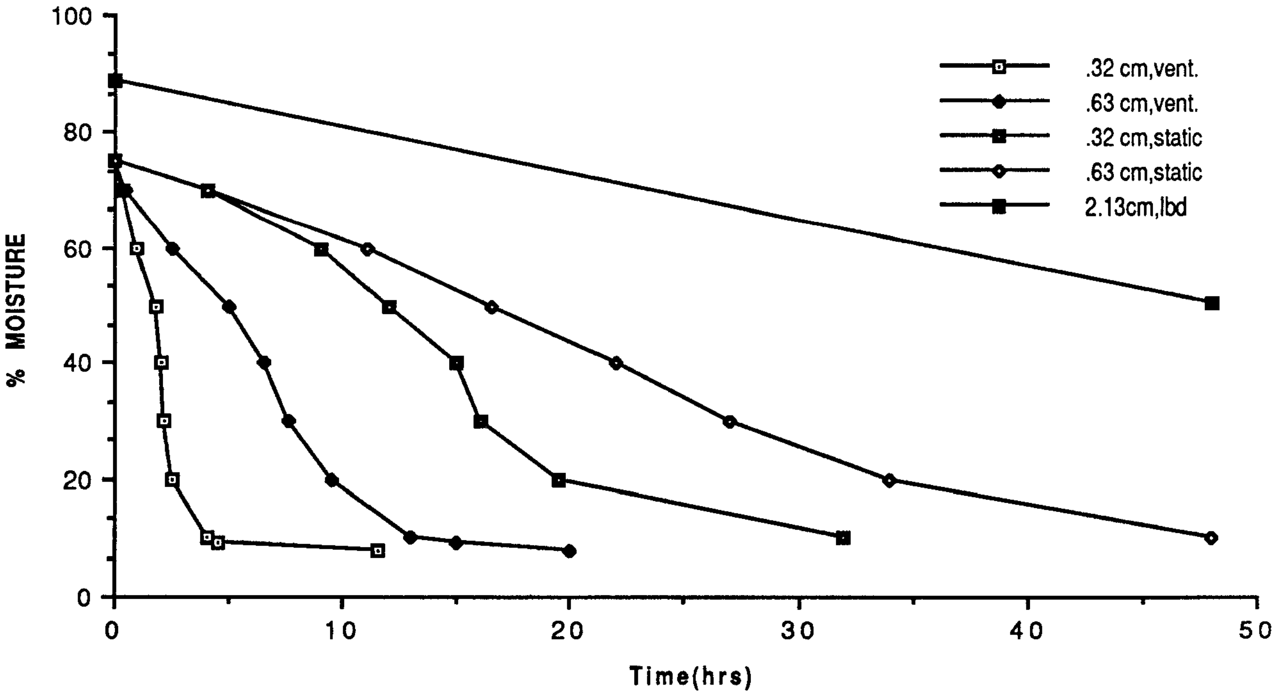

Figure 3.66
Manure Drying Curves, 50 hrs.

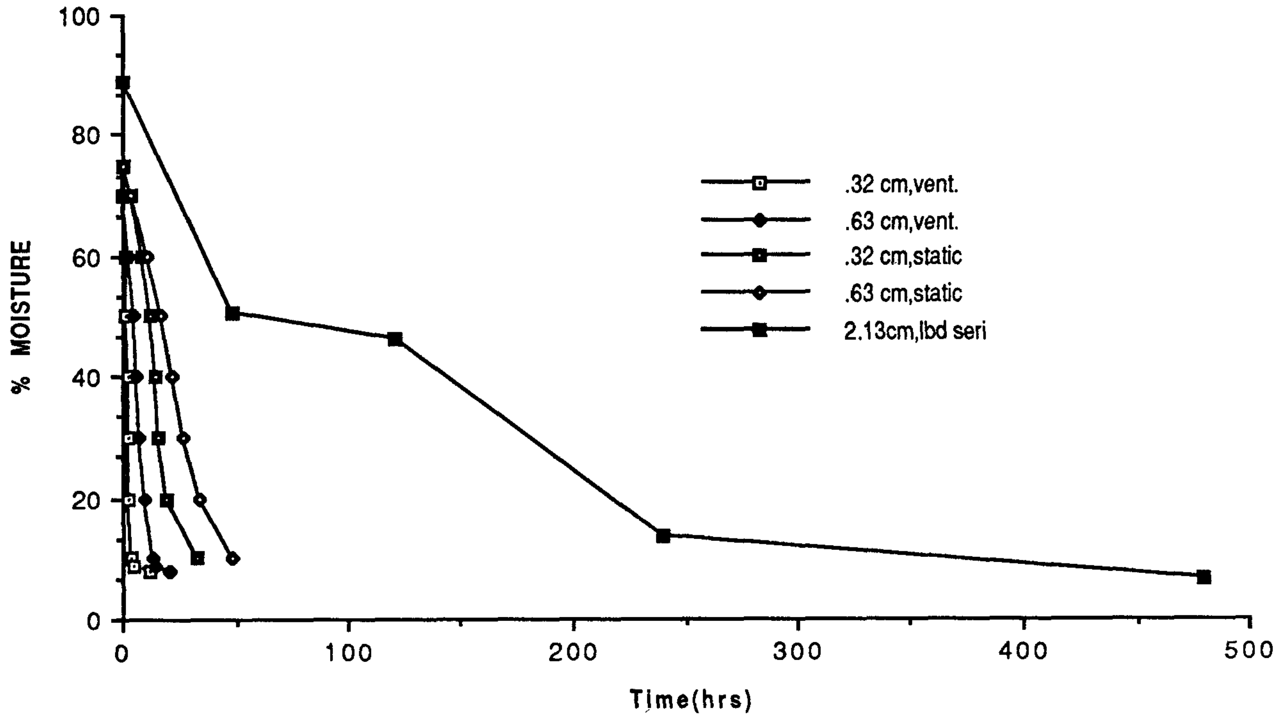

Figure 3.67
Manure Drying Curves

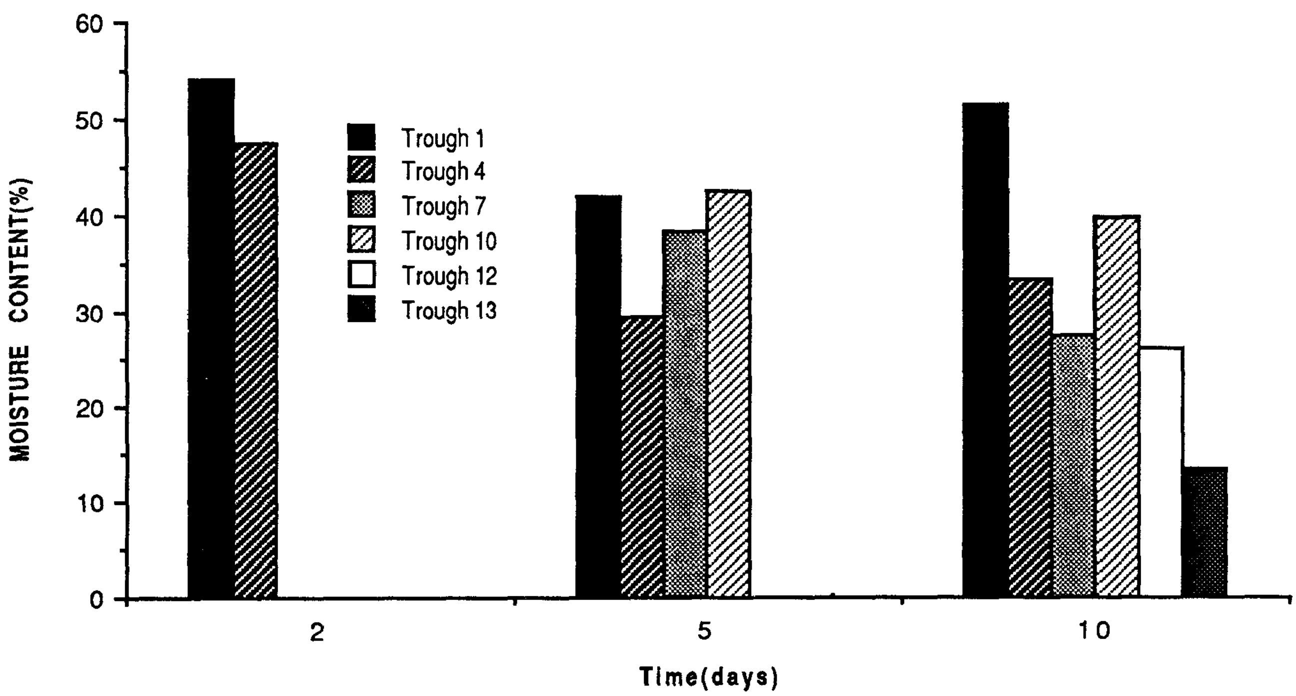

Figure 3.68
Trough Moisture Content(%)

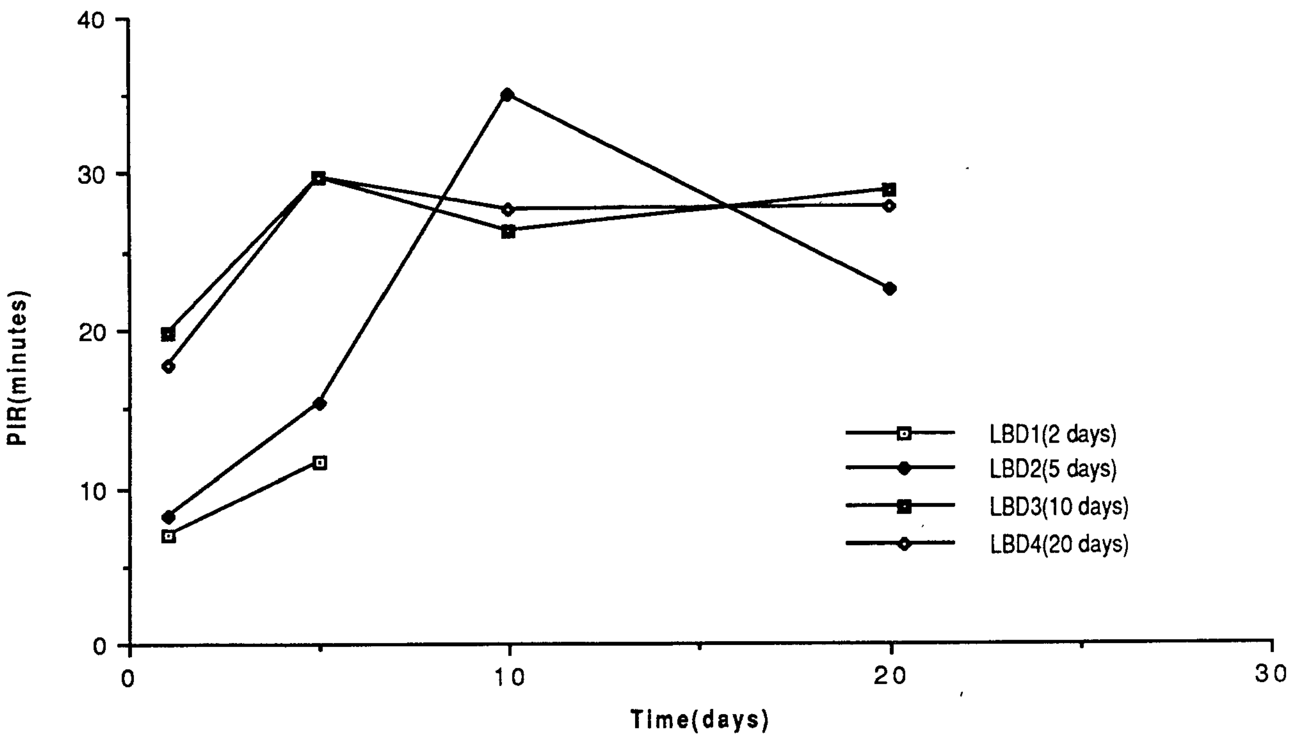

Figure 3.69
PIR, Series LBD

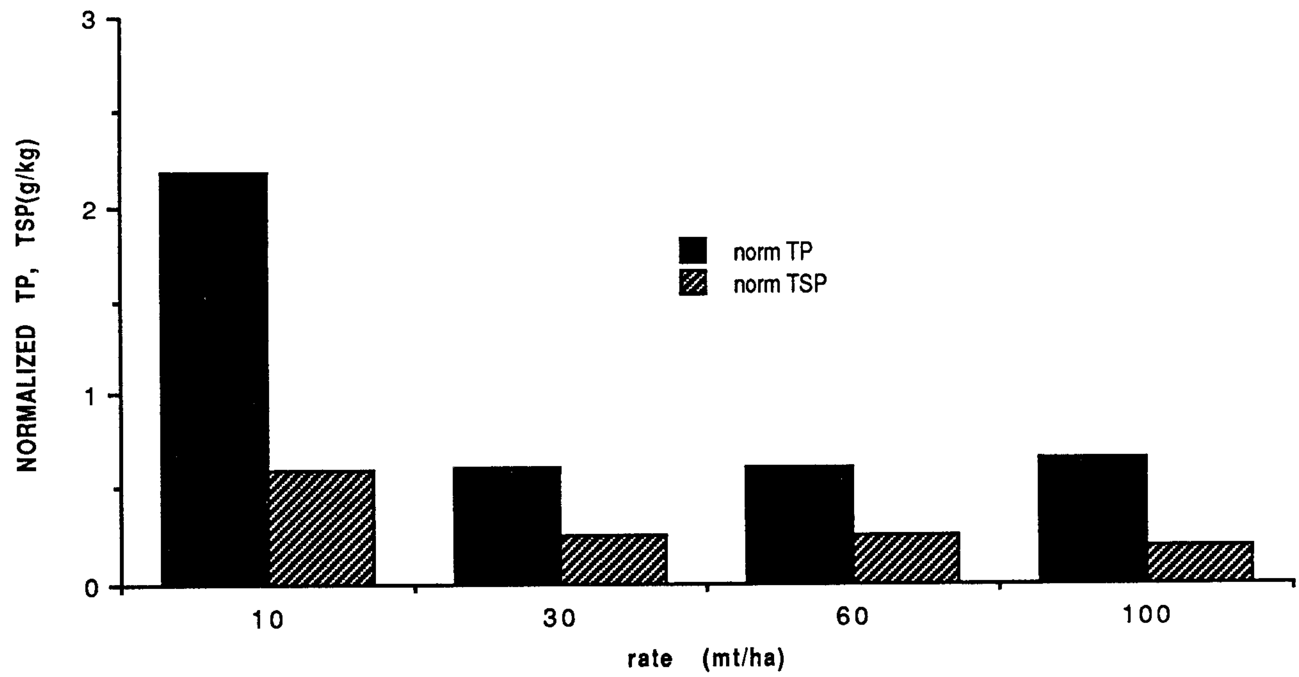

Figure 3.70
Normalized Load, by rate, farm series

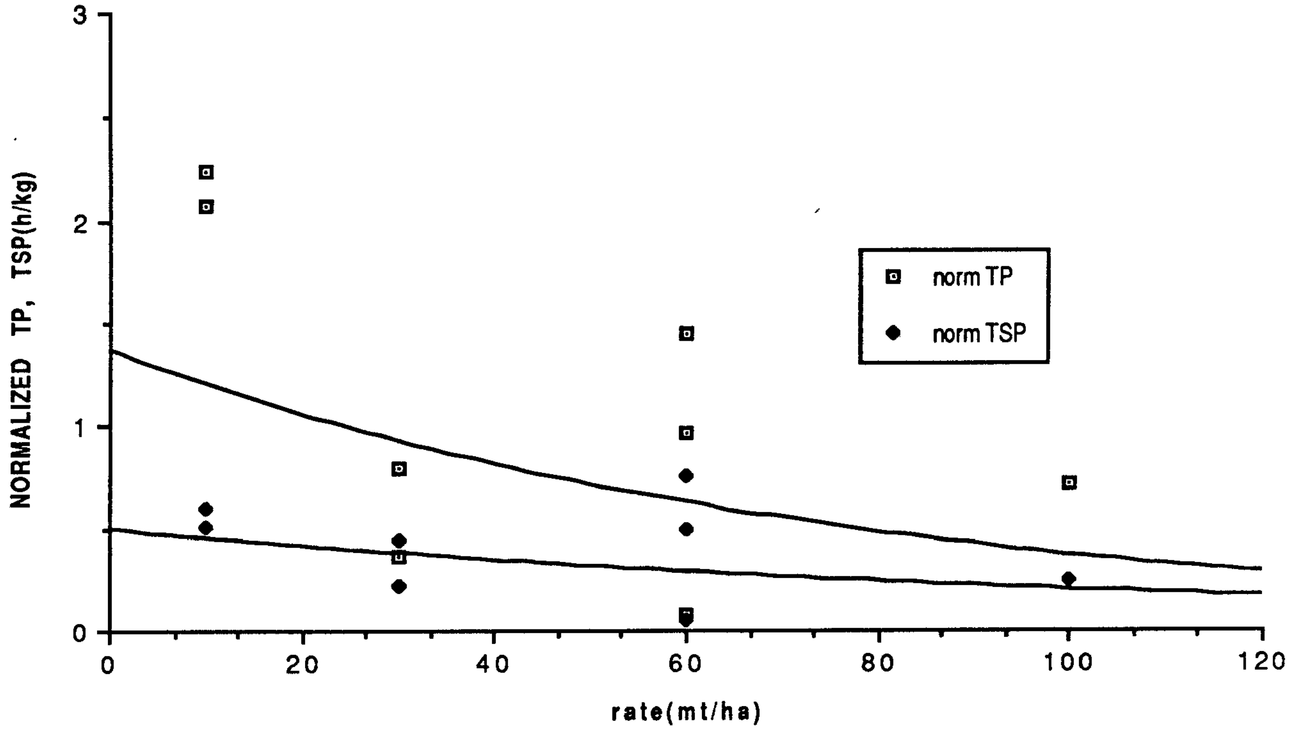

Figure 3.71
Normalized Load, farm series

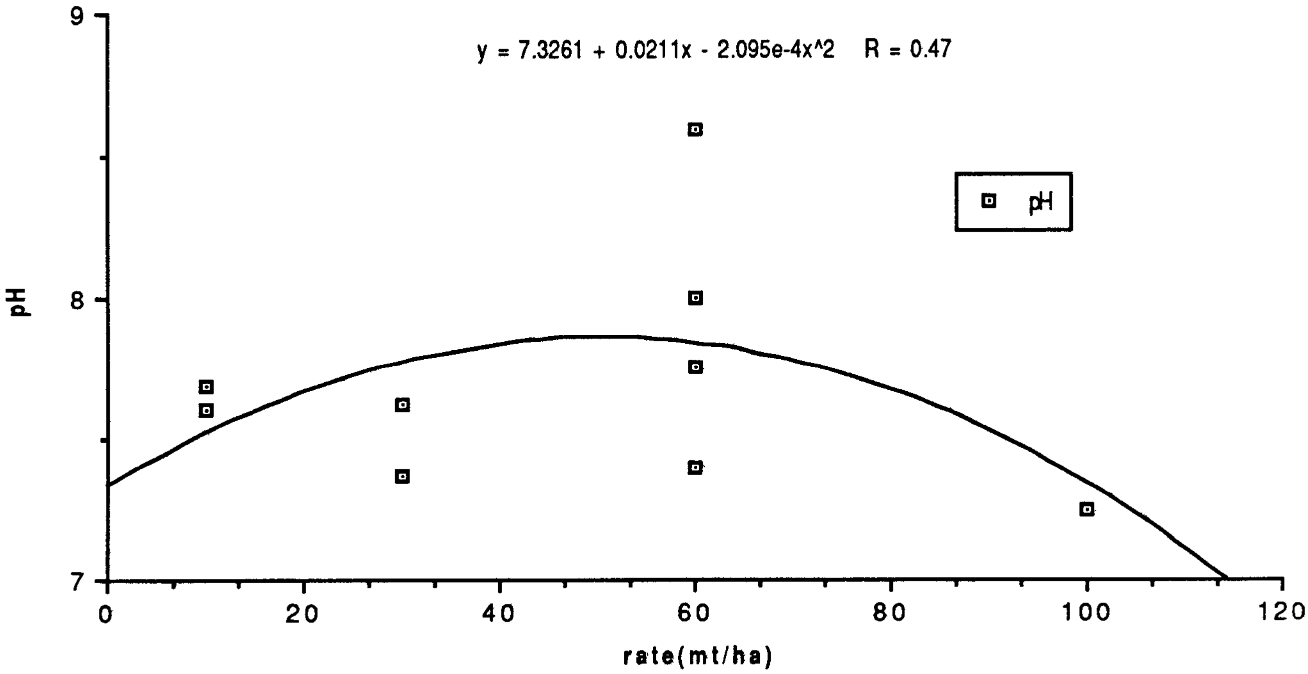

Figure 3.72
pH vs. Rate

Farm Series

When manure was applied at rates of 10-100 Mt/ha both normalized TP and TSP load decreased with increasing application rate (Figure 3.70). Although the TP normalized load indicated relatively constant values above 30 Mt/ha, TSP load indicated decreasing normalized loads after four drying days. This downward trend, although subtle, is indicated in Figure 3.71 for all pooled data.

The effect of pH on TSP concentration and load showed a high correlation in all series runs. This effect was also observed for farm series runs (TX1-TX20, AX1-AX28). In addition there appeared a maximum pH effect on surface applied plots (Figure 3.72) of approximately 7.8 at an application rate of 50 mt/ha. Decreases in pH were observed for rates less than and greater than 50 mt/ha.

The loading of TP and TSP associated with surface applications of manure for farm series runs (four drying days) indicate increased loading (Figure 3.73) with application rate for both TP and TSP. However, runoff volume decreased with increasing rate. Although the correlation coefficient indicates a weak relationship, this downward trend confirms earlier laboratory and field observations. The quantity of precipitation to initiate runoff (PIR) were not consistent (Figure 3.74) and probably reflected differences in manure characteristics and soil types between farms.

The relatively high fraction of TSP to TP load was observed in all manure treated soils in the laboratory, field and farm runs. In particular, surface applied treatments for farm runs supports this observation (Figures 3.75 and 3.76) with a high degree of correlation between TP and TSP concentration. Linear correlations between TP, TSP load and manure application rates (Figure 3.77) did not yield highly significant values. This is likely due, in part, to a high variance in runoff volume and the inherent spatial variability of the farm series runs.

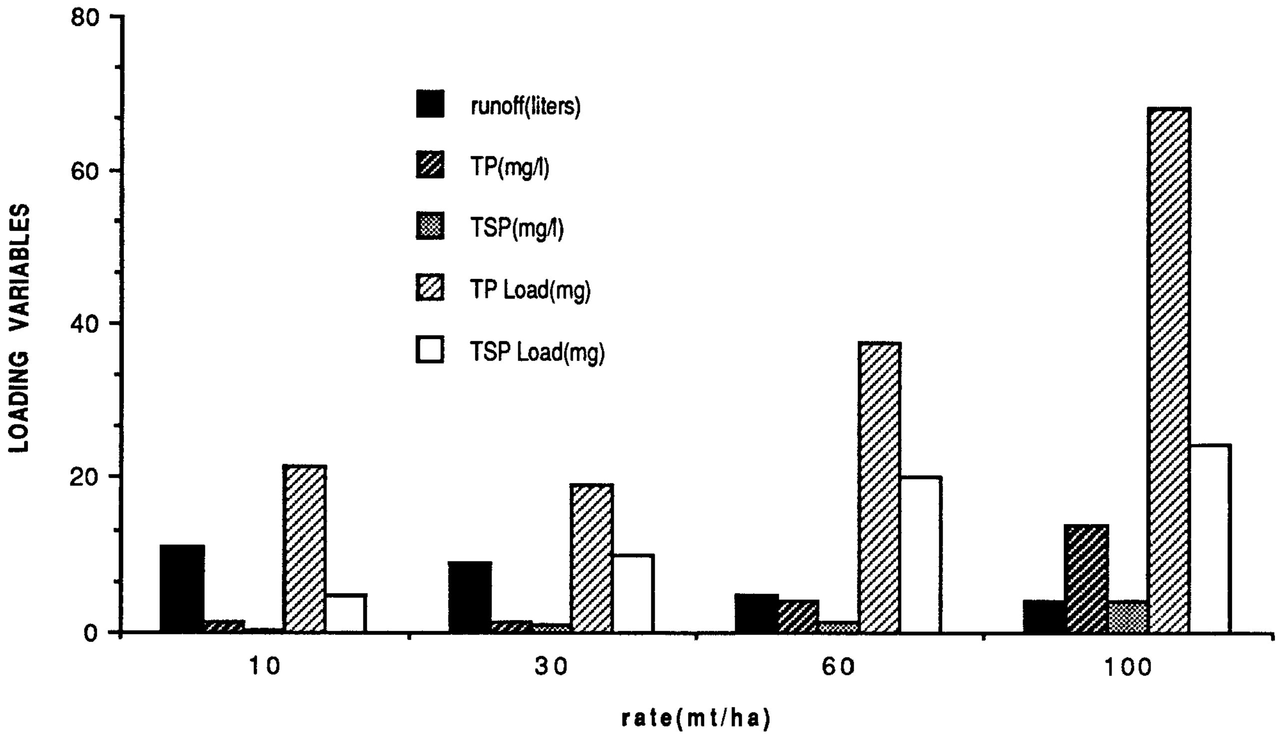

Figure 3.73
Surface Loading, farm series

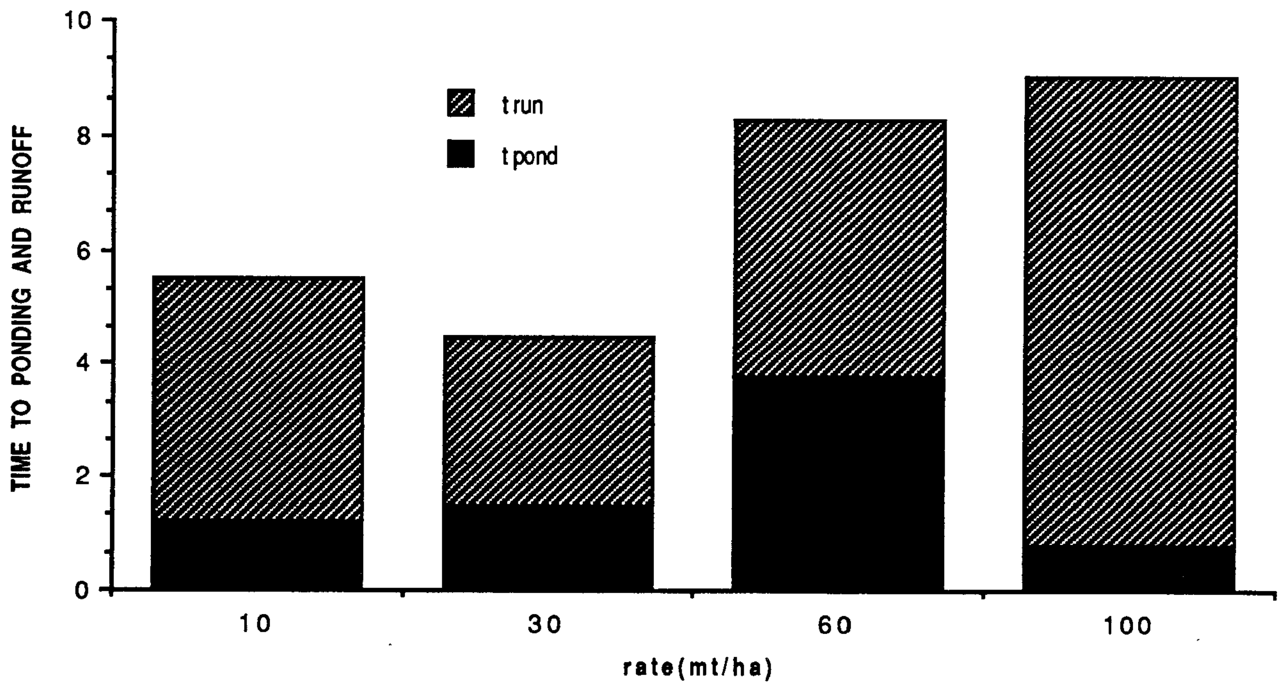

Figure 3.74
PIR, Surface Applications, farm series

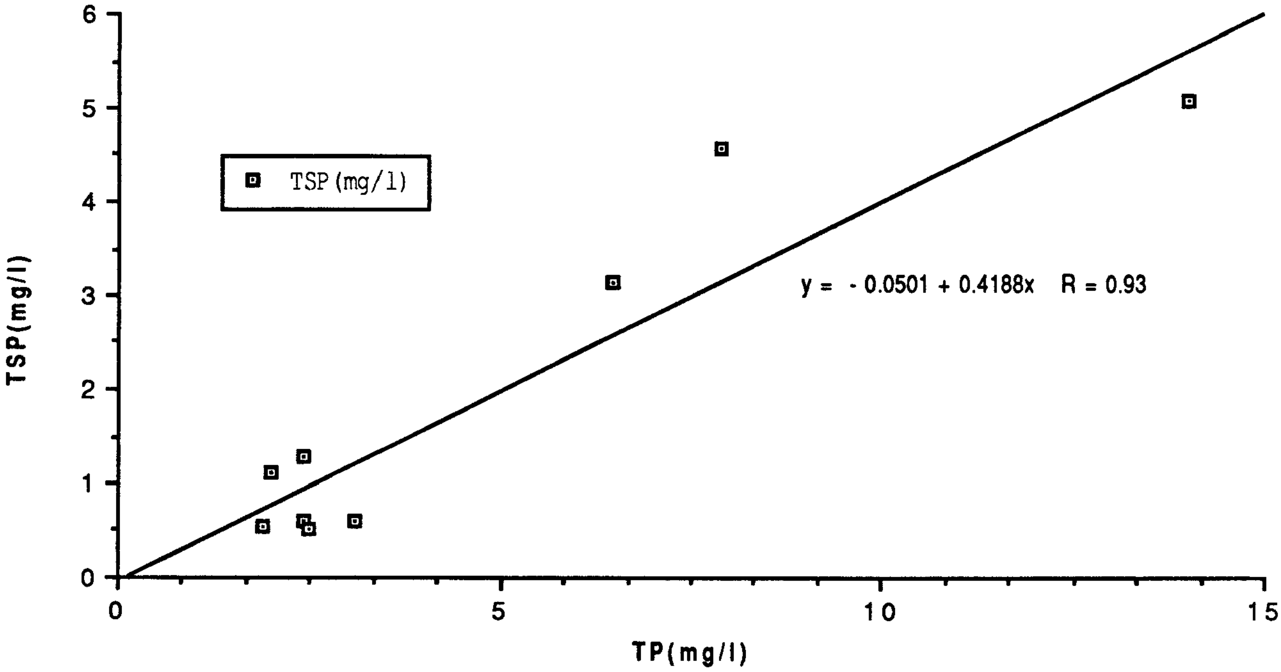

Figure 3.75
TP vs. TSP Concentration, farm series

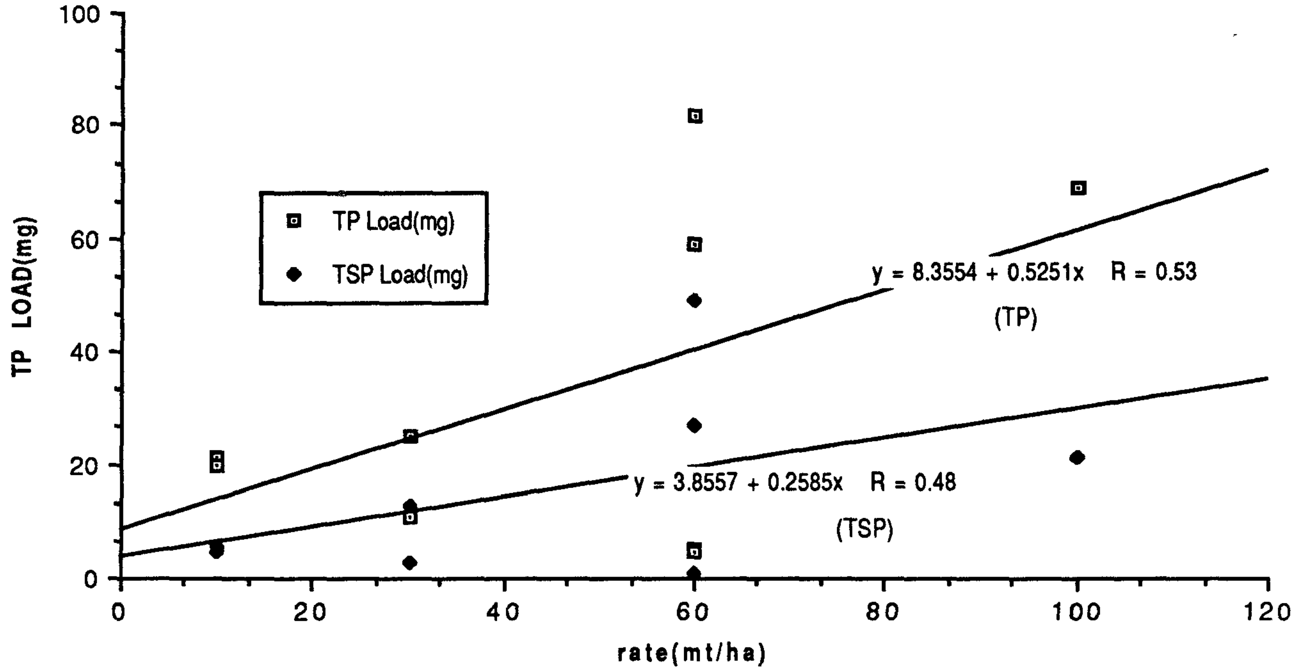

Figure 3.76
TP, TSP Loading vs. Rate, farm series

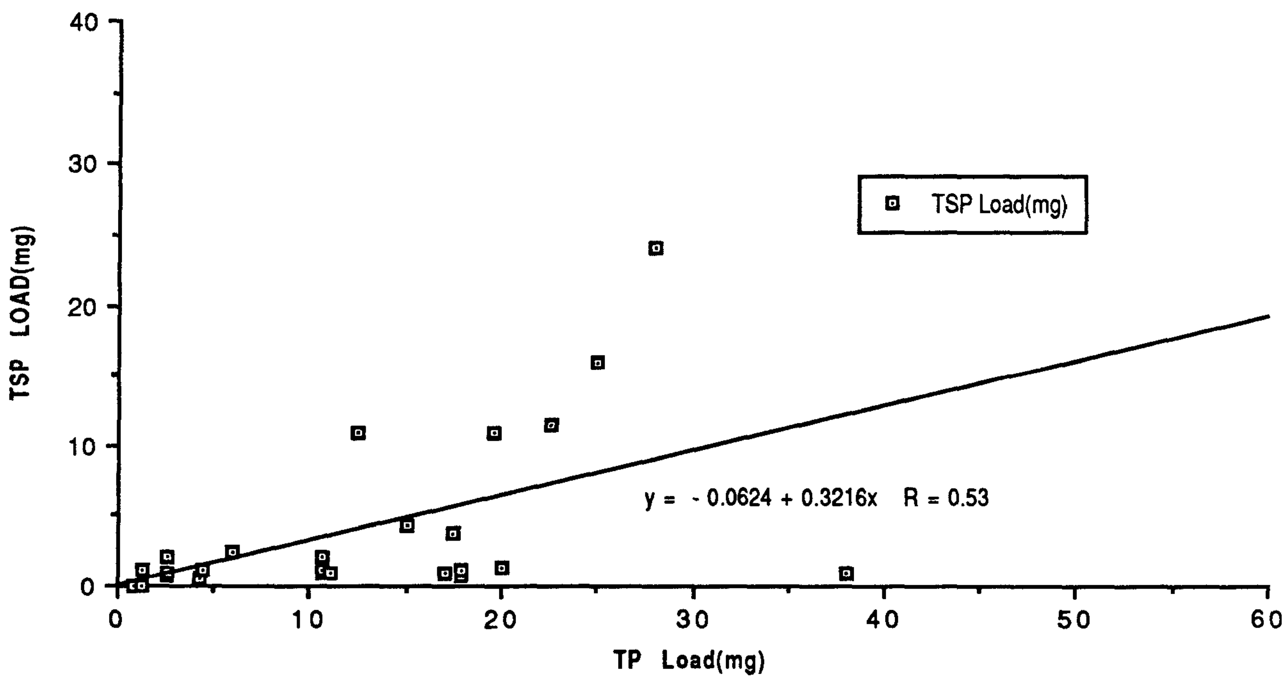

Figure 3.77
TP Load vs. TSP Load, farm series

SECTION IV
DISCUSSION

Application Rate Effects

Surface flow volume was not significantly related to changes in application rate for individual series runs. However, when all series data are analyzed on a unit area basis, trends can be identified which may help in explaining some of the physical differences between the short-term and long-term effects of manure applications on phosphorus losses. Figure 4.1 indicates that the volumes of surface runoff associated with high application rates are larger than those reflecting the low rates when precipitation follows 0-10 days after application for the pooled series data. When the soil manure pack is allowed to dry, surface runoff volumes associated with the high rate are less than those for the low rate when precipitation occurs at 25-300 days after application (Figure 4.1). The drying effect can be related to the interactions of several factors influencing the condition of the soil surface. These factors are discussed later in this section.

When precipitation occurs within two days of manure application, TP and TSP concentration in surface runoff from manured plots are significantly higher than control levels for the pooled data (Figures 4.2 and 4.3). Typically, the TP concentration approached 10 mg/L and TSP approached 3.0 mg/L for the first runoff event (t=0) immediately following manure application. After this initial level, subsequent simulated precipitation events (10, 25, 44, 59, 62 and 300 days) indicated greatly reduced concentrations converging toward control levels of 0.5-1.5 mg/L TP and 0.1-0.4 mg/L TSP for all pooled series data.

The net effect of manure application on flow volume and phosphorus concentration is to increase loading of TP and TSP by as much as an order of magnitude above control plots for the first simulated precipitation event following manure application if this event occurs within two days of application (Figures 4.4 and 4.5). After the first event, load differences tend to be considerably less. Differences between application rates do not indicate consistent trends for the pooled data nor do they exhibit a significant statistical relationship with the variability in TP, TSP loading. Therefore, it would appear that the application of manure will likely result in relatively high loading of TP, TSP for precipitation events immediately following manure application regardless of rate. Losses decrease appreciably with subsequent precipitation events and particularly after a drying of the soil manure pack.

Incorporation Effects

Surface flow volume appeared to be more sensitive to incorporation depth than to application rate (Figure 4.6) particularly for the case of surface applications. Manure incorporation of 3 cm noticeably improved infiltration and reduced runoff in most cases. The effect of a drying period on surface applied manure can be readily observed for runs at 25 and 44 days. In addition, the results of series LBD1-LBD4 indicate that under favorable drying conditions, a period of two to five days between surface application and the first precipitation event, will result in greatly reduced flow volumes. Generally, after the initial precipitation event, flow volume associated with surface applications varied with respect to other manure incorporation depths according to moisture content. For example, the relatively high value at 54 days (Figure 4.6) is associated with a relatively high moisture content of the soil manure pack.

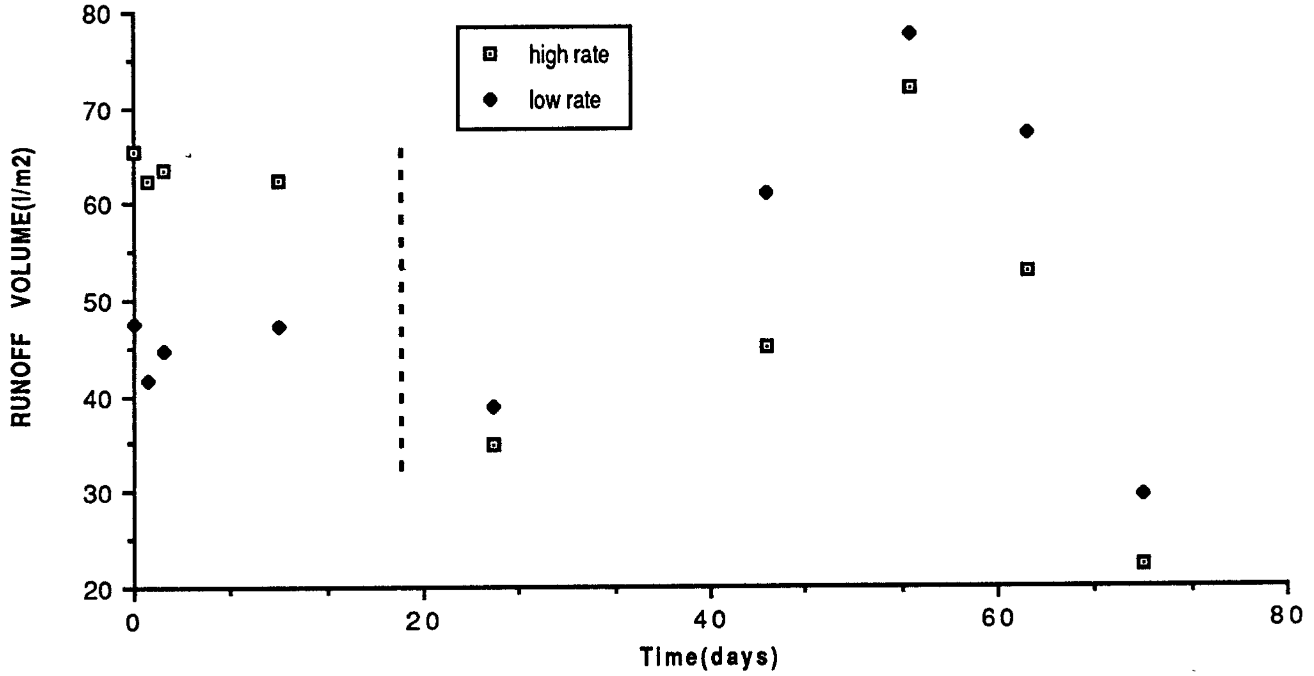

Figure 4.1
Mean Runoff Volume, by rate, all series

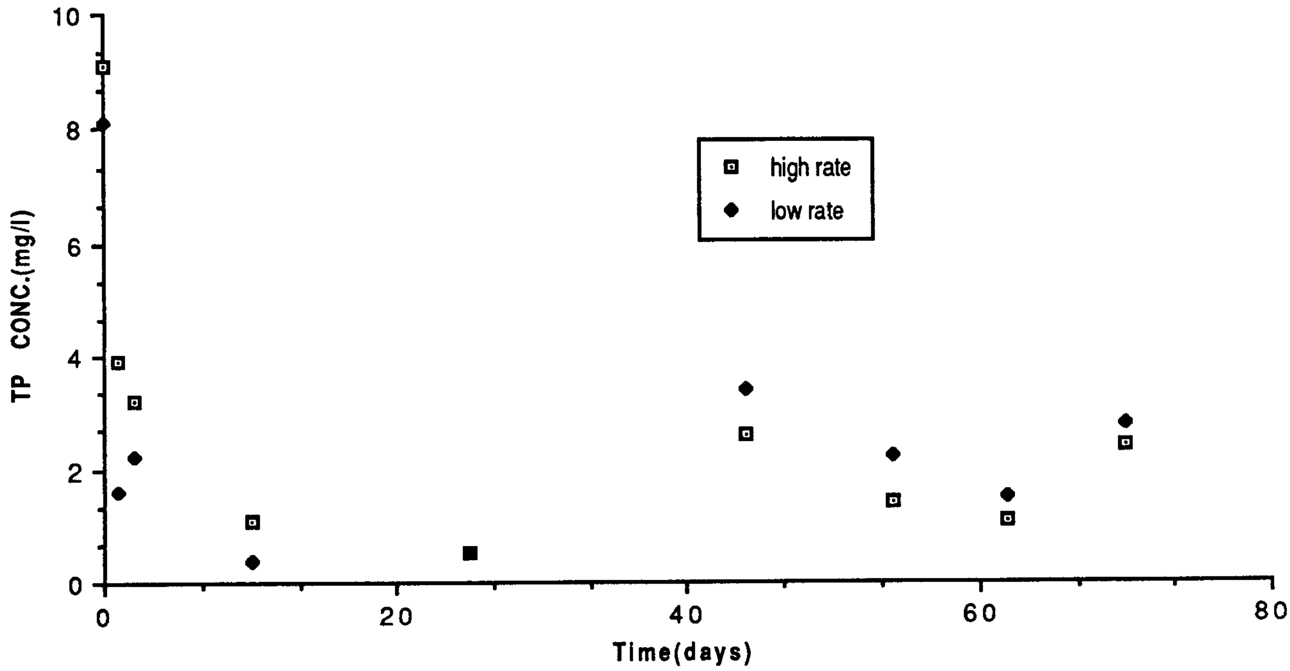

Figure 4.2
Mean TP Concentration, by rate, all series

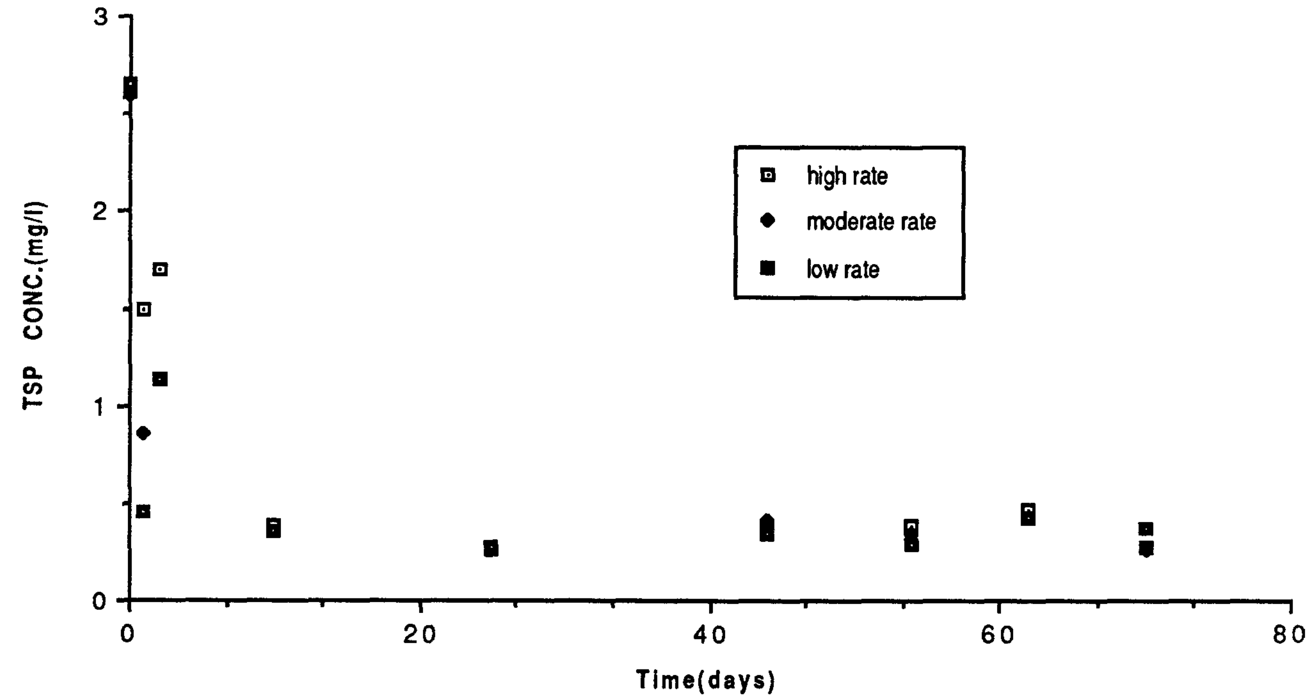

Figure 4.3
Mean TSP Concentration, by rate, all series

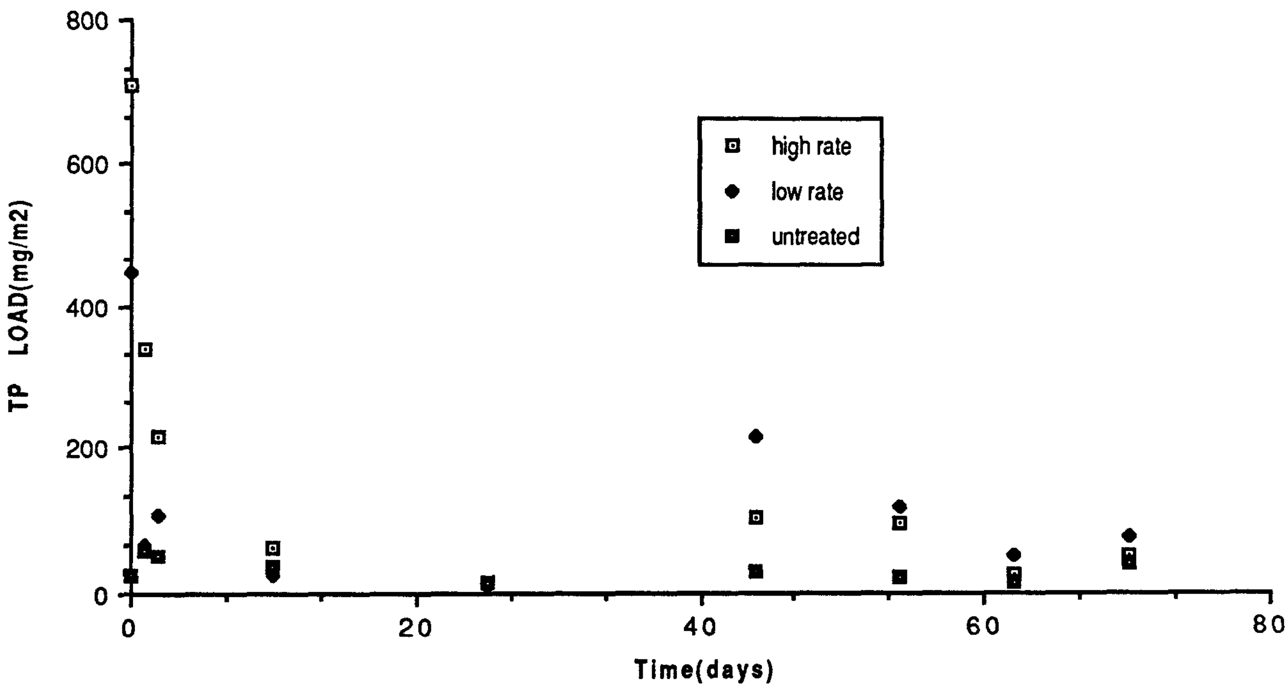

Figure 4.4
Mean TP Load, by rate, all series

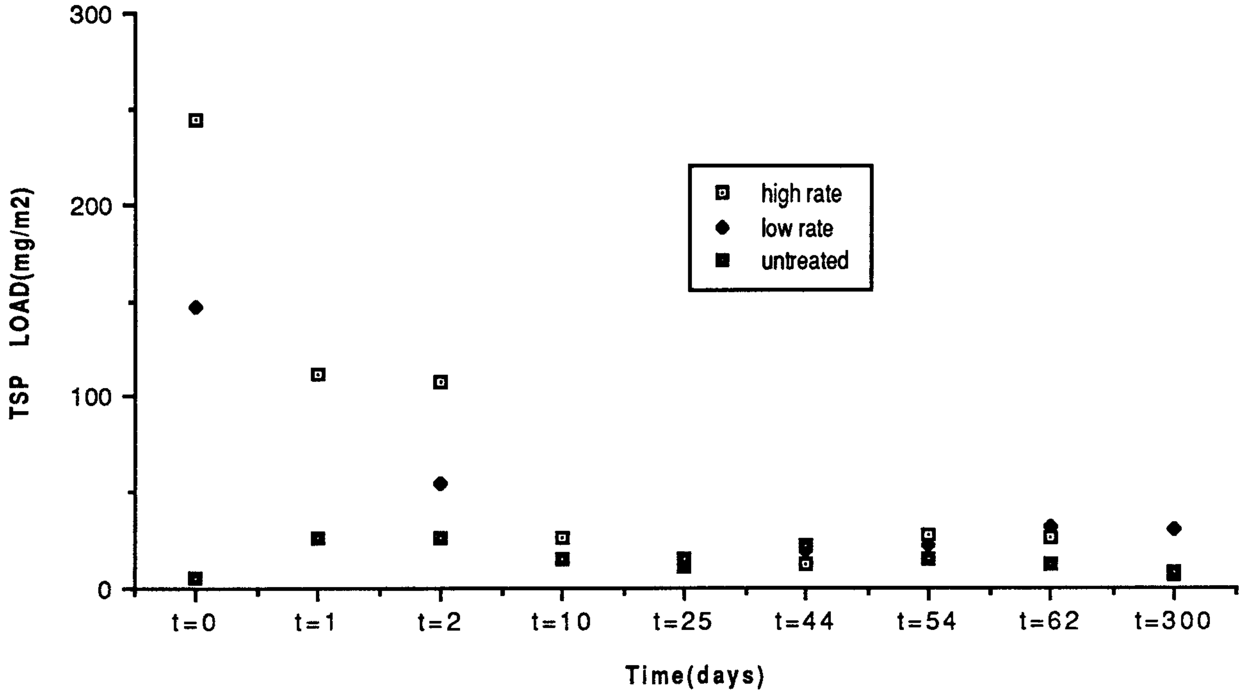

Figure 4.5
TSP Load, by rate, all series

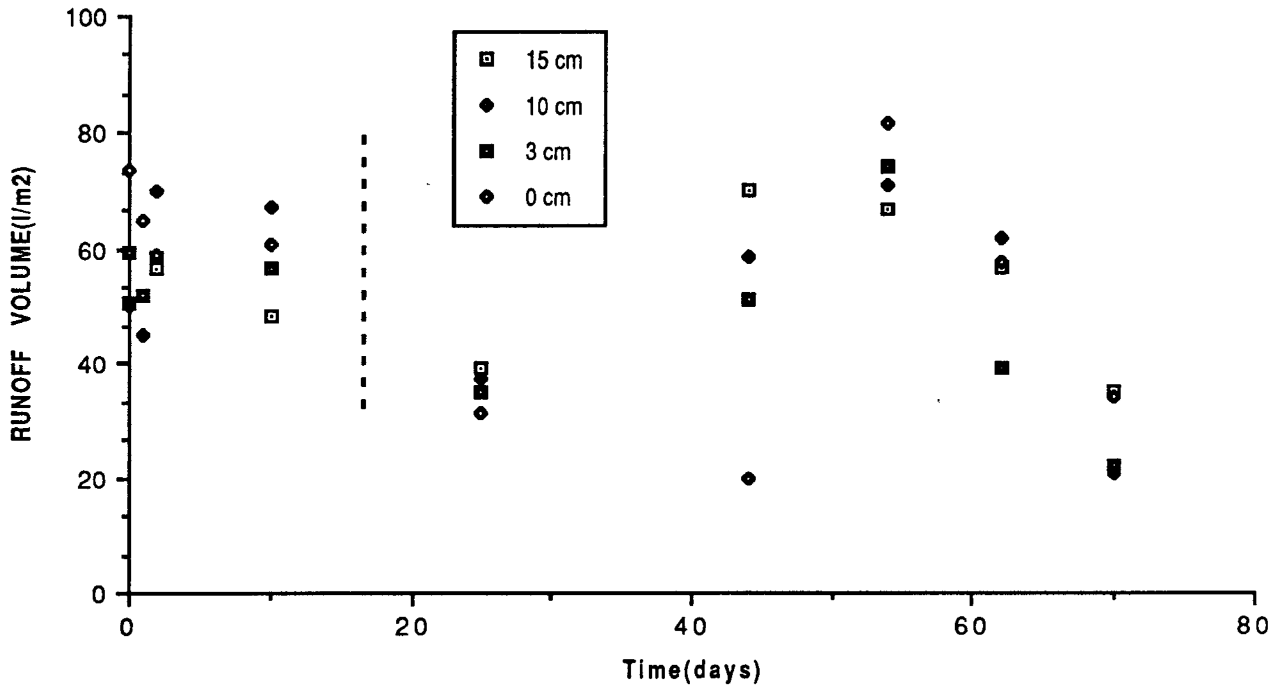

Figure 4.6
Mean Runoff Volume, by depth, all series

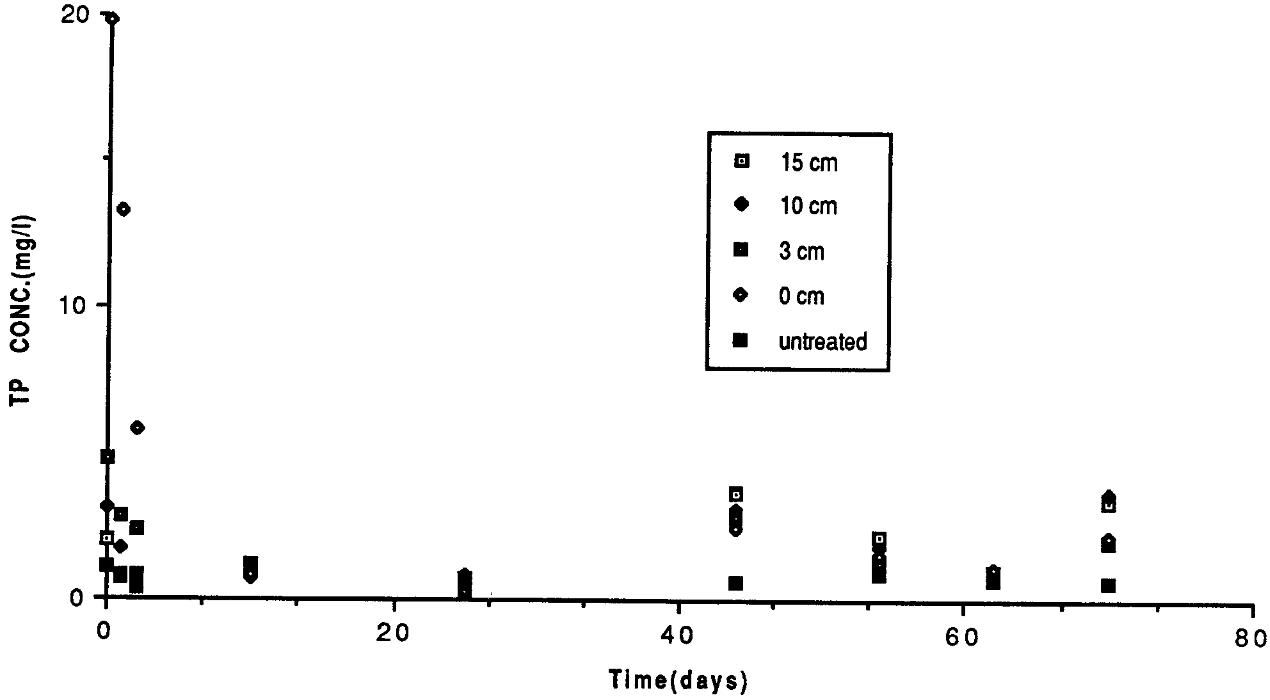

Figure 4.7
Mean TP Concentration, by depth, all series

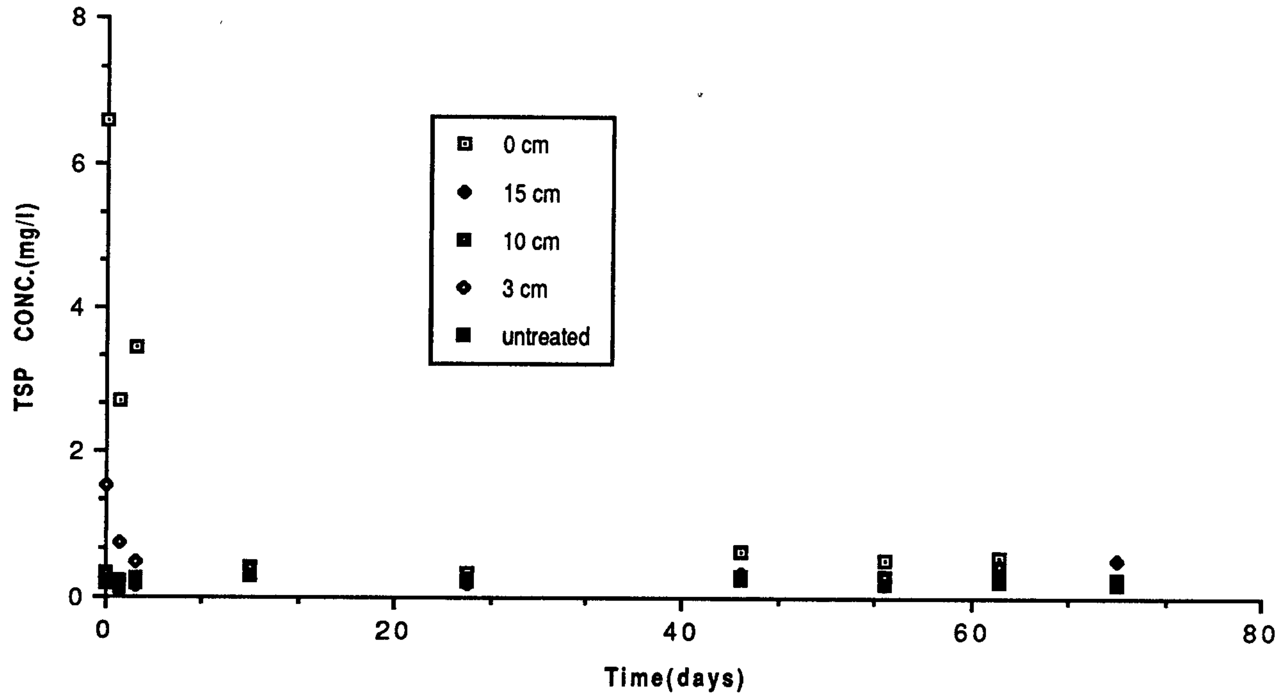

Figure 4.8
Mean TSP Concentration, by depth, all series

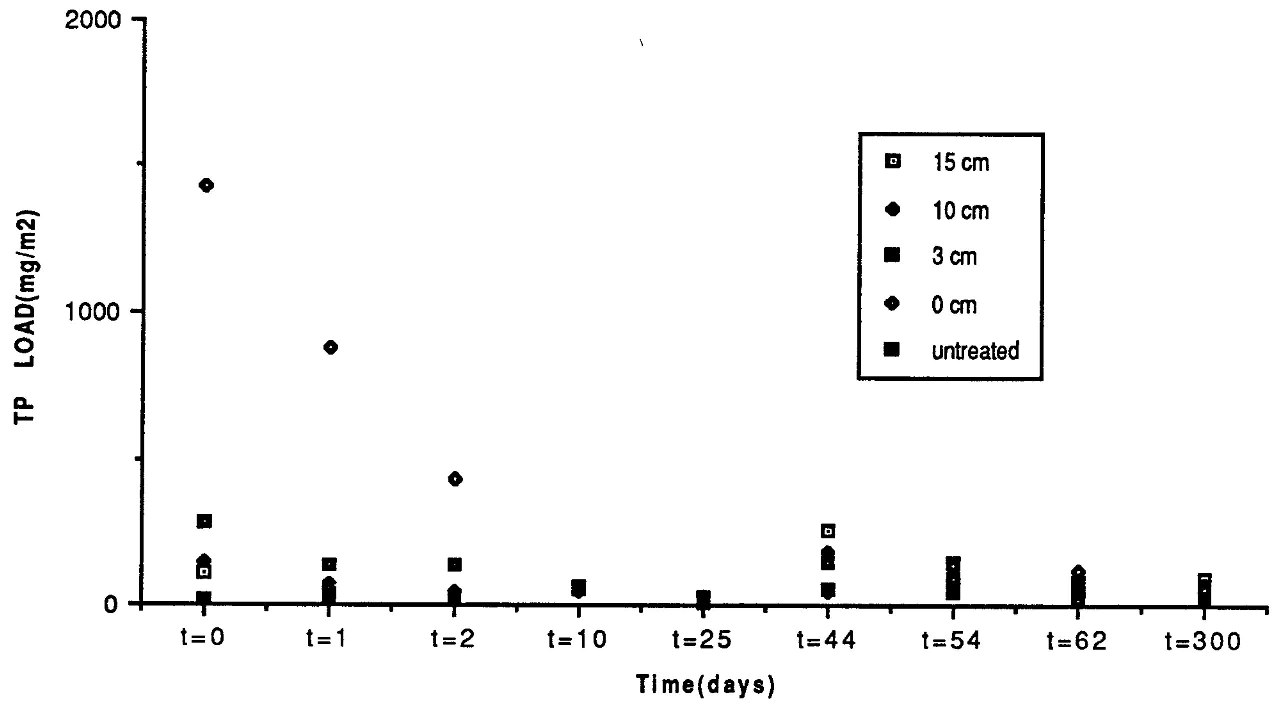

Figure 4.9
Mean TP Load, by depth, all series

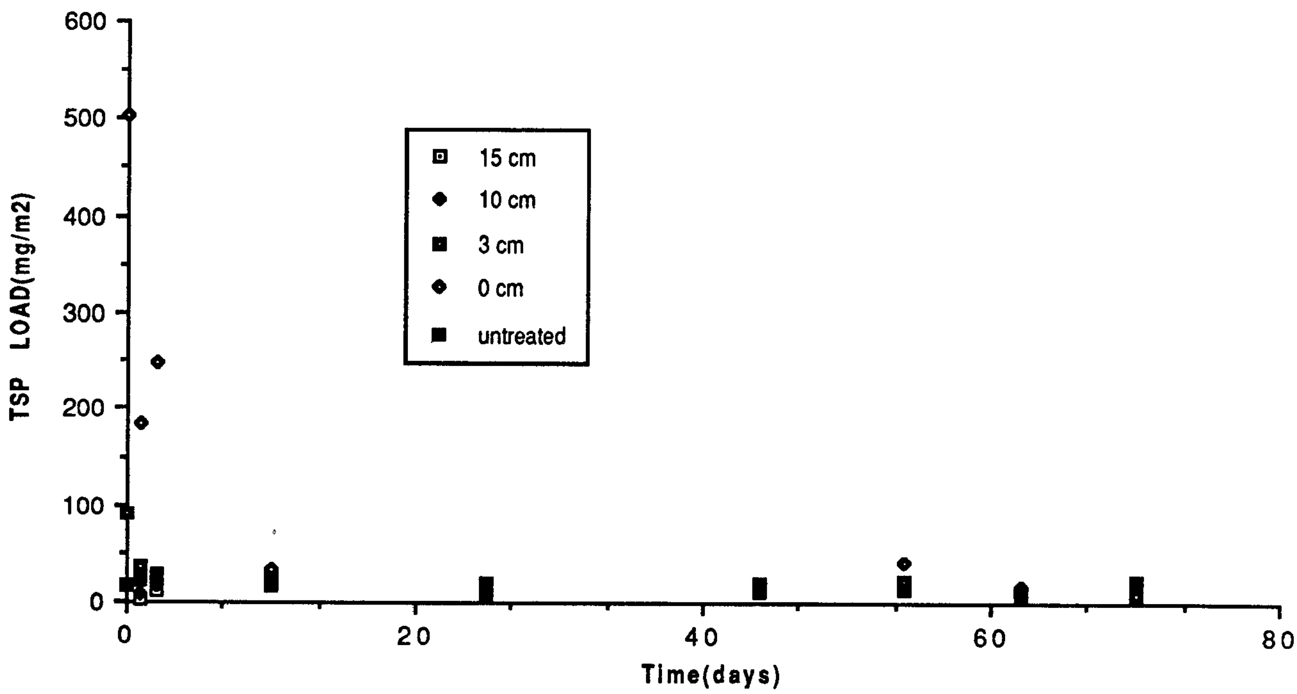

Figure 4.10
Mean TSP Load, by depth, all series

When all series data are pooled it is evident that incorporation depth had a strong influence on TP and TSP concentration for the first one or two events following manure incorporation (Figures 4.7 and 4.8). Typically, TP and TSP concentrations in surface runoff for the surface-applied treatments are one to two orders of magnitude greater than TP, TSP concentrations associated with the untreated troughs for this initial case. With subsequent precipitation events this pattern is greatly diminished but still somewhat evident, particularly the TSP concentrations (Figure 4.8).

The effect of incorporation depth on phosphorus loads in surface runoff is demonstrated in the total TSP loads for pooled data from all series in Figures 4.9 and 4.10. All series runs, whether manure applications or stabilized soil manure mixtures indicated decreased losses of phosphorus when manure was incorporated. It appears that any soil disturbance following surface manure application which left soil or residue on the surface of the manure or which mixed soil residue and manure to any extent would significantly reduce loading of all parameters. Wet-dry cycles cause the incorporation effect to be buffered. Finally, the shallower the incorporation depth the higher the TSP concentration for both the initial manure case and the dry manure soil mixture.

<u>Factors Affecting Phosphorus Loading</u>

Changes in TP, TSP loading in surface runoff with time indicate a dynamic physical biological chemical response for all treatments. This section discusses some of the physical changes which occurred during the various precipitation series. Since many of the physical effects of the different processes are competing, each will be described individually with a composite effect described in the summary.

<u>Surface Condition and Drying Time</u>

The time between manure application and the first precipitation event produces to substantial changes in TP, TSP loading. This effect decreases with an increasing number of wet-dry cycles. Since the highest load potential is associated with surface applications of manure, the time between surface manure application and the first precipitation event is particularly important. During the growing season, evaporation rates for central New York would vary from 1 to 4 mm/day. Therefore, a heavy (135 MT/ha) manure application to the surface would require up to 15 days to reach an equilibrium water content of 10-15%.

Once drying of the surface manure pack is complete, surface residue will result in decreased detachment energy at the soil surface and improved infiltration. Similarly, incorporated manure will leave residue in the soil profile which enhances infiltration characteristics. The laboratory and field studies demonstrated that precipitation events will cause erosion and removal of surface residue and fine organic particles. In the extreme case (300 day field observations), virtually all of the surface residue was transported off of the plot area. Therefore, as the number of precipitation events following manure application increase, the opportunities for surface residue to redistribute or be carried off the plot are increased. Both infiltration and phosphorus concentration in surface runoff are potentially affected by these processes.

The initial drying of surface applied manure is critical to the loading of phosphorus in subsequent runoff events. With two to three days of drying at temperatures between 65 - 70^{o}F and relative humidity of 40-55%, runoff volume and load were dramatically reduced. In particular, four conclusions can be drawn from the laboratory and farm runs:

- simultaneous drying and shrinkage of surface applications caused increases in infiltration and subsurface flow
- although suspended solids concentrations were appreciably less, subsurface concentrations (at 15 cm) were significantly greater
- changes in trough moisture content and total moisture retention indicated an immediate effect of incorporated manure
- depth of application and type and quantity of bedding are very important in determining surface residue, texture and subsequent loading values.

Precipitation to Initiate Runoff

The precipitation required to initiate runoff (PIR) clearly demonstrated the water retention benefits of manure-treated soils (Figures 4.11 and 4.12). Although PIR values increased with respect to the controls for all depths of incorporation, the relative increase of the surface applied treatments for the field series was not as great as in series LG1-LG4. This difference could be explained by the fact that much of the surface organic material and residue was transported out of the 1.35 m^2 field plot area during natural rainfall and snowmelt events. This was particularly true with surface application plots where little surface residue could be observed after 300 days.

Texture

Laboratory series LB1-LB6 utilized a Channery Bath soil, removed from an area adjacent to the field plots. Unlike series LG1-LG4 coarse aggregates and stones were not sieved. Similar to the field runs this soil reveals very good infiltration properties even for the high intensity simulated rainfall events. The air-dried soil (7.1% moisture) yielded little runoff during series LB1. This can be attributed to the very coarse textured unconsolidated soil along with large aggregates and rocks allowing rapid water entry through the soil surface.

Aggregation

Although aggregation was not specifically measured, this effect was observed for several series treatments. Where soil manure aggregation is evident, macropores and cracks in the surface would likely allow for greater infiltration or lessen the effect of surface sealing. In addition, soil aggregation will likely have an effect on the raindrop detachment energy required to dislodge and carry away soil-manure particles.

Suspended solids data indicate two competing processes. Initially, the mixing of manure with silt loam soil caused higher suspended solids concentrations. As the mixture dried, aggregation effects were visible and subsequent suspended solids concentrations in surface runoff were less.

The effect of changes in density and packing can be observed as relatively high suspended solids levels associated with greater incorporation depths. Although this trend continues with time, increased aggregation of the manure soil mixture causes suspended solids levels of all treatments to drop below control levels after 50 days.

pH in Surface Runoff

The manure amended soils produced a higher pH in surface runoff. In addition, changes in pH were highly correlated with TSP concentrations in runoff samples for all series runs. This relationship has important implications for control practices.

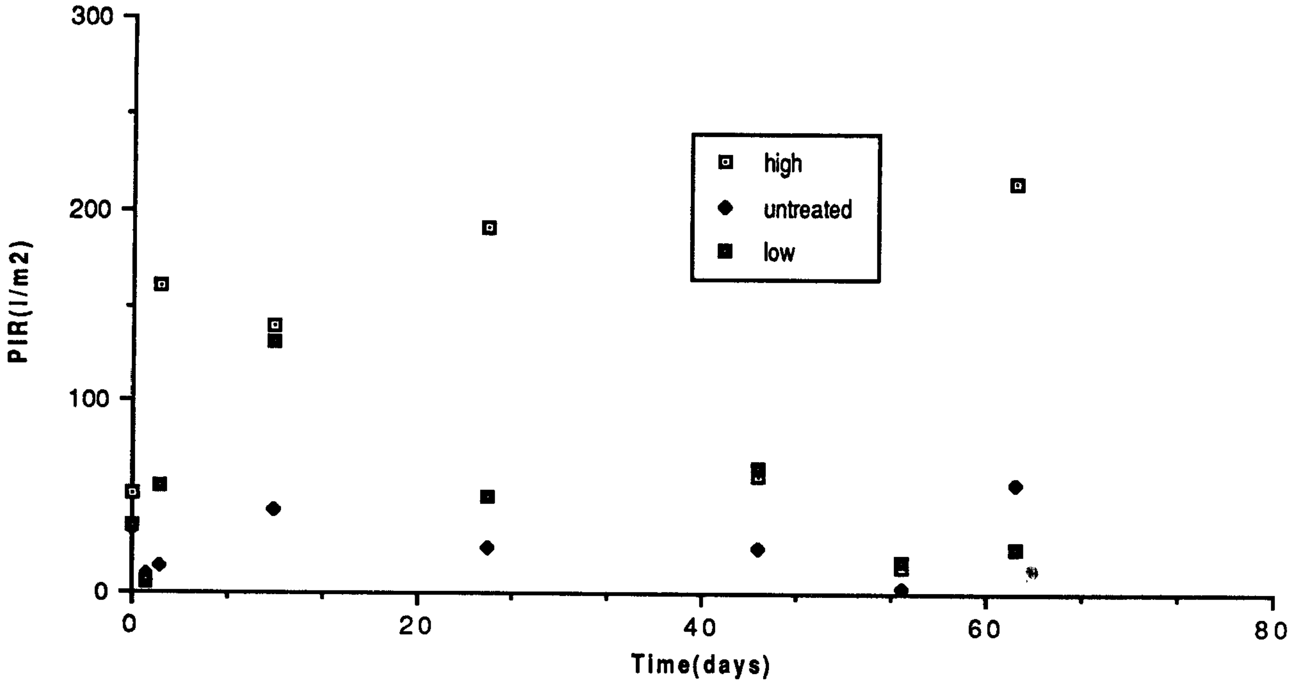

Figure 4.11
PIR, by rate, per unit area, all series

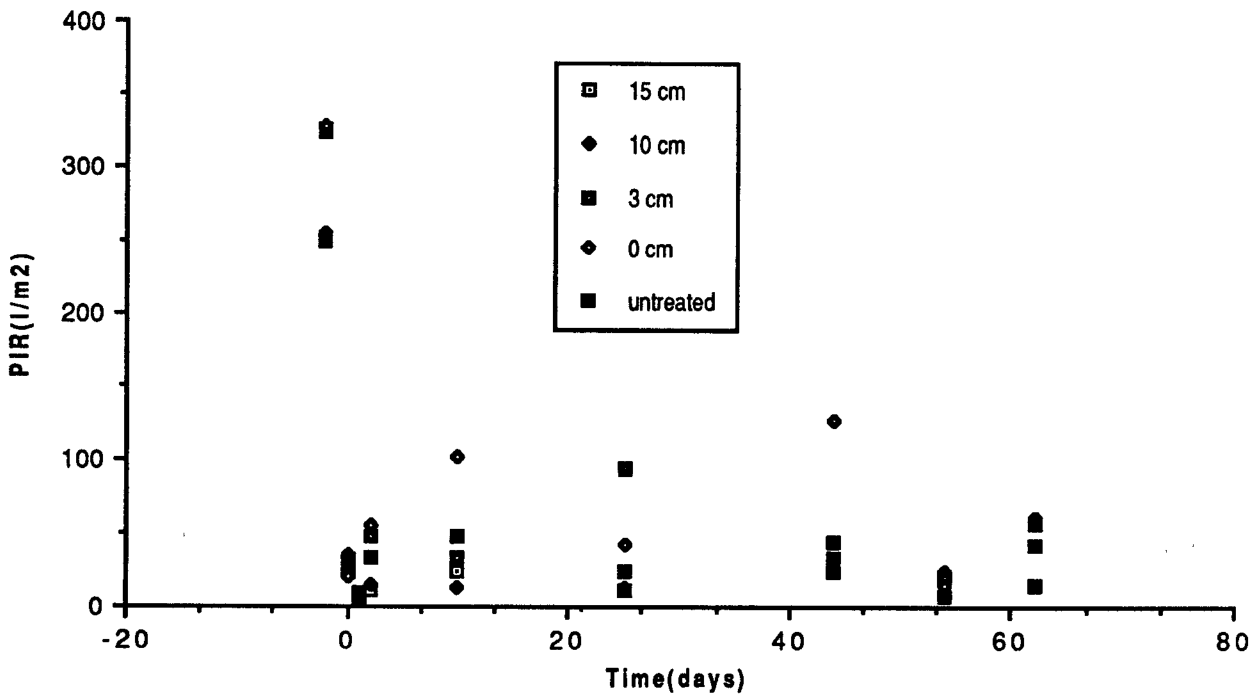

Figure 4.12
PIR, by depth, per unit area, all series

Normalized Load

Minimal incorporation of 3 cm greatly reduced unit areal load. Although normalized TP load from surface applications was almost three times that of the incorporation treatments (Figure 3.32) for precipitation immediately following manure application, this effect was reversed after a complete drying of the soil-manure pack. Normalized loads were similar following three wet-dry cycles (series LG4) for all depths of incorporation.

Normalized TSP load rates (Figure 3.33) were somewhat lower for higher rates of application. However, residual losses at 54 days indicated slightly higher rates of TSP losses for the higher application rate. This is likely the influence of higher mineralization rates of the surface applied manure as evidenced by the relatively high TSP losses for the surface applied case.

Changes in Nutrient Concentration within Events

Sample sequence was correlated with concentration of TP, TSP and TKN for pooled data from all series runs (Figures 4.13-4.15). The slope of all curves indicates a dilution effect after the initial high value associated with the first or second sample collected immediately after manure application. Subsequent samples indicate lower values that approach control levels after several wet-dry cycles. The time period between series varied from 1 to 40 days thus allowing mineralization of nutrients in some case. This process would explain the higher values of first samples collected after a break-in series (Figures 4.13-4.15).

WINTER CONDITIONS

Disposal of Manure on the Snowpack

The problem of manure application on the snowpack during periods when the snow is actively melting was studied by Steenhuis (1977). The laboratory and field work Steenhuis (1977) accomplished indicated that most of the nutrients in snow meltwater were soluble. He further observed that unfrozen soils under snowpacks retained relatively good hydrologic properties greatly reducing nutrient losses.

Steenhuis (1977) observed that the TP concentration in runoff was relatively low due primarily to the low energy level of snowmelt events. In addition, he observed that relatively small quantities of phosphorus were observed when manure was covered by the snowpack. These losses were primarily controlled by fresh water movement in the snowpack. He also observed that significant amounts of bedding increased phosphorus adsorption and directly decreased phosphorus losses in runoff.

SUMMARY

Drying Effect

After the initial wetting of the manure-soil pack the treatments were allowed to dry for time periods varying from 1 to 40 days. Depending on storage conditions the drying effect resulted in significantly reduced loading for series runs LG3, LB5 and LBD1-LBD4. Figure 4.16 illustrates this effect for the special case of surface applications. Series LBD1 was initially wetted two days after a high-rate manure application (135 MT/ha).

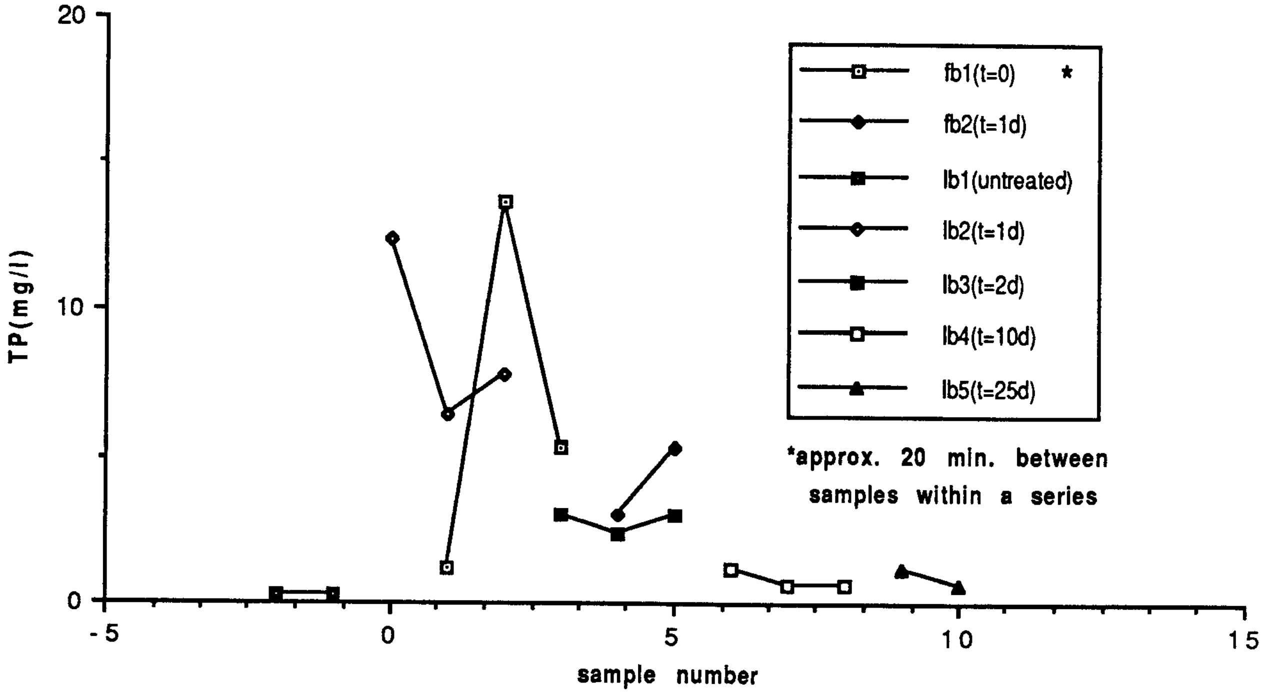

Figure 4.13
Composite TP Conc., by sequence, all series

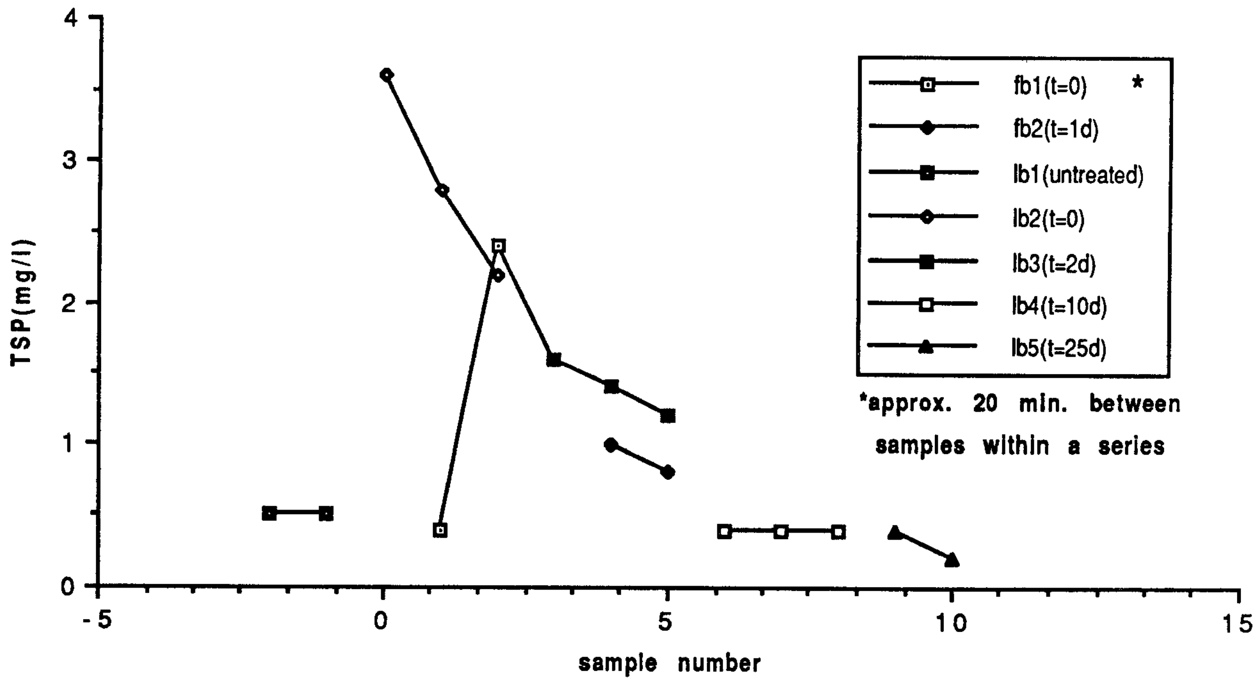

Figure 4.14
Composite TSP Conc., by sequence, all series

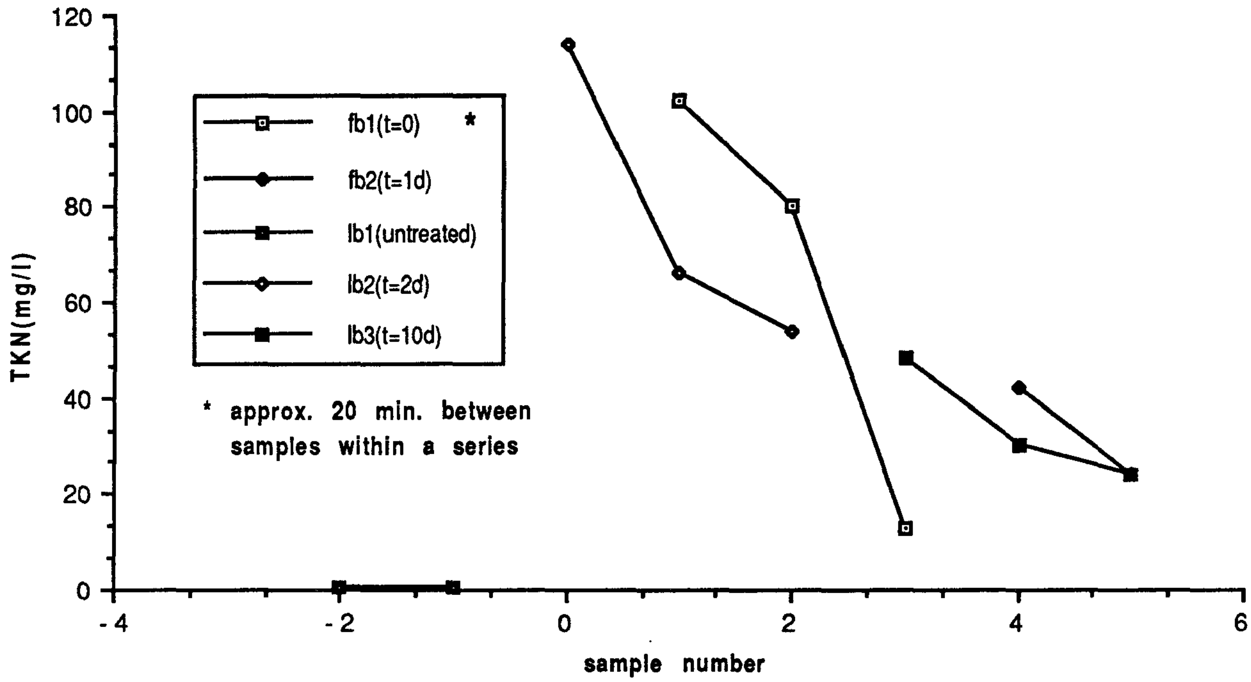

Figure 4.15
Composite TKN Conc., by sequence, all series

Subsequent rewetting of the soil-manure pack at 5, 10 and 20 days resulted in flow volumes which were appreciably higher than if the initial wetting were after a five-day drying period (LBD2). Similarly, 10 and 20-day drying periods before initial wetting also resulted in reduced runoff volumes. When drying conditions were not favorable, similar reductions in flow volume were not achieved until a 25-day period had elapsed (series LG3).

Effect of Bedding

The fiber and solids content of manure is likely to have a significant effect on surface condition following drying of the manure-soil pack. The manure collected from the EIDS farm contained approximately 0.5 kg/cow /day of bedding. This is within the expected range for freestall systems (0.4-0.9 kg/cow/day) reported by Safley (1978). Since the quantity of bedding used in stanchion systems varies from 1.1-3.4 kg/cow/day (Safley, 1978) this effect is important. The increased quantities of residue associated with greater utilization of bedding (particularly straw) will result in a surface cover more closely resembling surface conditions after reduced tillage operations.

Although time to initiate runoff is increased because of the relatively large quantity of dry surface residue remaining after the soil manure pack dries, some of this effect may be related to the fiber content of manure and its beneficial effect on surface infiltration (Hafez, 1974). The influence of the fiber is twofold: it prevents a crusting of the surface and it dissipates the energy of raindrop impact as any mulch cover would. Both of these effects would improve the hydrologic response and conductivity of manure treated soils. However, when surface applied manure dries, the light fine fiber component is mobile. Not only was transport and deposition evident within the plot area but movement off the plot was clearly evident after 300 days.

SECTION V

FARM APPLICATIONS

TILLAGE-MANURE SYSTEMS

Although the principal objectives of conservation tillage and manure incorporation are in conflict, tillage-manure systems can be developed which decrease TP and TSP losses. The overall criteria in designing tillage-manure systems include:

- evaluation of current practices
- development of spreading schedules
- special rate/incorporation practices (field renovation) for problem areas
- short-term storage
- tillage rotation systems
- manure-soil testing
- modified and experimental tillage systems
- supporting practices
- mobile evaluation systems

Current Practices

The daily spreading of manure is practiced on over 90% of Lake Ontario dairy farms. Improvements in current spreading practices as well as adoption of new tillage-manure systems will lead to reductions in total TP and TSP delivery.

The criteria for the location and rate of application of manure typically reflects practical limitations on time, labor and location of spreading. Spreading activities are not planned nor are they recorded. The result of these practices are poor uniformity of application and little certainty with respect to nutrient additions from applications.

Development of Spreading Schedules

The concept of spreading schedules was introduced by Robillard and Walter (1979, 1983). This type of phosphorus control measure is particularly appropriate for the problems associated with winter disposal. Specific applications of the spreading schedule design involve three components:

- identification of management periods
- distribution of manure applications for phosphorus control and agronomic constraints
- identification of storage requirements and associated disposal systems.

Management Periods

The identification of management periods establishes possible differences in manure disposal criteria. For example, in northern humid regions the following management periods might be considered:

Management Period	Disposal Variables
Spring tillage	rate of application, incorporation depth
Early crop stage growing season	low application rates
Early fall after harvest	rate of application
Fall tillage	incorporation depth
Late fall before snowfall and frozen ground	rate of application
Early winter period application area	rate of application - low delivery areas
Late winter period	low delivery areas
Spring thaw period	storage - safe application areas

Special Rate/Incorporation Practices

Results of the laboratory, field and farm studies indicate that rate, depth and time variables can be used to reduce total farm losses of TP and TSP. Specific practices which would accomplish these objectives are:

- field renovation (high application rates in no-till moldboard rotation)
- safe disposal areas established with diversion terraces, berms, and subsurface drainage as needed
- high application rates to fields harvested for corn silage before winter conditions
- high application rates keyed to probable drying conditions after application
- heavy rate strip applications which increase surface storage and allow equipment traffic lanes
- graduated rate applications.

Practical Implications

- heavy repeated surface applications will prevent or limit frost development and improve infiltration
- on corn silage fields heavy manure applications before snowfall or frozen ground will result in an improved hydraulic condition for winter and early spring runoff events
- during periods when delivery potential is high
  - spread on fields or areas where runoff and delivery potential are low
  - add straw or bedding material to absorb moisture
  - temporarily stockpile manure in a safe disposal area.

Short-term Storage

During periods of high snowfall, particularly in Oswego County, short-term storage is currently practiced. Typically the storage method is simply a stacking system. These systems do not necessarily result in reduced TP, TSP loading since there is generally no complementary implementation of practices to divert runoff from upland watersheds away from stacking areas.

Results from previous field studies (Robillard and Walter, 1983) indicate that high losses and delivery of phosphorus are associated with three primary mechanisms:

- precipitation or snowmelt immediately following surface applications

- manure applications during active thaw periods
- poor disposal practices which enhance losses such as channelization of runoff, stream crossings and poorly maintained equipment.

Tillage Rotation Systems

Reductions in TP, TSP loading can be achieved for Tillage-Manure Systems by the use of high rate, uniform applications to fields in a no-till/moldboard tillage rotation. This can be referred to as field renovation.

Typical daily manure spreading can be characterized as follows:

- low rate, non uniform applications
- disposal areas not sensitive to runoff potential
- unplanned, unrecorded disposal practices.

The negative effects of this type of system are:

- potentially high TP, TSP losses
- uncertain nutrient contributions
- lack of coordination with other tillage, agronomic practices.

When fields have been in no-till for several years high, uniform applications could be made in the fall and late spring before the field is moldboard plowed. If convenient, two or more moderate applications could be made between harvest and moldboard plowing. The moldboard incorporation of manure and residues would act to interrupt weed and insect cycles. In addition, nutrients would be redistributed throughout the root zone. Finally, the heavy manure application would add appreciable amounts of residue to the soil surface of fields harvested for corn silage.

Manure-Soil Testing

Good nutrient control practices will contribute to the achievement of reduced TP, TSP loading and optimal crop production. Some nutrient control decisions can be made if the following information is obtained:

- manure testing for nutrient content
- match available P crop requirement to P applications as closely as possible
- use soil testing methods to anticipate quantity of P needed
- if soil P levels are high, use starter P at planting only
- if soil P levels are low, heavy uniform manure applications which are immediately incorporated will increase soil P levels.

Modified and Experimental Tillage Systems

There has been a dramatic rise in ridge-till planting (a 45% increase during the 1985-86 period). This increase demonstrates the new systems being adapted for unique soil and climate problems.

Changes and adoption of reduced tillage systems are the key to their success, particularly where adverse soil and climate conditions prevail. The design of tillage-manure systems are no exception to this trend. The complexities of designing a flexible system to maintain residue cover and retain nutrients add an additional dimension to this adoption process. Nonetheless, this study demonstrates the many alternatives available to satisfy tillage, manure disposal and agronomic objectives on commercial dairy farms.

Supporting Practices

Practices which increase the accessibility to fields and/or decrease nutrient delivery loss potential allow for more control over manure applications and scheduling. The following examples could be considered supporting practices:

- access roads which improve field accessibility during the winter period
- farm road improvements which decrease rutting and channelization of water
- upgrading and maintenance of spreading equipment to decrease spillage during loading and transport and to increase the uniformity of application
- changes in the use of bedding to absorb moisture or provide additional surface residue (for example increasing the quantity of bedding used or changing from fine wood sawdust to straw bedding).

Tillage-Residue Systems and the Development of Soil Frost

An element of winter spreading criteria involves the development and decrease in soil frost. Benoit (1985, 1986) points out the following physical characteristics of soil frost development:

- dry soil will freeze before a wet soil
- frost depth decreases with increasing depth
- the rate of freezing, the number of freeze-thaw cycles and the soil water content at freezing influence the degree of soil structural modification caused by freezing.

For the tillage-residue systems evaluated by Benoit (1985), the greatest sensitivity of frost devélopment were to changes in soil moisture, hydraulic conductivity and thermal conductivity of frozen ground.

In this study, the plots with surface residue retained more snow than the non-residue plots. In particular, fields which had been no-tilled retained more snow than fields which had been fall chiseled.

For the tillage-residue systems studied by Benoit (1985, 1986) small differences in frost development occurred until the first snowfall event. From that time a direct negative relationship existed between snow accumulation and frost depth.

Mobile Evaluation Systems

The numerous farm simulated rainfall runs completed with the PWSI unit in Wayne and Oswego Counties verified the accuracy and flexibility of this type of evaluation system. With a complete set of laboratory and controlled field data with which to reference farm simulated precipitation runs, efficient evaluations of various manure-tillage systems can be accomplished. This type of evaluation system not only improves upon existing methods for comparing loads between various tillage manure systems but greatly enhances the opportunity to observe practices on operating commercial farms. In addition, the mobile evaluation system can be used to encourage innovation and experimentation among farm operators. The work in Wayne and Oswego Counties indicates that progressive farm operators will demonstrate a keen interest and participation in the evaluation of new tillage-manure systems.

Recommended Program Initiatives

As evidenced in the Wayne and Oswego County Tillage Demonstration Projects, the initiatives and experimentation of individual farm operators are important elements of a successful program. The initiatives take the form of equipment modifications, nutrient/pesticide changes and adaptions in the timing of operations. The fact that these new practices and adoptions are made in the context of existing farming operations means that they should be looked at closely as part of the phosphorus control program.

The flexibility and timeliness of mobile monitoring units such as the PWSI unit used for this study should be developed further. This type of evaluation technique should be modified not only to investigate the many tillage-manure systems options cited in this report but to develop instrumentation and methods for making winter and spring thaw evaluations.

A second consideration with respect to program initiatives in the Great Lakes is the linkage with groundwater monitoring and control. The interface between surface and groundwater monitoring and control is obviously important but has been overlooked in most cases to the detriment of both surface and groundwater program effectiveness.

Two separate conferences dealing with monitoring systems and surface-groundwater interfaces would provide direction and coordination for these important technical and policy questions. The emphasis of the monitoring systems conference would be evaluation of control practices on different farms, soils and the conjunctive development of practical field computer models. Ideally, model validation and control effectiveness calculations would utilize direct monitoring observations.

Research Needs

The micro-climate effects of sunlight, soil and wind on the drying of surface applied manure will likely result in appreciable differences in runoff potential and loading. The key to minimizing loading potential would be to relate weather variables to loading potential. These weather windows would key disposal to the probability of drying periods and surface-groundwater loss potential. The application rate, incorporation depth and other control variables would then change depending on time of year and hydrologic condition of the soil.

SECTION VI
CONCLUSIONS

Phosphorus is the limiting nutrient in many lake eutrophication processes. One source of phosphorus is livestock manure which is applied to cropland. The potential for relatively high TP and TSP loads in surface runoff has been associated with poorly managed livestock disposal operations.

The utilization of herbicides in crop production provides opportunities for reducing both tillage operations and soil erosion. The spectrum of tillage options varies from conventional moldboard to the minimal soil disturbance of no till systems. In every case nutrient losses from cropland are affected. There exists an inherent conflict between maintenance of surface residue associated with reduced tillage systems and the incorporation of manure to reduce losses of phosphorus in surface runoff. This research addresses one aspect of these conflicting objectives by quantifying TP, TSP losses associated with the application and incorporation of manure.

Elevated TSP losses have been linked to conservation tillage systems which result in an accumulation of nutrients at the soil surface. Similarly, manure disposal practices have been associated with elevated TP and TSP losses when manure is surface applied. There are numerous alternatives for coordinating manure applications and conservation tillage to minimize phosphorus losses. Application rate, incorporation depth, and time of application all can be varied as well as the specific tillage system used. In addition, the rotation of tillage operations in a sequence to accommodate manure disposal presents some options to farm operators.

Laboratory, field and farm experiments were designed to accomplish the following:

- observe phosphorus losses for a range manure application rates (22-135 MT/ha) and incorporation depths (0-20 cm)
- quantify changes with time which relate phosphorus load to various combinations or rate depth treatments
- incorporate the above results into practical recommendations for the development of tillage-manure systems to control phosphorus losses.

The twelve rate-depth treatments used in the study represent a realistic range of manure disposal options. Level 1 studies investigated the rate-depth-time relationship under controlled laboratory conditions. Level 2 was conducted under more variable field conditions and level 3 studies extended these results to various tillage-manure systems to minimize phosphorus losses on operating dairy farms.

The results of all experimental runs indicated that runoff volume varied with the time between initial manure application and the first precipitation event as well as with an increasing number of wet-dry cycles. Runoff was as high as 81% of the 11.9 cm simulated precipitation for events immediately following manure application and as low as 22% for the case of a relatively dry manure-soil pack. Depending on drying rates, initial high runoff rates were greatly reduced after 5 to 25 days. After this period, manure-treated soils typically produced a lower runoff volume than untreated plots. Respective mean TP, TSP concentrations in surface runoff for all treatments was 7.7 and 2.1 mg/L. These concentrations are relatively high for cropland (Loehr, 1974). The corresponding loads from experimental plots associated with the various series runs ranged from untreated values(.09-4.0 hg/ha TP) for the high application rate (135 MT/ha) to the surface. A relatively large fraction of this load (29-48%) was in a soluble form compared with untreated plots which recorded a mean TSP/TP ratio of 0.13.

Initial high losses of TP and TSP in surface runoff are significantly buffered by subsequent wet-dry cycles. After a two to five-day drying period, improved infiltration and decreased concentration of TP, TSP can be observed for the manure-treated soils. A complete drying of the soil-manure mixture results in increased soil moisture retention. This effect was observed for all series runs. After a 25 to 50 day period, depending on the number of wet-dry cycles and drying conditions, TP and TSP loading approached the untreated case.

Changes in TSP concentration over time indicated the manure-amended soils caused both a high initial flush of soluble phosphorus and a more sustained supply of soluble P in surface runoff for subsequent precipitation events compared with the untreated plots. For the case of 135 MT/ha application rate to the surface, there was a 30-fold increase in TSP and a 10-fold increase in TP over the control. This ratio did decrease over time, but after 10 months residual TSP losses were typically still greater than the control.

Normalized loads indicated that loads from higher rate applications resulted in lower losses per unit of manure applied. When normalized loads are compared by depth of incorporation, the surface-applied case produced considerably higher losses.

The analysis of individual simulated precipitation events provides some information which is useful in extrapolating to events of differing intensity and duration. Generally, phosphorus concentration peaked within 30 minutes of the beginning of runoff. Concentration then decreased exponentially for the remainder of the run, converging toward a minimum value.

The dynamic loading changes from the initial application of manure to the first few wet-dry cycles indicate the importance of observing and estimating phosphorus losses on an event basis. After the soil-manure mixture had dried and been rewetted several times, loading values did stabilize and approached untreated levels.

The application of manure to the surface resulted in an accumulation of surface residue after several wet-dry cycles. This residue effect could explain, in part, the lower runoff rates and mass losses associated with surface applications. This residue was light and mobile causing a redistribution over the surface following each simulated precipitation event and a movement off of field plots over a longer period.

The controlled laboratory and field experiments of Phase I were extended to farms in Wayne and Oswego Counties. Simulated precipitation was used to compare manure application rate, incorporation depth, residue cover, tillage method, soil type and crop on commercially operating dairy farms. The data from these studies were used to verify preliminary Phase I findings and to observe how residue, tillage, soil type and crop cover effect the basic rate-depth TP and TSP loads observed in Phase I.

Results of simulated precipitation runs during the growing season indicated appreciable differences between TP, TSP loading from areas with different residue cover, manure application rates, cover crop and soil type.

The effect of residue cover was to decrease TP losses while TSP loads were increased or remained at higher levels for longer time periods. Surface manure applications and residue cover typically improved infiltration and water holding capacity. Although the farm series runs were not able to accurately account for previous manure applications to fields, the benefits of manure amended soils were reflected in relatively low TP loading values.

Maintenance of a surface residue caused differences in surface runoff to be relatively small between treatments even when manure was applied over the residue. For events just two days after application of manure, TSP concentration was higher than the levels observed on a bare soil. The high residual TSP load for manure over residue suggests that sub residue soil conditions are favorable to the supply of soluble phosphorus and that the process is flow controlled.

Crop and soil type did significantly effect TP, TSP loading with alfalfa indicating lower losses of TP, TSP. Simulated precipitation runs on the clay loam soil indicated higher runoff rates but lower TSP concentrations resulting in increased TP load and decreased TSP load compared to the silt loam and sandy loam soils.

There was a high correlation between TSP concentration and TP concentration and load for all farm series runs. In addition, TSP was a high fraction of TP load for all manure amended soils, particularly surface applications.

The effects of drying and application rate were repeated in the farm series, although the variation and trends of these series were not as clear as previous laboratory and field runs. However, the farms series runs validated these results for the growing season, indicating dramatically decreased TP, TSP load with four days of field drying before the next precipitation event. In addition, normalized loads resulted in lower TP, TSP losses for higher application rates. After four drying days infiltration for all soil types improved with increasing surface application rate.

The development of tillage-manure systems to reduce TP, TSP loads are possible. Management periods, application rates, incorporation, and storage are all elements of the system. Special problem-oriented practices can be developed to deal with disposal limitations and specific agronomic objectives. Finally, on-farm monitoring systems for evaluating tillage manure alternatives should be used in conjunction with farm adoption and experimentation for various tillage-manure practices.

Use of the sprinkling infiltrometer established control over several precipitation variables (intensity, energy, droplet size) and provided an opportunity to look at some of the physical processes influencing phosphorus losses independent of precipitation variables. The loading data collected in the laboratory and field trials are consistent with the concept of a shallow zone of interaction where phosphorus loss rates can be related to a mass of interacting soil and water. This concept has been modeled and quantified by Sharpley et al, (1981a). Their model relates accumulated phosphorus losses to initial soil phosphorus levels, time and the mass of water and soil interacting. The impact of the rainfall on the soil surface determines the mixing depth. Typically, this mixing depth (zone of interaction) is less than 1 cm and in some cases less than 1 mm.

Findings from all laboratory, field and farm trials result in several conclusions, all having implications for the development of tillage-manure systems to minimize phosphorus losses:

1. The runoff volume associated with manure application is strongly influenced by the drying time between application and the first precipitation event.

2. The initial high runoff rates of manure-treated soils compared to the untreated case are reversed 5-25 days after application under growing season conditions.

3. TP and TSP concentrations exhibited a wide range, but typically decreased exponentially from a high value associated with initial manure applications.

4. High TP and TSP loads are clearly associated with the first few precipitation events following manure application.

5. The estimation or prediction of TP, TSP losses from manured cropland should be accomplished on an event basis, particularly for the first few precipitation events following manure application.

6. Incorporation depth explained much of the data variability for runoff volume, TP, TSP concentration and loading, while manure application rates (22-135 MT/ha) appeared to have little effect.

7. Minimal incorporation (2-3 cm) of applied manure will greatly decrease losses of TP and TSP in surface runoff.

8. Variations in mean TP, TSP concentrations within events indicate a dilution effect after initial high concentration levels.

9. With 5-15 days of drying between precipitation events, some increase in the TSP/TP ratio was noted. This change could reflect a higher rate of phosphorus availability for the manure amended soils.

10. The amount of bedding in manure will influence residue cover for surface manure applications. The benefits of this residue are similar to residues associated with conservation tillage systems. However, the quality of this cover is different with much of the residual bedding being transported off of the application site over time.

11. After several wet-dry cycles during the growing season, losses of TP and TSP in surface runoff appear to approach losses observed in untreated soil. During the non-growing season the number of wet-dry cycles required to achieve this effect will be greater.

12. Normalized TP, TSP data indicate lower losses per unit manure applied for higher application rates.

13. The concept of a shallow surface zone of interaction appears consistent with the loading data collected for all series runs. The accumulation of nutrients in this zone and the physical mixing of soil and water during events can be estimated for specific soils using the model developed by Sharpley et al, (1981a). Surface conditions (texture, roughness, residue) are an important element of this interaction zone.

14. There are many opportunities for meeting residue and incorporation objectives within the context of farming operations are many, particularly if manure spreading activities are integrated into a three to five-year tillage cycle.

15. The sprinkling infiltrometer is a promising instrument for the evaluation of phosphorus losses for various tillage manure practices.

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APPENDIX A
INFILTROMETER REVIEW AND EVALUATION

A.1 TYPES AND CHARACTERISTICS OF RAINFALL SIMULATORS REVIEWED

The two principle types of simulators that have been utilized for both laboratory and field studies are the drop forming type and the sprinkling type.

In the construction of many of the simulators described below, natural rainfall characteristics as reported by Laws (1941) and Laws and Parsons (1943) were used as an important design criteria. In his original measurements, Laws (1941) reported terminal velocities of 1-6 mm water drops from heights of 0.5 - 20 m. Together Laws and Parsons (1943) investigated the drop size composition of natural rainfall at different levels of intensity.

A.1.1 Drop forming type simulators

Adams et al (1957) constructed a drop forming type infiltrometer for erosion studies. The apparatus was set up to provide precipitation over a relatively small area (15 cm in diameter). Steinfordt and Hillel (1966) developed an infiltrometer delivering variable intensities of 4-100 mm/hr. In order to simulate the random distribution of natural rainfall over the soil surface an eccentric rotor was linked to the drop forming module. The simulator, as with many drop forming units, supplied large drop sizes and low impact velocities which were unrepresentative of natural rainfall. However, Steinfordt and Hillel (1966) point out that for their studies of surface sealing that the simulator was probably adequate.

Both Blackburn et al (1974) and Munn and Huntington (1976) developed drop forming type infiltrometers for field application. The velocity and energy characteristics of the unit developed by Munn and Huntington (1976) were comparable to sprinkling infiltrometers (Table A.1). The uniformity of drop sizes was cited as the principal difference between the drop forming and the sprinkling type.

Romkens et al (1975) improved the uniformity of application of drop forming simulators by super-positioning three motions of a closely packed unit of hypodermic needles. The system also allowed variation of drop diameter by changing needle size and storage volume. Selby (1970), Hamon (1978), Kleijn et al (1979) and Walker et al (1977) all improved drop forming units to more closely match natural rainfall characteristics. In particular, Kleijn extended many of the empirical studies of drop forming characteristics by relating flow rate of drop formers to drop size parameters. In addition, Kleijn (1979) used a cam and slotted disk mechanism to simulate non-repetitious movement and improve the uniformity of application. Walker et al (1977) achieved 95% of the terminal velocity and comparable energy characteristics by constructing a tower of 12.3 m in a laboratory.

In general the limiting factors in utilizing drop forming simulators has been achieving terminal velocities and uniformity of application. As a result, researchers have more commonly used sprinkling-type infiltrometers.

A.1.2 Sprinkling type infiltrometers

An early sprinkling-type infiltrometer using a full cone commercial nozzle was developed by Castel (1956). Bertrand and Parr constructed the Purdue-type sprinkling infiltrometer in 1961. Dixon and Peterson modified this unit in 1964 and 1968 while Amerman (1970) made further improvements in 1970. Anderson et al (1968) utilized the basic design of Bertrand and Parr (1961) to apply precipitation to a 35.7m^2 area which is considerably larger than the 1.35m^2 plot area of Bertrand and Parr. Turner and Langford (1969) determined that the most important factors influencing drop size were:

- nozzle type,
- position in the area wetted,
- operating pressure, and
- height of the nozzle above the test surface

TABLE A.1

Simulator	Plot Area m^2	Drop Diameter mm	Height of Drop Fall m	Drop Velocity m/s	KJ per Unit Volume J/ha-cm
Meeuwig	0.34	3.00	0.42.5	3.1 x 10^5	
Adams	0.067	5.56	1.04.3	9.2 x 10^5	
McQueen	0.067	5.61	1.55.2	1.4 x 10^6	
Type-F	7.4	nozzle	pressure	variable	1.5 x 10^6
Blackburn	0.84	3.00	2.15.5	1.5 x 10^6	
Sprinkling	1.48	nozzle	pressure	variable	1.6 x 10^6
Tahos Basin	0.37	3.20	2.55.9	1.7 x 10^6	
Rainulator	16.7	nozzle	pressure	variable	6.2 x 10^6

(after Munn and Huntington, 1976)

Utilizing this criteria they determined that the Meyer and McCune (1958) simulator using a Veejet 80100 (Spraying Systems) nozzle open downwards at a pressure of six p.s.i. from a height of 2.4m gave the most acceptable drop size and velocity spectra and uniformity of application. Turner and Langford (1969) also postulated that if actual discharge rates were too high that the spray period should be changed and not the discharge.

Shriner et al (1977) designed an infiltrometer which could supply intensities of 0.5 to 2.7 cm/hr, a drop size of 0.1-3.2 mm and the system was completely programmable. Zegelin and White (1982) utilized an electronically pulsing solenoid valve between a pressurized water supply and the nozzle to simulate natural rainfall of varying intensity. They used full jet nozzles (Spraying Systems) with a wide angle full cone spray pattern. Foster et al (1982) used simultaneously oscillating nozzles with intermittent pulse sprays to achieve variable precipitation intensity. As with Turner and Langford (1969) and Zegelin and White (1982), Foster et al (1982) point out the importance of changing application time to achieve intensity levels rather than change flow/pressure relationships at the nozzle. However, Sloneker and Moldenhauer have pointed out that the energy to initiate runoff eventually increases as the nozzle off time becomes larger. Like Meyer and McCune (1958), Foster et al (1982) used a Veejet 80100 nozzle with impact velocity nearly equal to the velocity from natural raindrops when the nozzle was placed 2.4 m above the soil surface. The drops produced by the Foster et al (1982) unit were slightly smaller than natural raindrops with kinetic energy about 75% of natural precipitation.

Pulses of spray were generated and controlled by an industrial process controller programmed specifically for the drop size, velocity and intensity characteristics required for each run.

In summary, there appears to be many advantages of sprinkling type infiltrometers over the drop forming type:

- the availability of numerous nozzle types from commercial suppliers
- pressure and flow regulation for specific nozzles offer unlimited droplet size, velocity profiles, and intensity ranges
- since all systems are pressurized, the fall height required to achieve near terminal velocities is less than the drop forming units
- for certain nozzles the uniformity of application is much better than drop forming units.

A.2 THE PURDUE-WISCONSIN TYPE SPRINKLING INFILTROMETER

The availability of a Purdue-Wisconsin-type sprinkling infiltrometer was fortunate for a number of reasons.

- based on the preceding literature review it was concluded that the sprinkling infiltrometer had several advantages over the drop forming units
- the Purdue-type infiltrometer developed by Bertrand and Parr (1961) was the culmination of an extensive literature review and experimentation with various nozzle types and pressure/flow regulation
- several investigators had used the Purdue type infiltrometer inspiring modifications and improvements, particularly those changes accomplished by Dixon and Peterson at the University of Wisconsin
- rainfall and energy characteristics of nozzles used with the Purdue-type infiltrometer have been reported by other investigators.

A.2.1 Development and Modifications

Bertrand and Parr (1961) tested 24 different nozzles for drop size and drop distribution at various combinations of pressure and height. Of the 24, six nozzles met the criteria for distribution uniformity and intensity. These nozzles were then tested further for drop size distribution, drop velocity and kinetic energy. These tests resulted in the selection of three nozzles which were full-cone, medium angle, center-jet type nozzles. When operated at the indicated pressure and height they provided the following levels of intensity (Table A.2):

Table A.2

Nozzle	Height (m)	Pressure (psi)	Intensity (cm/hr)
5B	2.7	6	6.4
5D	2.7	9	8.3
7LA	2.7	6	11.4

Dixon and Peterson (1964) made several modifications to the infiltrometer developed by Bertrand and Parr (1961) including changes in the pumping unit, nozzle pressure control system, runoff collection system, runoff measuring system, tower and cover, and spray nozzle assembly. Later Dixon and Peterson (1968) designed a vacuum runoff collection system which eliminated much of the excavation required for field operation. Amerman et al (1970) designed a rotating disk to achieve variable intensities for a given nozzle without changing drop size and velocity profiles.

A.2.2 Possible Modifications of the Purdue-Wisconsin Simulator

An improved system for regulating pressure and intermittent operating times is important. The addition of a timer and electronically pulsing solenoid valve as described by Zegelin and White (1982) should be investigated. The addition of a rotating disk first described by Amerman et al (1970) and later by Rawitz et al (1972) and Grieson and Oades (1977) would increase control options. The modifications of the water distribution system, nozzle mounting procedure, and external sensing of vacuum collected runoff described by Rawitz et al (1972) should also be evaluated. Finally the programming controls designed by Foster et al (1982) and data handling system developed by Chow and Ten (1974) would likely improve the operating efficiency of the system and data management.

The canopy-runoff collection system should be streamlined. The canopy frame should be constructed of light weight aluminum and the canvas material replaced by nylon. The frame should be collapsible and supported from the supply wagon rather than self supporting. Similarly the runoff collection system should be mounted on the supply wagon to eliminate the very difficult and tedious set up.

The supply wagon should be equipped with wide track tires and the recirculation system improved to capture all precipitation except that directly falling on the plot and a narrow border area. The weight of the supply wagon should be used to hydraulically press the plot frames into the soil at the desired location.

The data recording system should be upgraded to collect flow data, on-line analysis of suspended solids, pH and selected ions. All data including flow weighted concentrations and loading calculations should be recorded on discs for later analysis or modelling purposes.

Overall, the PWSI unit should be modified to allow one-person operation with the capability of 15-20 runs per day. Finally, the unit could incorporate equipment to collect groundwater samples under a plot area which is under simulated rainfall or ponding conditions.

APPENDIX B

PWSI OPERATING CHARACTERISTICS AND PROCEDURES

This appendix lists the components and operating characteristics of the Purdue-Wisconsin Sprinkling Infiltrometer (PWSI) unit used in all laboratory and field evaluations:

PWSI Components --

The principle component in the PWSI unit is the nozzle. The criteria used in evaluating a nozzles performance include:

- uniform drop distribution over the plot area
- drop velocity approaching terminal velocity
- total energy values similar to natural rainfall

The 7LA nozzles used in all laboratory and field runs indicated a small coefficient of variation (4.04%) and total kinetic energy dissipated at the soil surface was similar to natural rainfall. The distribution of droplet size is given in Table B.1. The concentration of droplets in the 1.5-3.0 mm range is consistent with sizes expected from natural rainfall.

TABLE B.1

DISTRIBUTION OF DROPLET SIZES FOR 7LA NOZZLE

SIZE RANGE (mm)	PERCENT
> 3.32	1.0
3.326 - 2.744	5.1
2.793 - 2.362	6.7
2.361 - 1.651	19.3
1.650 - 1.410	10.3
1.409 - 1.168	8.3
1.167 - 0.833	13.9
.832 - 0.147	20.1
< 0.146	14.8

Other operating characteristics of the 7LA nozzle include:

- total Area of Application - 3.32 m radius centered below the plumb line of the nozzle
- intensity vs. pressure - Figure B.1 indicates total flow volume at various nozzle pressures.

The 12 gauge galvanized plot frames cover a total area of 1.35 mm^2. An angle iron driving frame is used to drive the frames 3-5 cm into the soil. A collection T made of 1.25

cm perforated copper tubing and 2.0 cm rubber hose was used to collect runoff and direct it through the rubber hose to the runoff collection tank.

The runoff collection system was designed and constructed by Dixon and Peterson (1964, 1968) and essentially replaced the system constructed by Bertrand and Parr (1962). The collection tank consisted of a 302L steel pressure tank equipped with a Belfort FN1 portable level recorder (12-hour chart). The vacuum in the tank is driven by a single cylinder, single stage air compressor which is powered by the 3.5 Briggs and Stratton engine.

The telescoping aluminum tower is constructed of 2.54 cm and 3.18 cm pipe. The telescoping legs are adjusted to the desired height with friction valve collars. The canvas cover is cut specifically in the shape of a truncated pyramid to minimize wind effects during operation.

The water supply and reticulation system provides a gravity feed from the supply tanks to a 3.8 cm centrifugal pump which directs the flow to a 7.6L pressure tank which, in turn, directs flow through a rubber hose and the 7LA nozzle. Monitoring of line pressures and the pressure at the nozzle head is provided through farm pressure gauges.

Operating Procedures --

The procedure involved for one run (one trough) is described below:

- trough is transported from storage to weighing station using a dolly
- weight recorded prior to rainfall simulation run
- trough is transported from weighing station to rainfall simulation area
- using steel blocks under flange, trough is placed at a 2% slope
- height of 7LA nozzle is adjusted so that nozzle tip is 2.74 m above soil surface of trough
- plumb line is used to check that nozzle is directly above trough center
- height and plumb procedures are repeated until proper alignment is achieved
- sheet metal lid is placed over trough
- 590 mL Malgene subsurface sample bottle is placed in sheet metal support hook and connected to trough drainage tube
- engine and pump are started
- supply valve is turned on
- pressure at nozzle head is adjusted to six p.s.i.
- lid is removed from trough
- plastic raingauges are introduced next to trough
- runoff collection tank is checked to be sure vacuum pressure is increasing

A summary of operating systems constants are provided in Table B.2.

TABLE B.2
PWSI OPERATING SYSTEMS CONSTANTS

SYSTEM COMPONENT	CONSTANT
Lab Trough Area	$0.186 m^2$
Field Plot Area	$1.35\ m^2$
Application Area	$8.04\ m^2$
Precip/Tank Ratio	0.18/1.0 unit
Operating Suction	60-90 mm Hg
Line Pressure	2-10 psi
Nozzle Set	6 psi, 9' above plot
Water Supply	3780L.
Chart Conversion, Flow,	(ΔY) 3.029 L
, Time	(ΔX) 5.0 = time
Coefficient of Variation of Application	4.04%
Field Plot Conversion to Acres	30,000
Aluminum Tower	base 12'x12', top 8'x8'

* U.S. G.P.O.:1991-281-724:43567

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15. SUPPLEMENTARY NOTES

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16. ABSTRACT

A sprinkling infiltrometer was used to evaluate total phosphorus (TP) and total soluble phosphorus (TSP) losses in surface runoff from plots receiving manure application rates of 22-135 MT/ha and from plots where manure had been incorporated to depths varying from 0-20 cm. Both laboratory and field trials were conducted utilizing simulated precipitation. Infiltrometer runs were repeated for various drying conditions of the soil manure mixture at time intervals varying from 1-30 days.

Significantly higher TP and TSP loads in surface runoff were associated with surface applications of manure immediately followed by a precipitation event. For the standard 12-cm, 60-minute event, TP and TSP loads were as high as 13.4 and 7.7 kg/ha, respectively. These loads were 20-25 times greater that observed TP, TSP loads from control plots. Typically, the high loading rates were short-lived with the positive effects of manure amendments on infiltration, moisture retention and phosphorus sorption being observed after drying periods of 5-25 days. Generally, after several wet-dry cycles TP, TSP loads approached control levels.

The sprinkling infiltrometer provides the basis for a promising method of on-site evaluation of tillage-manure systems. The versatility of such an instrument in a laboratory and field setting is advantageous. Tillage-manure systems and other phosphorus control measures can be accurately compared using such techniques. Lastly, the accumulation of a data bank from infiltrometer runs provides a basis for more comprehensive comparisons of tillage-manure phosphorus control options.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTIONS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field Group
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