

STORMWATER-BORNE POLLUTANT EXPORT FROM TURFGRASS
ESTABLISHED ON SOILS AMENDED WITH COMPOSTED DOMESTIC
WASTEWATER SLUDGES

by

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(ABSTRACT)

The differences in pollutant export from identical land areas treated with fertilizer and/or composted domestic wastewater sludge (compost) were evaluated. Three plots were constructed with a Glenelg silty clay soil and seeded with Falcon fescue (Festuca 'Falcon'): Plot 1 received conventional fertilizer; Plot 2 received a combination of compost and reduced conventional fertilizer; and Plot 3 received only compost. Runoff was collected and analyzed for soluble orthophosphate as P, total soluble phosphorus as P, total phosphorus as P, soluble ammonia as N, soluble Kjeldahl nitrogen as N, total Kjeldahl nitrogen as N, nitrite plus nitrate as N, total suspended solids, chemical

oxygen demand, cadmium, copper, lead, nickel, zinc, chromium, and iron. Compost was found to improve moisture retention in the soil and crop, sustain plant growth during excessive dry periods, improve the quality of the crop, reduce runoff, and reduce soil erosion. The export of all pollutants was reduced by the use of compost. The use of fertilizer in combination with the compost did not provide any observable benefit. Instead, the fertilizer provided excessive soluble orthophosphate, total soluble phosphorus, and oxidized nitrogen which were subsequently exported from the test plot. The increased export of soluble Kjeldahl nitrogen may have been caused by excess insoluble N from the fertilizer application, which may have reacted with the organic matter, forming soluble organic nitrogen. The use of compost as a soil amendment significantly reduced the pollutant export which, in turn, reduced the potential impact on receiving waters.

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I. Introduction

The management and disposal of sewage sludge is a primary environmental problem. An estimated 8.6 million dry metric tons of sewage sludge are produced annually (Feliciano, 1982) in the U.S. Sludge production increases as the population increases. In addition, technology has improved in the wastewater industry such that better pollutant removals are possible, which subsequently leads to higher sludge production. Sludge incineration, burial, and ocean dumping are rapidly losing their appeal:

- (a) Incineration is expensive and has potential adverse impact on air quality from stack emissions;
- (b) Landfilling sludge is expensive due to the high land costs and has potential adverse impact to groundwater from leachate and to surface water from runoff;
- (c) Ocean disposal, which is economical for coastal areas only, is publically unpopular due to the potential health risks and is usually a political and legal issue.

Generally, all sludge management and disposal facilities are difficult to site due to negative public opinion of sewage sludge. However, composting facilities are beginning to gain favor with wastewater professionals, politicians, and the public. This has occurred as research, pilot studies, and full-scale operating compost facilities have shown that composting can yield a stable, odor-free, and relatively pathogen-free product. Land application of digested, stabilized sewage sludge is also popular in this

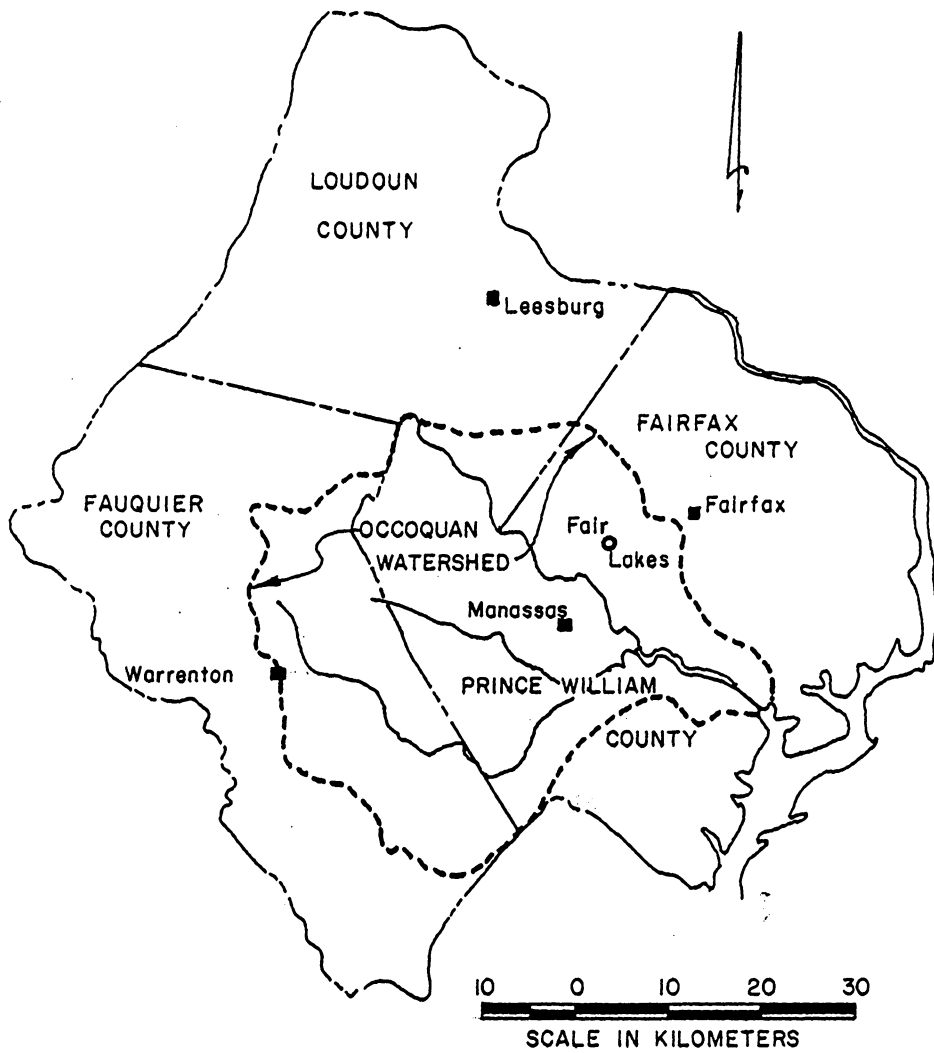
country (Feliciano, 1982). In fact, land application, including composting, is the most widely practiced sludge management method in the U.S. (Feliciano, 1982; Goldstein, 1985). The trend in recent years to view sewage sludge as a resource rather than a disposal problem is reinforced as agricultural application of sewage sludge is proving to be cost effective, energy saving, productive in terms of crop yield, and beneficial to the soil (Pierce, 1984).

Perhaps the most widely reported research in sludge management methods during the 1970's was performed by the United States Agriculture Department (USDA) in Beltsville, Maryland. It was here that the Beltsville Aerated Pile Method was developed in cooperation with the United States Environmental Protection Agency (EPA) and the Maryland Environmental Service (Willson et al., 1980). In this method, undigested sewage sludge is mixed with wood chips into a pile with a triangular cross section, 15 feet wide by 7.5 feet high, and is then aerated. As the organic material is decomposed by thermophilic, aerobic microorganisms, the compost pile is heated to pasteurizing temperatures (55-70 C) destroying the enteric pathogens found in the sewage sludge (Hornick et al, 1979). After 21 days, the piles are dried, screened and cured for 30 days. The resulting product is a humus-like material that can be used as a soil conditioner and fertilizer, is essentially odorless and free

of enteric pathogens. Compost has been shown to improve the physical properties of soil resulting in higher crop yields.

Compost has long been recognized for enhancing lawns and gardens. When used as a soil amendment and mixed with existing soil, it improves aeration, water retention, and soil structure (Gouin, 1982; Hornick et al., 1979). Additionally, it naturally provides nutrients that plants require for growth and maintenance, with the benefit of slow mineralization. Unlike conventional fertilizers, compost releases these nutrients slowly, making them available for plant growth over a relatively long time period (Hornick et al., 1979). When available for sale, compost produced from municipal wastewater sludge is usually affordably priced in comparison to top soil, peat moss, and fertilizer.

For these reasons, a local developer in Fairfax County, Virginia, submitted an application to the State Health Department to use wastewater sludge compost, produced at the Upper Occoquan Sewage Authority (UOSA), as a soil amendment for turfgrass establishment in a large new development, Fair Lakes, on the site shown in Figure 1. This request was approved with the proviso that public access to the development be restricted for a minimum of sixty days following application. The application was then sent to the Virginia State Water Control Board (SWCB) which approved the request with the same condition. After given the



LOCATION OF FAIR LAKES WITHIN THE
OCCOQUAN WATERSHED

FIGURE 1

opportunity to comment, Fairfax County officials expressed serious concern over the unchecked application of compost in the subject area (Fairfax County staff records, March 25, 1985). This concern arose because the Occoquan Reservoir, the receiving body for the watershed, is a primary drinking water source for over 850,000 customers in the Northern Virginia suburbs (Warfield, 1987).

The Occoquan Reservoir was formed by a dam constructed at the mouth of the drainage basin in 1957, and was plagued by cultural eutrophication in the 1960's (Randall et al., 1978). An extensive study performed by Metcalf & Eddy Engineers (1969) determined that the reservoir water quality was endangered by eleven secondary treatment plant point sources discharging into its tributaries. The SWCB issued a policy for protection of the Occoquan Reservoir in 1971 (SWCB, 1971). Subsequently, the Upper Occoquan Sewage Authority (UOSA) wastewater treatment facility was constructed as a regional advanced wastewater treatment plant which replaced the secondary treatment plants in 1978. In addition, the policy also established the Occoquan Watershed Monitoring Program which maintains records of water quality in the Reservoir.

Though the UOSA plant alleviated point source pollution of the reservoir, nonpoint sources continued to adversely impact water quality. Following start-up of UOSA,

researchers concluded that, primarily due to increased urbanization in the watershed, point sources have had a much reduced effect on the water quality as compared to the nonpoint sources. Randall et al.(1978) found that 85.2% of the total nitrogen and 89.5% of the total phosphorus entering the reservoir could be attributed to loads generated and transported by stormwater runoff.

The Fairfax County Board of Supervisors (BOS) limited development in the Occoquan Reservoir based on the SWCB Occoquan Policy (SWCB, 1971). The BOS requires that any uses and land use activities within the watershed cannot further degrade the water quality of the reservoir. Because of the unknown water quality impact of stormwater runoff from the compost-amended areas of Fair Lakes, the County requested that compost be applied to only a small portion of the development. Further, a strict monitoring program was to be implemented to determine whether compost application had any detrimental affect on water quality in the watershed (Fairfax County staff records, March 25, 1985).

The developer agreed to fund the monitoring program for one year. The Occoquan Watershed Monitoring Laboratory (OWML), a Virginia Tech facility located in Manassas, Virginia, was selected to implement the monitoring program and perform the chemical analyses.

The monitoring program, as originally proposed, was to

consist of grab samples of stormwater runoff from the treated areas in Fair Lakes during a minimum of twelve storm events. Likewise, runoff samples were to be taken from areas treated with conventional fertilizer so that a fair comparison of pollutant export could be made. However, a field visit revealed that the two areas were not sufficiently similar to make a realistic comparison of the runoff. Further, it was determined that samples taken from the composted areas would likely be contaminated from other pollutant sources during a runoff event. This was due to the fact that the composted areas drained into curb inlets which also received runoff from the road surface. In contrast, the conventionally fertilized areas, graded as swales, drained into yard inlets through a grate and received insignificant runoff from other sources.

In order to collect runoff samples representing only the compost or fertilizer effects, it became necessary to create a situation where the site runoff was characteristic of a specific treatment. Three plots were constructed, each using Glenelg soil imported from Fair Lakes and treated with identical application rates of materials as those used in the control and test areas in the Fair Lakes development. When possible, the entire runoff from each plot was to be measured, and a representative sample collected for analyses by OWML.

The primary purpose of this project was to determine whether domestic wastewater sludge compost can be safely used as a soil amendment in a protected watershed without detriment to receiving water quality. Towards this purpose, a comparison was made of the runoff from identical land areas treated with (1) conventional fertilizer, (2) conventional fertilizer and compost, and (3) compost. Falcon fescue (Festuca 'Falcon') was grown in three test plots treated accordingly. Of particular interest were the concentration and loadings of nutrients, suspended solids, chemical oxygen demand, and trace metals. Soil productivity and the quality of the fescue crop were also evaluated.

II. Review of the Literature

Background

As early as the late nineteenth century, the need to control flooding and to protect navigable river basins from the damaging effects of storm water was recognized. Subsequently, Federal laws were enacted to establish projects for flood control, wetland management, and land-use of floodplain areas (Novotny and Chesters, 1981). The primary focus of storm water management during the 1930's was on the protection of large river basins from flooding and erosion, and the reduction of drastic soil losses from the current agricultural practices of that time. The U.S. Army Corps of Engineers and the U.S. Soil Conservation Service were the lead agencies assigned to these tasks, respectively (Novotny and Chesters, 1981). It was not until the late 1960's that other deleterious effects of storm water became evident and the severity realized: nonpoint pollution problems had developed into a serious threat to the nation's water resources. Problems were not limited to runoff from rural areas (i.e., farmland and floodplains). Runoff from urban areas was additionally recognized as a considerable source of pollutants.

The Federal Water Pollution Control Act (PL 92-500) of 1972 and its 1977 amendment was the first water pollution

control law to recognize the problem of nonpoint pollution and the need to develop abatement methods (Novotny and Chesters, 1981). Research to study sources of nonpoint pollution began under Section 208 of PL 92-500. After reviewing the results of ninety-three nonpoint research projects , the Environmental Protection Agency (EPA) did not find sufficient information to provide an understanding of the pollution aspects of urban runoff (USEPA, 1983a). A nationwide study, the Nationwide Urban Runoff Program (NURP) was therefore undertaken to characterize the pollutants in urban runoff and to assess the receiving water quality effects and the effectiveness of control measures to reduce pollutant loads from nonpoint urban runoff (USEPA, 1983a).

There are six main problems caused by rural and urban nonpoint pollution (Novotny and Chesters, 1983):

(1) Sediment is the most widespread pollutant from nonpoint sources. It reduces light penetration, causes turbidity, and clogs up waterways and reduces the useful life of reservoirs. The aquatic environment in the water body is altered and harmed by excessive sediment in the water column and bottom.

2) Dissolved oxygen in the receiving water body may be reduced due to the degradation of oxygen-demanding materials delivered by nonpoint runoff from various sources including animal feedlots, urban storm sewers, and combined sewer

systems. In addition, high volumes of storm water may resuspend bottom sediments. This may, in turn, increase the oxygen demand in the water body. Fish and other wildlife depend on healthy dissolved oxygen concentrations in the water for their survival.

(3) Nutrients, particularly nitrogen (N) and phosphorus (P), delivered by nonpoint runoff cause eutrophication of surface waters. Here, the production of organic matter, usually excessive growths of algae and aquatic weeds, is promoted by the high levels of nitrogen and phosphorus. Impounded waters, such as lakes and reservoirs, are especially affected. Although other nutrients are found in nonpoint runoff, nitrogen and phosphorus are of major concern. They are considered the limiting nutrients controlling algae and aquatic plant growth. Concentration levels in excess of 0.3 mg/l N and 0.01 mg/l P are considered sufficient to stimulate algal growth (Sawyer, 1952).

(4) Trace metals in various concentrations are toxic to the aquatic life in the receiving water. The man-induced mobilization is higher than the natural rate for the following metals (Novotny et al., 1983): Ag, Cd, Cu, Hg, Ni, Pb, Sb, Sn, Zn. Trace metals are found in atmospheric fallout as well as from industrial and other urban sources.

(5) Organic chemicals, such as DDT and PCB's, reach the receiving waters by runoff and are particularly troublesome due to the potential for biomagnification. Here, lower trophic level organisms may acquire a low, even undetectable concentration of an organic chemical. But as the food web progresses upward to the higher trophic level organisms, the concentrations found may be several orders of magnitude higher. The ultimate effects of biomagnification may include fish kills and poisoning to humans who may ingest contaminated fish.

(6) The pH of the receiving waters may be altered by nonpoint pollution resulting in fish kills and changes in other aquatic life. For example, ammonia toxicity occurs at high pH values, where the nonionized ammonia species is dominant.

Runoff and Rainfall

The NURP study characterized urban runoff based on sampling more than 2300 separate storm events at 81 different sites in 22 different cities. The study found that the land use category (residential, mixed, commercial, open/non-urban) did not have a significant influence on site concentrations for the various constituents. Table 1 presents the mean concentration of each listed constituent averaged over the four land use categories (USEPA, 1983a),

Table 1 Mean Pollutant Concentrations
in Stormwater Runoff

<u>Constituent</u>	<u>Site Mean Concentration</u> (mg/l)	
	NURP (USEPA, 1983a)	Weibel (1969)
TSS	180	227
BOD	12	17
COD	82	111
TP	0.42	0.36
TSP	0.15	*
TKN	1.90	2.1
OXN**	0.86	1.0
Cu	0.043	*
Pb	0.182	*
Zn	0.202	*

* Not reported in Weibel study.

** Oxidized nitrogen (nitrite plus nitrate as N).

and also presents the results of similar work done in Cincinnati for an urban, mixed residential-light commercial area (Weibel, 1969).

These values are in agreement with those found by Czekalski and Kocialkowski (1963) for TP, 0.11-0.53 mg/l, but are higher than those found for Cu, 0.8-6.5 ug/l and Zn, 5.5-30 ug/l. It should be noted that these values exceed the discharge concentrations of most advanced wastewater treatment facilities. The NURP study also concluded that nutrients in urban runoff may accelerate the eutrophication problem and severely limit recreational uses, especially in lakes.

The effects of runoff on any receiving water body depend on site specific characteristics, such as:

- (a) the type, size, and hydrology of the water body;
- (b) its designated use which identifies the specific pollutants of interest;
- (c) the pollutant characteristics of the runoff; and
- (d) the amount of runoff determined by the amount and frequency of rain and land use (USEPA, 1983a).

Runoff occurs from a rainfall event whenever the volume of water exceeds the amount that can be absorbed by the soil. Rain alone has constituents of interest, especially when considering a reservoir as the receiving water body. Table 2 presents the average concentrations of various pollutants found in rain in the Washington, D.C. Metropolitan area (NVPDC, 1983), which includes monitored sites in Fairfax County. Column (2) represents the rain

Table 2: Mean Pollutant Concentration in Rain

Constituent	(1) Rain Weighted Average Concentration (mg/L)	(2) Percent of Runoff Concentration
COD	9.1	11%
TP	0.02	5%
TKN	0.5	26%
OXN	0.5	58%
Cu	27	63%
Pb	116	64%
Zn	95	47%

Note:

Column (1) data are volume weighted average concentrations from rain monitored in the Washington, D.C. Metropolitan area for the NURP; results taken from NVPDC, 1983.

Column (2) represents the rain contribution of each constituent as a percentage of the concentration found in stormwater runoff, as reported in NURP (USEPA, 1983a).

concentrations cited in column (1) as a percentage of typical stormwater runoff concentrations as reported in NURP (USEPA, 1983a). It may be seen that, in addition to its erosion, dissolution and transport capabilities, rain may be a significant contributor to the supply of nutrients in runoff. Biggar and Corey (1969) note that these amounts are not enough to significantly improve crop yield. The constituents found in rain would not contribute in their entirety to the constituent runoff concentrations, unless the runoff was from a completely impervious surface. Normally, rain mixes with and/or infiltrates soil. The constituents in surface runoff from soil, grassed or cropped, depend on a variety of parameters, including the soil and vegetation types.

Suspended matter, expressed as total suspended solids (TSS), in runoff is caused primarily by the energy of impact of the rain on the aggregates of soil particles at exposed soil surfaces. The TSS affects the nutrient status of the runoff water, as organic nitrogen and both organic and inorganic phosphorus are carried with suspended solids in runoff. The soluble nitrogen and phosphorus concentrations in runoff could be decreased if they were sorbed from the runoff onto the suspended matter (Biggar and Corey, 1969). Other pollutants including organic matter and trace metals may be carried in sediment from runoff (Novotny and

Chesters, 1981).

Fertilizer versus Compost

The intent of this study was to determine whether sewage sludge compost could be used in a protected watershed as a fertilizer and soil amendment without detrimental effects to receiving water quality. The focus of the literature review is to determine the type and quantities of constituents found in compost and fertilizer, and the subsequent amounts available for release to runoff waters. Of primary concern are nitrogen, phosphorus, trace metals, chemical oxygen demand, and suspended solids. The crop used in this study was falcon fescue (Festuca 'Falcon'), and the soil was a Glenelg silty clay.

The use of fertilizers has been documented widely in the literature as a source of nutrients in stormwater runoff (Correll, 1983). Rising fertilizer prices, fewer raw materials, and the desire to restore and maintain environmental quality are a few of the factors influencing the consideration and use of organic wastes such as sewage sludge compost (compost) as a fertilizer substitute (Barbarika, et al., 1980) Research has shown that compost applied at equivalent fertilizer N rates produces higher crop yields and decreased soil erosion (Barbarika et al, 1980; Parr et al., 1978). The quality of the crop is also

often improved when using sludge instead of commercial inorganic fertilizer, as reported by Utschig et al.(1986). In this study, winter wheat was grown using sludge to supply nitrogen requirments had consistent significantly higher protein content than that grown with inorganic fertilizer. This increased protein content made the crop more profitable at market. Hornick, et al.(1983) stated that changes in the soil physical properties due to the addition of compost also decreased the loss of nutrients by runoff. Research performed by Parr et al.(1978) confirmed that compost-amended soils had a greater water storage capacity for plant growth. In heavy-textured soils (such as the silty clay used in this project) Parr et al.(1978) reported that compost amendment minimized surface runoff. In experiments with sewage sludge compost mixed with three different soil types, Taylor et al.(1978) also demonstrated the increased water holding capacity of compost-amended soils and additionally reported increased pH values. The sludge used in the compost process was undigested and lime-stabilized which largely accounted for the pH increase. Because plants cannot absorb nutrients from a dry zone (Tisdale and Nelson, 1975), soils amended with compost can provide water for plant growth long after fertilized soil has lost all moisture during extended dry periods. Epstein et al.(1976) concluded that improved

water retention and increased water content in compost-amended soils could reduce water stress in plants during the growing season. Water is required by all plants for the manufacture of carbohydrates, the hydration of protoplasm, and the translocation of foods and minerals within the plant. In a study reported by Tisdale and Nelson (1975), fescue yield and nutrient uptake were found to be directly related to the amount of soil moisture.

The improvements over fertilizer application alone are due primarily to the following physical improvements in compost-amended soil: increased water content and retention, enhanced aggregation, increased soil aeration and permeability, increased water infiltration, and decreased surface crusting and bulk density (especially for clay soils) (Hornick et al, 1980; Hornick, 1980; Epstein et al., 1976, Parr et al., 1978).

In comparison to fertilizer, compost has shown greater potential in improving marginal soil and producing greater crop yields. These effects were evident even when multiple annual applications of fertilizer were compared to a single compost application (Tester, 1982; Barbarika, 1980).

Additionally, compost application has been shown to suppress certain soil-borne diseases (Lumsden, et al., 1981). In greenhouse applications, compost proved superior to peat-based products because it provided substantial

amounts of plant nutrients and eliminated a possible source of infection from plant pathogens often found in peat (Sterrett and Chaney, 1982).

In research performed specifically on turfgrasses in marginal soils, better quality turfgrass was grown in compost-amended soils than in soils treated with conventional mineral fertilizers (Murray, 1978; Murray et al., 1980; Duell, 1982). Patterson et al. (1981) found that where traditional expensive top soil and fertilizer would have been required for turfgrass establishment and maintenance, compost applied in sufficient amounts significantly improved the marginal site. Seedling establishment is more rapid in compost-amended soil (Murray, 1978; Duell, 1980).

For turfgrasses, the nitrogen content and its mineralization rate are the most important factors in production. The goal of turfgrass production is not to produce the most vegetation, but instead to produce a healthy, uniform grass (Hornick et al., 1983). For establishment, 99 metric tons/hectare (45 tons/acre) to 298 metric tons/hectare (134 tons/acre) should be incorporated into the top 10-15 cm of the soil. The low end of the range applies to fertile soils; the high value applies to sandy or subsoils. This rate assumes a compost with 40% moisture, 1.5% total nitrogen, and 1.5% total phosphorus. At these

rates, sufficient nitrogen and phosphorus will be available for turfgrass establishment. Potassium addition may be required depending on the soil content. These rates were calculated assuming that only 10% of the total nitrogen content of the compost was available during the first year after application (Hornick et al., 1983). Tester et al. (1977) demonstrated in incubation studies that the inorganic N fraction, most of which is in the ammonium form, is rapidly immobilized into the organic N form because of high carbon-to-nitrogen (C:N) ratios that occur in compost-amended soils. Therefore, inorganic N content is not used to determine the amount of available N for crop establishment. Willson et al. (1980) found the inorganic N was immediately available to the plant and its fraction was accounted for in the 10% mineralization rate prediction.

The interesting benefit of using compost as a fertilizer source is that one application provides a nitrogen source for the next several years. The N mineralization rates are estimated to be 10% total N for the first year, 5% of the remaining N for years two through five, and 2% of the remaining N for years thereafter. The availability of P in successive years has not been determined to date (Hornick et al., 1983). If applying large quantities of compost is too cumbersome, which may be the case for farm crop production, the compost may be applied at

the recommended establishment rate for the first year N supply only, then supplemented later. According to Hornick et al., for higher quality turfgrass, compost should be applied to supply only half of the nitrogen requirement. Later, a water soluble N source should be added to provide the other half, producing good color in the late spring and early summer (Hornick et al., 1983).

The greatest potential for compost in the turfgrass industry, according to Hornick et al.(1983), is in the production of sod. Little to no additional fertilizer or insecticide is required when compost is used for sod production. As noted previously, however, additional potassium may be required. Compost-grown sod will need to be mowed more frequently, but the trade-off is that it may be harvested sooner. Additionally, compost-grown sod weighs 30-40% less than sod grown with conventional fertilizer, resulting in lower transportation costs. Parr et al. (1978) demonstrated the benefits of compost used as a top soil and fertilizer substitute. The researchers reported better quality plants and grasses with more extensive root systems, lower mortality when transplanted, earlier marketability than those grown in fertilizer. Several sources agree that compost is an excellent fertilizer and soil conditioner that should be used for public grounds, golf courses, parks, and other recreational land areas (Parr

et al., 1978; Hornick et al., 1979; Barbarika et al., 1980). Research by the USDA has shown that compost may be used to significantly aid the revegetation and reclamation of disturbed land (surface mined, topsoil removed, etc.). In a relatively short time period (3-5 years), the land treated with compost may be restored to a high level of productivity (Hornick, 1982).

The cost of using compost in plant production is not simply derived from the amount of N, P, and K available in the compost; only approximately 10% of the total N is available for the first year, as the remainder is organically bound (Barbarika et al., 1980). Further, the improvements to the soil physical properties due to compost amendment are not considered in this type of cost comparison. A grower may receive substantial economic benefit from compost-grown crops, for the following reasons:

- (a) the increase in profit due to increased prices from improved plant quality;
- (b) the increase in the amount of crop for sale due to higher yields; and
- (c) the decrease in the amount of other material and labor inputs such as adding top soil or peat or other organic supplement as would be necessary for marginal soils (Hornick et al., 1983).

Other constituents in compost, such as micronutrients (trace metals), also add a value to the use of compost. This was most dramatically confirmed by Sikora et al. (1980) who showed that benefits resulted from the combination of compost with a commercial fertilizer due to

the compost's other constituents and properties.

A reduction in profitability could result from using a compost that contained high levels of soluble salts, toxic metals, or had a high C:N ratio (Hornick et al., 1983). The C:N ratio may be controlled somewhat by selection and screening of the bulking agent used in compost production. Some composts may increase the salinity and chloride levels in the soil which may affect salt-sensitive plants (Epstein et al., 1976). Some identified potential problems are discussed at length in sections to follow.

Pathogens in Compost

Domestic wastewater sludges normally contain fecal coliforms and pathogens which may cause illness or disease to consumers of crops that may be grown in land-applied sludges. Compost, unlike sludge, can be effectively pathogen-free. The pathogen of most concern is Salmonella, because it can sustain growth outside of its host. Other organisms, however, can also be found in sludge. However, the standards for producing compost to be released to the public require the compost piles to be sustained at temperatures above 140°F which effectively destroys pathogenic organisms (Willson et al., 1980). The Salmonella content of compost is checked by a Salmonella assay to determine whether the compost operation is operating

properly. Periodic Salmonella assays may be used to determine if pathogenic destruction is adequate.

Toxic Metals

The most serious limitation of applying municipal sewage sludge to soils concerns the amount and fate of toxic metals. These metals may accumulate in the soil, be assimilated in the crop, and enter the food chain through direct and indirect ingestion, thus increasing the dietary intake by livestock, as well as humans (Gambrell et al., 1986, Parr et al., 1978).

Domestic sludges contain heavy/toxic metals in varying concentrations, largely depending on the industrial contribution and the presence of an effective industrial pretreatment program. Some metals are found naturally in soils in significant concentrations (Novotny et al., 1983). Table 3 shows the concentrations of selected metals in dry digested sewage sludges, soil, UOSA compost, the Virginia Sewerage Regulations maximum and desired levels, and two commercially available soil conditioners. It may be noted that the composting process drastically reduces the concentration of metals found, which makes compost the preferred means of applying sludge on land where crops are to be grown. This reduction occurs due to dilution and leaching during the composting process. The metals in UOSA

Table 3: Concentrations of Selected Metals in Sludge, Soil, and Compost

Element	Units	Typical Median Sludge (1)	Typical Median Sludge (2)	Typical Soil (2)	VA Sewerage Regulations Maximum (3)	VA Sewerage Regulations Desired (3)	UOSA Compost Average (4)	UOSA Compost Project (5)	Espoma Holly-Tone (4)	Milorganite (4)
Cadmium	mg/kg	16	10	0.1	25	5	6.1	24.7	43	93
Copper	mg/kg	850	800	15	1000	250	320	414.5	465	560
Lead	mg/kg	500	500	25	1000	1000	140	160	250	630
Mercury	mg/kg	5	6	NA	15	2	1.4	NA	NA	NA
Nickel	mg/kg	82	80	25	200	50	30	35.5	115	113
Zinc	mg/kg	1740	1700	50	2500	750	680	557	870	1500
Chromium	mg/kg	890	500	25	No limit	No limit	140	112.3	1590	5940

(1) Sommers, 1977

(2) Chaney and Giordano, 1977; Chaney, 1982

(3) VA Sewerage Regs, 1977

(4) UOSA, 1983

(5) UOSA Finished Compost Analysis, Stockpile AS033, used for this project

NA = Not Available

sewage sludge compost, in particular, are well within the limits set by its regulators.

In 1979, EPA published criteria for land-application of solid wastes, which include sewage sludge compost, for the production of food-chain crops (USEPA, 1979). The criteria are summarized as follows:

- (1) soil pH must be maintained at or above 6.5 during initial application; and
- (2) annual cadmium (Cd) application rates for root crops, leafy vegetables, and tobacco grown for human consumption, as well as for other food-chain crops, must not exceed 0.5 kg/ hectare (0.45 lb/acre).

It should be noted that these criteria do not apply to turfgrass since metal toxicity to a consumer is not a potential problem as it is with food-chain crops.

Recommendations in the literature state that after the initial compost application during which the soil pH must be at or above 6.5, the pH should be maintained between 6.0 and 6.5 to preclude problems with metals toxicity in food-chain crops (Parr et al., 1978; Hornick et al., 1983). Compost-amended soil raises the pH of the soil higher than sludge or fertilizer (Chaney et al., 1978), with which lime must usually be added to adjust the pH.

A number of chemical and physical soil properties affect the availability and uptake of metals in plants. They include pH, organic matter, cation exchange capacity (CEC), and texture (amount of clay, silt, sand). In acid soils, phytotoxicity and plant availability of metals is

increased (Parr et al., 1978), confirming Chaney et al. (1978) findings that soil pH influenced metal sorption to soil constituents. In USDA research at Beltsville, heavy metals were found to be less available to plants in composted sludges than to those grown using raw or digested sludges (R.L. Chaney and E. Epstein, unpublished data, found in Parr et al., 1978). At equal pH, crops grown in soils high in organic matter have been found to accumulate less cadmium. As the amount of organic matter increases, metals are less available for plant uptake (Hornick et al., 1983). This is most significant because cadmium is the metal of greatest concern in crop production due to its ease of absorption by most crops and absence of phytotoxicity at the concentrations usually encountered.

When metals from compost are mixed into the soil, they are chelated by or adsorbed to soil constituents (i.e., organic matter, hydrous oxides of iron, aluminum, and clays) leaving only very small amounts of the added metals in the soil solution. Their availability to plants is controlled by the equilibrium process in the amended soil (Lindsay, 1979). The soil pH is inversely related to the quantity of soluble metals in the soil solution. Metals in solution are available to the plant roots for absorption (Chaney, 1981).

Cation Exchange Capacity

The CEC of a soil is an expression of the soil capacity to exchange metal cations in centimoles per kilogram of oven-dried soil. CEC is higher for soils with high clay and/or organic matter content (Tisdale and Nelson, 1975). Heavy metals are less available to plants in soils with high CEC values, because the metals become bound to abundant cation exchange sites (Parr et al., 1978). Epstein et al. (1976) found that the CEC of soils increased as much as three times when sludge or compost was added. After a two year study period, the CEC values in sludge and compost-amended soils still remained significantly higher than those of the control soils which had been fertilized conventionally. At higher CEC, Haghiri (1974) found that toxic metals were more likely to be bound and thus were less available to plants. Organic carbon was found to increase over the study period (Epstein et al, 1976), which would cause an increase in the CEC (Kononova, 1975). Listed in Table 4 are the recommended maximum allowable cumulative sludge metal loadings cited in the USDA literature as a function of the CEC for privately owned land (Parr et al., 1978), which assumes the background pH of soil is less than 6.5 .

On publically controlled land, the USDA recommends that up to five times the amounts of metals listed above may be applied if the compost is disked into the soil to a depth

Table 4 : Recommended Cumulative Maximum Allowable Sludge
Metal Loadings as a Function of CEC

Metal	Soil Cation Exchange Capacity (cmol/kg) (1)		
	0 - 5	5 - 15	>15
(Maximum metal addition, kg/ha*)			
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20
Pb	500	1000	2000

(1) CEC was determined prior to sludge application using 1 N neutral ammonium acetate and is expressed here as a weighted average for a depth of 50 cm. * Multiply by 0.89 to convert to lbs/acre.

Source: Parr et al. (1978)

of at least 15 cm. If incorporated deeper, proportionately more metals can be applied, ie., a higher compost application rate may be used. Under all circumstances, the pH must be maintained between 6.0 - 6.5 (Parr et al., 1978).

In a long-term study over 6.5 years, Sarkis (1987) compared the heavy metal availability and uptake in crops grown in composted soils versus commercially fertilized soils. Sarkis reported that the percent plant availability for a particular metal did not necessarily increase with the cumulative loading rate. In fact, the compost applications were determined to have had little to no adverse impact on the crops or soil monitored with respect to metal accumulation. Research by Day et al. (1986) showed that when using dried sludge (relatively high in cadmium, zinc, copper and nickel) for fertilizer value on barley grain, the uptake of heavy metals in the crop was no greater than with the inorganic fertilizer.

Cadmium

As mentioned above, the control of cadmium in plant uptake is most important. Soil cadmium has caused severe human health problems throughout the world, especially in Japan (Chaney, 1981). Cadmium may be absorbed by plants, achieving levels that are toxic to humans but not to the plant itself. Accumulation of cadmium in humans can cause

kidney dysfunction. In soils, pH has the greatest influence on the availability and thus on crop absorption of cadmium. Chaney (1981) reported that changing the soil pH from 6.5 to 5.5 can more than doubled crop cadmium. The organic matter supplied by compost greatly increases the adsorption capacity of cadmium into the soil. Compost produced with limed sludges reduce the risk of cadmium uptake even more because of their effect on soil pH. Chaney et al.(1978) and Chaney (1981) reported that sludge applied cadmium remained available for several years (at least five according to Chaney et al., 1978 research). Lowering of soil pH due to natural processes in sludge amended soils caused increased crop uptake of cadmium. Likewise, pH increases due to lime addition can substantially reduce crop accumulation of cadmium. At an equal pH, crops accumulated less cadmium from soils with higher organic matter (Chaney et al., 1978). Thus, compost made with limed sludges control the uptake of Cd better and longer than sludge alone due to the pH control capacity and amount of organic matter available.

The World Health Organization has set the maximum level of dietary cadmium intake at less than 70 ug/day. The U.S. Food and Drug Administration reports that citizens consume between 70-90 % of this level. It is clear that humans should limit further intake of cadmium wherever possible.

Zinc

Zinc, found in relatively high concentrations in compost, has low solubility in soil due to its strong adsorption onto soil minerals (magnesite and dolomite) and thus is relatively immobile (Tisdale and Nelson, 1975). Wet, poorly drained soils with low redox potential are more effective for immobilizing both zinc and cadmium, making both less available for plant uptake. Plant contamination with cadmium and zinc increases as soil redox potential increases (Gambrell et al., 1986). Over a 140 day trial, compost applications of 240 metric tons per hectare (108 tons/acre) resulted in reduced redox potentials compared to conventionally fertilized soil (Epstein et al., 1976).

Zinc is very important in terms of controlling cadmium toxicity. Zinc is phytotoxic to plants and thus exposure to it and cadmium are limited to consumers in the food chain. Phytotoxicity occurs when a metal is absorbed by a plant at concentrations that severely reduce crop growth and yield (Chaney, 1981). Other metals, including copper and nickel, are also phytotoxic. This phytotoxicity protects humans from risk of excessive zinc and cadmium intake, because such plants would not be suitable for market.

Zinc phytotoxicity occurs before amounts of cadmium

sufficient to endanger the food-chain can be absorbed. For some plants, zinc actually inhibits cadmium uptake at low cadmium/zinc (Cd/Zn) ratios (i.e., when zinc levels are very high). Chaney (1981) reported that the zinc phytotoxicity may limit the cadmium level accumulated by plants if the applied Cd/Zn ratio was between 1-1.5%. Preferably, the cadmium content should not exceed 1% of the zinc content (Cd/Zn less than 1%). Parr et al. (1978) added that where the level of cadmium exceeded 25 mg/kg (in the compost), the cadmium was most likely coming from an abatable source.

Other Metals

Other trace metals contributed by compost include lead, chromium, nickel, copper, iron, and mercury. All but copper and nickel form what Chaney refers to as a "Soil-Plant Barrier", i.e., when absorbed by plants, they become insoluble and are not translocated to the edible plant parts (Chaney, 1980). Dowdy and Ham (1977) reported that chromium was not significantly absorbed by most crops. Copper, usually found in soil in its ionic form, is readily adsorbed by clay minerals or bound with organic matter. Copper is less available for plant uptake when there are increased amounts of organic matter and the pH is neutral or basic (Tisdale and Nelson, 1975). In a study with sewage sludge land applications, Keefer et al. (1986)

reported that the small amount of copper absorbed in edible crop parts appeared to be of little concern for food chain consumers. The absorption of nickel in plants was found to be related to the water soluble nickel concentration in the sludge, however, it was not absorbed to a toxic level.

Copper, iron, and zinc are among the micronutrients required by plants. All are absorbed in their ionic form and as salts of organic complexes. Tisdale and Nelson (1975) state that the amount of these micronutrients in relation to one another is perhaps more important than the individual amounts present in the plant.

In the NURP study, copper, lead and zinc in urban runoff were found to pose a significant threat to aquatic uses, especially in the southern and southeastern U.S. (USEPA, 1983a). Surface water hardness strongly influences the level of toxicity.

Nitrogen for Plant Nutrition

Nitrogen (N) is one of the principle constituents required by plants for nutrition. Nitrogen is typically absorbed in the form of nitrate, $\text{NO}_3\text{-N}$, although smaller amounts of ammonium, $\text{NH}_4\text{-N}$ and urea, NH_2CONH_2 may be absorbed. Once inside the plant, nitrates are key to the production of plant proteins. Nitrogen is also part of the chlorophyll molecule and is therefore associated with

healthy growth and the deep green color of many plants (Fahn, 1974). Nitrogen in soil organic matter must be converted by microbial processes into inorganic forms before it can be used by plants. Organic nitrogen is mineralized to form ammonium. This and existing ammonium are oxidized by microbial processes to nitrite ($\text{NO}_2\text{-N}$) which quickly oxidizes to nitrate ($\text{NO}_3\text{-N}$). This oxidation process, usually referred to as nitrification, will occur only when pH is in the range of 4.5-9.0, dissolved oxygen is greater than 0.2 mg/l, and the temperature is between 5 and 40 C. Nitrate is quite mobile in soil and will move with drainage waters (Page and Pratt, 1975). Denitrification of the nitrate to N_2 , nitrogen gas, can occur if the soil solution becomes anoxic and if it contains sufficient organic carbon or reduced forms of sulfur. Bouwer and Chaney (1974) found that one milligram of organic carbon was required for each milligram of nitrate reduced to nitrogen gas (N_2). Once nitrate has escaped the root zone and other regions where it may be denitrified, it closely follows the movement of groundwater. Groundwater recharge systems which treat secondary effluent have been designed to minimize the amount of nitrate that escapes the root zone or denitrification below. Two recharge projects demonstrated that nitrogen could be removed from the soil by cyclic flooding and drying. During flooding(i.e., rainfall) $\text{NH}_4\text{-N}$ was adsorbed

onto soil particles. When the soil was allowed to dry, oxygen entered the soil and the $\text{NH}_4\text{-N}$ was nitrified to $\text{NO}_3\text{-N}$. During subsequent flooding conditions, the soil became anoxic and the $\text{NO}_3\text{-N}$ was denitrified to N_2 gas. Bouwer et al., reported approximately 30% nitrogen reductions by this recharge method, presumably by denitrification.

Nitrogen Found in Compost

Most nitrogen found in sewage sludge compost is in the organic form and must be mineralized to inorganic ammonium before nitrification to nitrate can occur. At this point, it is available for plant uptake. In USDA Beltsville studies reported by Parr et al.(1978), 15-20% of the organic nitrogen present in the compost, when incorporated into the soil, will become available during the first cropping year. Other USDA research discussed earlier in this review found 10% to be available (Hornick et al, 1983).

The organic matter in the compost-amended soil is important because of the following:

- (a) it promotes good soil structure and water storage;
- (b) it increases the CEC which reduces leaching losses of potassium, calcium, and magnesium (important plant nutrients); and
- (c) it provides a "reservoir" for soil nitrogen, whose mineralization provides a continuous, though limited supply of nutrients including N and P.

The term organic matter encompasses two main types of

material: (1) humus, that which is stable and is not subject to rapid decomposition, and (2) rapidly decomposing material requiring mineralized nitrogen for decomposition by heterotrophic soil microorganisms. Stable soil organic matter has a carbon-to-nitrogen(C:N) ratio of 10:1. If the organic matter contains large amounts of carbon compared to nitrogen, the heterotrophs will use the mineralized ammonium or nitrate present in the soil for the decomposition process. If the nitrogen content is high in proportion to the carbon present, mineralized nitrogen will not be depleted by the microorganisms and will be produced by the decomposition of organic matter (Tisdale and Nelson, 1975).

The C:N ratio of sewage sludge is normally less than 15. Organic materials such as woodchips are added to the compost process to increase the carbon content so that rapid decomposition of the sludge to compost occurs. After the compost has matured, excess organic materials are removed for reuse. This lowers the C:N ratio to a value less than 20 where N will mineralize and be available for plant uptake (Willson, 1980).

The rate of mineralization in soils is affected by the following (Tisdale and Nelson, 1975):

- (a) the amount of ammonium;
- (b) population of nitrifying organisms in the soil;
- (c) soil reaction (pH, supply of calcium, phosphorus, and balance of iron, copper, magnesium, and other ions);

- (d) soil aeration; and
- (e) soil moisture.

Compost-amended soils, especially those made with limed sludges, set the pH above 4.5 where the nitrification reaction will occur, and contribute the calcium and other nutrients necessary for mineralization. As previously discussed, compost-amended soil allows good oxygen transfer into the soil which promotes mineralization. The soil moisture in compost-amended soils is usually very high compared to unamended soils. This increase in mineralization rate is offset somewhat by this high moisture content. Sikora et al (1986) found that in land application of sewage sludges, mineralized N exceeding plant needs was found in the soil profile below the root zone. In split plots where fertilizer N had been added in addition to sludge, mineralized N was even deeper in the soil profile.

Case History

Sikora et al. (1980, 1982) performed extended tests on the use of sewage sludge compost for growing Kentucky '31' Tall Fescue. Two types of soil, a loamy sand and a silt loam (with relatively high clay fraction) were amended with four(4) rates of compost (0-6% dry wt) plus two rates of N, P, or nitrogen plus phosphorus (N+P) (0 or 195 kg/ha). The controls were limed for pH control and received the same fertilizer variations. Not surprisingly, yields were

linearly related to compost amendment in both soils. The largest yield increment, however, was for the highest compost rate that received fertilizer N+P.

The total N uptake by fescue receiving N+P fertilizer was approximately equal to that resulting from compost applied at the 6% rate. However, the compost-grown fescue had more nitrogen distributed throughout the plant and had more extensive root development whereas fertilizer-grown fescue showed nitrogen only in the roots.

The addition of lime or compost to either soil increased the N uptake by fescue. When additional N sources were added via fertilizer, the fescue accumulated N to an excess level during the earlier growth stages. The addition of fertilizer N resulted in the same level of N uptake for all compost rates. This indicates that the N supply from the compost alone was not sufficient. During the 167 day test period, the fescue utilized approximately 8% of the compost N and 80% of the fertilizer N.

The amount of N utilized by fescue at each of the four sampling dates for both soils showed a high correlation with fescue yield.

The fertilizer N had nearly depleted at the third clipping (120 days), but nutrients in the compost treatments were still available. The yields for the composted plots were still very high (only slightly less than the first

clipping), and were highest for the highest compost rate (6%). Among the different rates of compost-amended fescue, the difference in compost rates did not become apparent until after 167 days.

Sikora et al.(1980) concluded that the compost amendment level should be based on the residual N in the compost-amended soils that will be available during the second and third years. In similar research, Epstein et al. (1976) reported inorganic nitrogen was still being released after 2 years since the initial application. Even though higher compost rates improved the soil physical properties, Sikora et al.(1980) felt that inorganic N applied through commercial fertilizers would have to be added anyway. It should be noted that in soils treated with compost (made from limed sludges) versus those treated with lime, the composted crops had higher yields.

The higher yields of fescue grown with a combination of compost and fertilizer N indicated to Sikora et al.(1980) that compost appeared to increase the plant efficiency in use of commercial mineralized fertilizer N.

Crop Responses to Fertilizer N

Tisdale and Nelson (1975) noted various crop responses to fertilizer N:

- (a) the continued use of fertilizer would lead to a drop in pH and a subsequent drop in crop yields unless lime

was added;

(b) fertilizer N, especially ammoniacal, could readily nitrify and leach out and be lost to the soil; and

(c) some N sources such as anhydrous ammonia, nitrogen solutions, urea, and other ammoniacal materials may be volatilized and lost as ammonia as a result of improper placement or surface applications to alkaline soils.

Ammonia from fertilizers can be toxic if placed too close to seed or plants.

Nitrogen in Runoff

Regardless of its source, $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ are very soluble. Ammonium ions are held on the cation-exchange sites in soils so the concentrations found in the soil solution is low. Nitrate is readily soluble in the soil solution and is most susceptible to leaching (Tester et al., 1977).

If present at the soil surface at the beginning of a rainfall, the ammonium will be dissolved and carried into the soil. If runoff subsequently occurs, little soluble N will be left at the surface to be carried away. Thus, runoff usually contains low concentrations of soluble inorganic nitrogen. Biggar and Corey (1969) report that nitrate contents of runoff are usually less than the average nitrate found in rain, as the first rain sweeps most of the nitrate from the air into the soil.

Nitrate in concentrations over 10 mg/l as N in drinking water has been found to cause serious health problems in infants (methemoglobinemia, "blue baby" syndrome). A potential pollution source is from excess nitrate, due to

over-fertilization, in the soil water that percolates past the root zone into groundwater, and may contain significantly more nitrate than surface water runoff. The nitrate will remain soluble in the groundwater which can resurface onto land or discharge into surface waters. Biggar and Corey (1969) estimate that 4-50 lbs/ac/yr of total N are lost to runoff and percolation, and 1-10 lbs/ac/yr of nitrate are lost. As discussed previously, nitrogen may also be carried in suspended matter, usually organic or clay particles, that erode and deposit in surface waters.

Cornell (1983) noted that excessive nutrient discharges from agricultural watersheds were a problem for receiving waters. Nutrient losses from the land may have to be replaced at considerable cost to maintain land productivity, depending on crop production needs.

Phosphorus

Phosphorus is one of the three major nutrients required by plants, yet is found in much smaller quantities than nitrogen and potassium. Phosphorus movement in soils is due primarily to the transport of soluble orthophosphates by water flowing through the soil. Its adsorption/desorption in soils is due to the equilibrium status of the soil solution (Novotny et al., 1975). Plants absorb most of their

phosphorus as the primary orthophosphate ion H_2PO_4^- ; smaller amounts of $\text{HPO}_4^{=}$ are also absorbed (Tisdale and Nelson, 1975). The pH of the soil around the roots dictates the preferred ion to be absorbed: at higher pH values, $\text{HPO}_4^{=}$ is absorbed and at lower values, H_2PO_4^- is absorbed. Other phosphate forms - pyro and meta - can be absorbed by the soil and are good sources of fertilizer phosphorus.

Tisdale and Nelson (1975) further state that P is important for the reproductive system and seed formation in plants; P is also essential in energy transfer processes. Adequate P is especially important in the early life stages. Its shortage is readily apparent by a marked reduction in plant growth. In the presence of ammonium, phosphorus increases the root growth. Uptake is also increased in the presence of ammonium, not nitrate.

Phosphorus is readily mobilized by plants. Likewise, its mobility in soil is quite restricted (Page and Pratt, 1975). Phosphate is not very soluble in soil naturally, as the inorganic forms are either adsorbed or precipitated by iron and aluminum minerals in acid-to-neutral soils, or precipitated by calcium in neutral-to-alkaline soils (Biggar and Corey, 1969; Sikora and Corey, 1976). Phosphorus added by fertilizers or released by organic matter decomposition is quickly converted to an insoluble form in the soil. Biggar and Corey (1969) reported that the value of soluble P

in the soil solution of surface soils rarely exceeded 0.2 mg/l, and were typically in the range of 0.01-0.1 mg/l. Because of this immobilization involving phosphate and minerals, downward movement of P is very slow and limited. The more colloidal material in a soil, the greater the adsorptive capacity for P. Thus the capacity of a soil to retain P is directly related to its content of reactive colloids (clay, clays coated with carbonates and iron and aluminum oxides, and alkaline earth carbonates). Coarse-textured soils have variable capacity for retaining P, depending on the ion concentrations in the soil, especially the iron content (Evans and Sorensen, 1985).

Phosphorus mineralization, i.e., organic P (inosite hexaphosphate) transformed to inorganic P, occurs through microbial activity in the organic matter of a soil (Whiting and Heck, 1926). When the rate of mineralization exceeds the rate of immobilization, extractable P is available for plant uptake.

On a dry weight basis, total P found in sludge ranges from 1-6% (Epstein et al, 1976; Page and Pratt, 1975). Compost usually contains 1.5% P (3.5% P_2O_5) on a dry weight basis, approximately 8 kg Total P/metric ton (16 lbs/ton) compost (Hornick et al, 1983). The availability of P from compost is inversely related to the amount of iron and aluminum found in the compost-soil mixture (Pastene and

Corey, 1980). In addition, compost made from lime-stabilized sludges containing iron-precipitated P have even lower percent availabilities (McCoy, 1984).

Sikora et al.(1982) found that P from raw sludge compost was only 25-40% as available as that from triple superphosphate. Based on this research, the compost P recommendation of the USDA is 2.5 times that for commercial fertilizer P for a particular crop and geographic area. For lime-stabilized sludges containing iron-precipitated P, higher application rates would be required. Hornick et al. (1983) recommended 33-45 metric tons of compost per hectare (15-20 tons/acre) be applied to satisfy the P requirement of turfgrasses. It should be noted that Chaney et al.(1980) reported that temporary salt toxicity may occur if sludges using ferric chloride to remove P were used to make the compost. At this application rate, and in general when adding compost to satisfy the P demand, fertilizer N would be needed to satisfy the N demand. As mentioned earlier, for turfgrass establishment, compost should be incorporated into the top 10-15 cm of the soil.

Phosphorus Retention in Soils

The availability of P is indirectly related to its fixation or retention in soils. Tisdale and Nelson (1975) site the following factors that affect P availability:

- (a) type of clay;
- (b) time of reaction;
- (c) soil pH;
- (d) temperature; and
- (e) organic matter.

In clays, the more surface area exposed, the greater the amount of P fixation will take place. P fixation also increases as the concentration of iron and aluminum in the soil increases. The extent of P fixation by adsorption or precipitation by iron and aluminum depends on the soil pH. Fixation occurs readily below 5.5 and above 7.0 . At long reaction times when P and soil are in contact, more P fixation will occur. For this reason, soluble superphosphates should be applied in band placements rather than broadcast or mixed in. Band placement is the direct application of fertilizer to a planted seed or plant. It differs from broadcast application which disperses fertilizer over the general area of the planted seeds/plants and does not necessarily contact each seed/plant. Plants utilize soluble fertilizer P better when it is band placed or added in granules. Soils in the warmer climates generally fix P more than those in cooler climates. This is largely due to the amount of hydrous oxides of Fe and Al typically present in the warmer climate soils because they are more weathered. The increased amounts of organic material in a soil increases soil P availability.

The relationship between C, N and P has been suggested

at 100:10:1 for soil organic matter (Tisdale and Nelson, 1975). The decomposition of organic matter in the soil is responsible for organic P mineralization to inorganic P for plant uptake.

Since little P is lost in leaching, and crop removals are generally small, the amount of fertilizer P applied in successive years may be reduced. Plants absorb inorganic P from solution in proportion to the inorganic P ion concentration in solution. If other factors are not limiting, growth will then be proportional to the amount of P absorbed by the plant (Tisdale and Nelson, 1975).

Crop Response to Fertilizer Phosphorus

Tisdale and Nelson (1975) list several guidelines for fertilizer P application. A subset are listed below:

- (a) as mentioned previously, water soluble phosphate (P source) and ammonium sulfate (N source) have proved to work well together. The reason phosphate does not work as well with nitrate is not known;
- (b) it is recommended that powdered, water insoluble P be applied to calcareous soils, and granular, water soluble P be applied to acid soils;
- (c) highly water soluble P should be applied for rapid growth and establishment of crops; and
- (d) water soluble fertilizer P is most available to the crop when band-placed in the soil.

Phosphorus in Runoff

Phosphorus concentrations in runoff are usually less than 1.0 mg/l (USEPA, 1983; Weibel, 1969; Biggar and Corey, 1969). P applied to the soil surface from fertilizers tends

to be readily fixed at the surface (Biggar and Corey, 1969). The phosphates are in near-equilibrium in the soil solution, and although rainfall percolating through the soil will carry P downward, more is quickly dissolved to maintain this equilibrium concentration. The runoff concentration would potentially be as high as the surface soil equilibrium concentration (Lindsay, 1979).

Soluble P concentrations are also usually low in groundwater because P precipitates in the subsoil with iron, aluminum and other minerals. Therefore, the majority of the soil P should reach surface waters through the runoff, though these amounts are usually low.

Suspended solids may carry significant P in runoff because P is very immobile. Total P losses, mostly through erosion, have been reported by Biggar and Corey (1969) at 0-20 lbs/acre/year; total soluble P was 0.04-2.0 lbs/acre/year. It should be noted that these ranges represent a range of soil types as well, and higher values may be found depending on the soil type and other conditions.

Ahuja et al.(1982) studied the effects of soil slope and rainfall characteristics on the amount of soluble P in runoff. They confirmed that sediment-transported P loads far exceeded the runoff of the soluble P load. The turbulent mixing of the thin surface soil layer due to

rainfall impact and runoff flow caused soil P desorption. Different rainfall, runoff, and soil characteristics influenced the amount of sediment, as well as the water-to-soil ratio, which both determine the amount of P released to runoff.

Ahuja et al.(1982) reported that soil P concentrations increased with increased slope length. This was due to the increase in P desorbed per unit area, caused by the increased depth and velocity of the overland flow on the longer slopes. Further, the degree of soil cover and the kinetic energy of the raindrops were directly related to the amount of soil mass interacting with the rainfall and subsequent runoff. Thus, under field conditions, grass and other plant cover intercepted the rainfall. The impact was subsequently decreased which thus decreased the soil chemical release to the runoff. Grass or plant cover decreased the amount of water, sediment, and P released due to rainfall impact. Results also indicated that for the first 30 minutes of rainfall, as the storm size increased, average P solution concentration decreased, which was a result of the kinetics of P desorption.

Potassium

Potassium, the third of the major plant nutrients, is absorbed by the plant in its ionic form, K^+ . The amount of

plant-available K is usually a small portion of the total K found in the soil. Potassium is added by fertilizers in the soluble salt form (KCl , KSO_4 , KNO_3 , etc.) K^+ is very mobile in the plant, and it is essential as a catalyst for several physiological functions. Crop yields and visible physical deformities occur when potassium availability is deficient (Tisdale and Nelson, 1975).

Most sewage sludge composts have limited potassium concentrations that are often not sufficient to meet plant needs. Thus, depending on the crop, potassium must be added through commercial fertilizers when compost is applied at rates to supply the crops N and/or P needs.

Lime Addition for Soil/Crop Improvement

Liming is typically recommended to many homeowners to raise the pH of their soils so that fertilizer applications will be more effective. Lime also provides the additional calcium or magnesium required for plant growth to soils that may be deficient. Liming reduces the activity or solubility of aluminum, iron, and manganese when sufficient quantities are added, thereby reducing their toxicity to plants. These metals, unless controlled by pH adjustment to 5.5-6.0, can interfere with plant absorption of calcium, magnesium, and other basic cations. Aluminum can retard growth of or kill fine root hairs responsible for plant nutrient uptake

(Russell, 1977). Inorganic phosphates are freed by the inactivation of aluminum and iron at higher pH values. Adjustments should not exceed 7.0, however, because above this pH calcium or magnesium phosphates may precipitate. The availability of micronutrients (copper, zinc, iron, etc.) required by plants in very small quantities are controlled by the pH of the soil. Decreased pH increases their availability and thus toxicity. Lime pH adjustment to 5.5-6.9 inactivates these toxic metals rendering them insoluble and unavailable. Organisms, such as Nitrosomas and Nitrobacter, that convert ammonia to nitrate require large amounts of active calcium. Liming to raise the pH to 5.5-6.0 enhances nitrification. The fixation of atmospheric N, used as an N source for organic matter decomposition, occurs more rapidly in this pH range. The decomposition process is also expedited in this pH range (Tisdale and Nelson, 1975).

Table 5 presents a comparison of sludge and compost for selected constituents including pH, C, N, and P.

Table 5
Selected Analysis of Sludge and Compost

Element	Unit	Typical Median Sludge (1)	Blue Plains (2) Digested Sludge	Compost	UOSA Compost Average (3)	UOSA Compost Project (4)
pH		NA	6.5	6.8	8.1	7.3
water	%	NA	76	35	39	39
Organic C	%	30.4	24	13	NA	NA
Total N	%	3.3	2.3	0.9	1.4	1.23
NH4+N	mg/kg	NA	1210	190	NA	376
P	%	2.3	2.2	1.0	1.8	1.69
K	%	0.3	0.2	0.1	0.1	0.08
Ca	%	3.9	2.0	2.0	22.9	NA

(1) Sommers, 1977

(2) Chaney and Giordano, 1977; Chaney, 1982

(3) UOSA, 1983

(4) UOSA Finished Compost Analysis, Stockpile AS033, used for this project

NA = Not Available

III. MATERIALS AND METHODS

In order to compare pollutant export from turfgrasses established with compost versus conventional fertilizer, three test plots were designed and constructed adjacent to each other. This was done to insure that all test environments were identical. Each plot was built up off the ground using soil imported from the Fair Lakes development. The soil was a Glenelg, Typic Hapludults. The seed, fertilizer, and compost application rates used on the test plots were also those as applied in the Fair Lakes development. Note that when referring to the Fair Lakes development, the term "field" will be used. The plots were designed to replicate the field conditions as best as possible. The actual rainfall at the test plot area was slightly different than in the field, but it was only important that the rainfall on the test plots be uniform in order to make a valid comparison. The design slopes for the test plots were also selected to duplicate field conditions, where typically 3% slopes are used on grassed swale and median areas (Virginia Department of Transportation, 1986). The design specified each plot to be 25 ft by 25 ft, with a 3% slope from back to front, and a 3.3% slope from side to center. The runoff would then flow toward the center of the plots from the sides, and from back to front down the center

of the plot and exit at the front center into the collection apparatus, as shown in Figure 2.

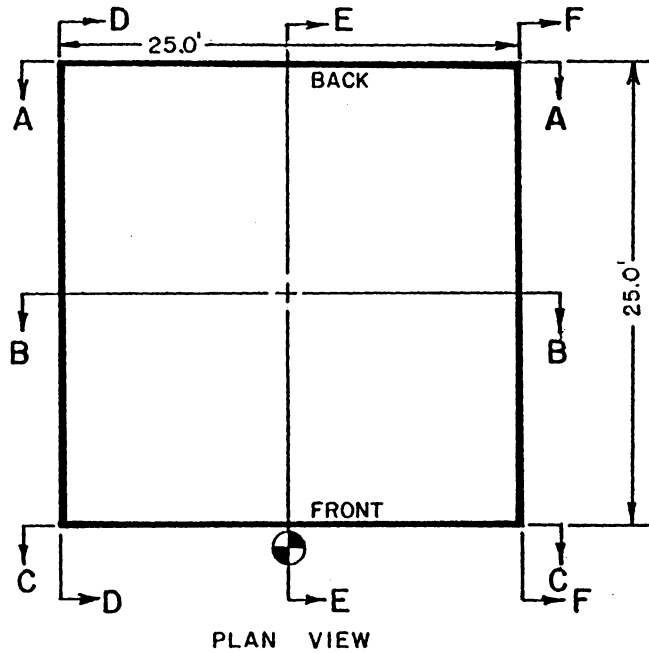
UOSA Compost Production

The test compost was produced from domestic wastewater sludge at UOSA, which receives primarily a domestic waste stream. Industrial contributions are restricted by UOSA's enforcement of the industrial pretreatment regulations. The design of the composting process at UOSA differs from the Beltsville Method in three areas which assure a more consistent, high quality compost (Robbins, 1982):

- (1) the composting area is covered by a large building which serves to protect the operation from the elements;
- (2) the compost pad is concrete instead of asphalt; and
- (3) the aeration system is designed to provide more control over air delivery.

The enclosure reduces the adverse effects of precipitation which may reduce composting temperatures and retard biological activity. The concrete pad allows improved equipment handling and site operations and maintenance. The controlled aeration system "provides the flexibility to meet the oxygen requirements in the most cost effective manner, eliminates oxygen limitations, and provides maximum moisture removal (Robbins, 1982)."

The UOSA composting process differs from the method used at Beltsville and others due to its use of finished




SAMPLE COLLECTION: MANHOLE/BARREL (PROVIDED BY HAZEL-PETERSON) INTO WHICH CARBOY IS PLACED TO COLLECT RUNOFF. TOP LIP OF MANHOLE IS TO BE FLUSH WITH EXISTING GROUND AND FRONT CENTER EDGE OF PLOT.

TYPICAL PLOT DESIGN

PLAN & SIDE VIEWS

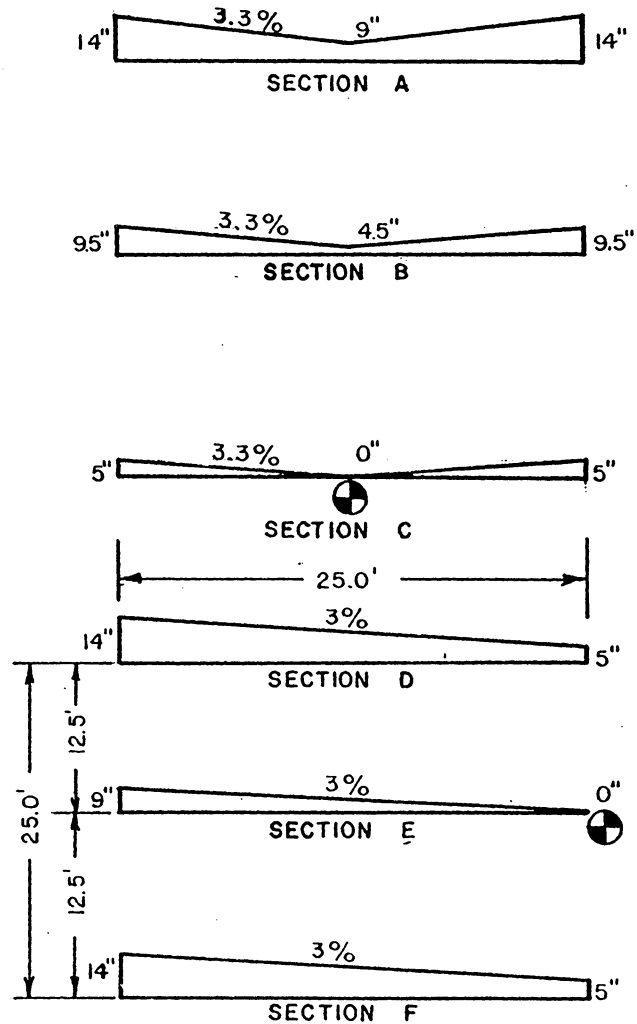


FIGURE 2

compost as the bulking agent. The filtered sludge produced at UOSA has high solids content due to lime conditioning prior to dewatering and chemical sludge precoat used to aid filter press operations. This high sludge solids content and the controlled environment of the compost process allow for the production of a finished product which can later be used as the bulking agent. Significant cost savings are realized at UOSA since expensive bulking agents (i.e., wood chips) are not required (Robbins, 1982).

Location and Preparation of Sampling Sites

The plots were built on the grounds of the UOSA Treatment Facility located approximately 8 miles from Fair Lakes, as shown in Figure 3. The developer delivered soil from the same source used to grade the areas where the compost had been used in the field. UOSA staff built frames for the plots according to the author's design as shown in Figure 2 with non-treated lumber. The edges of each plot were lined with heavy garden plastic to collect the runoff and guide it through a funnel into 20-liter Nalgene carboys. The carboys were placed at the front center (low spot) of each plot in a manhole (large rubber trash can) located in the ground, its top flush with the front center. UOSA staff filled the framed areas with the soil imported from Fair Lakes and compacted it according to procedures used in the

LOCATION OF U.O.S.A.

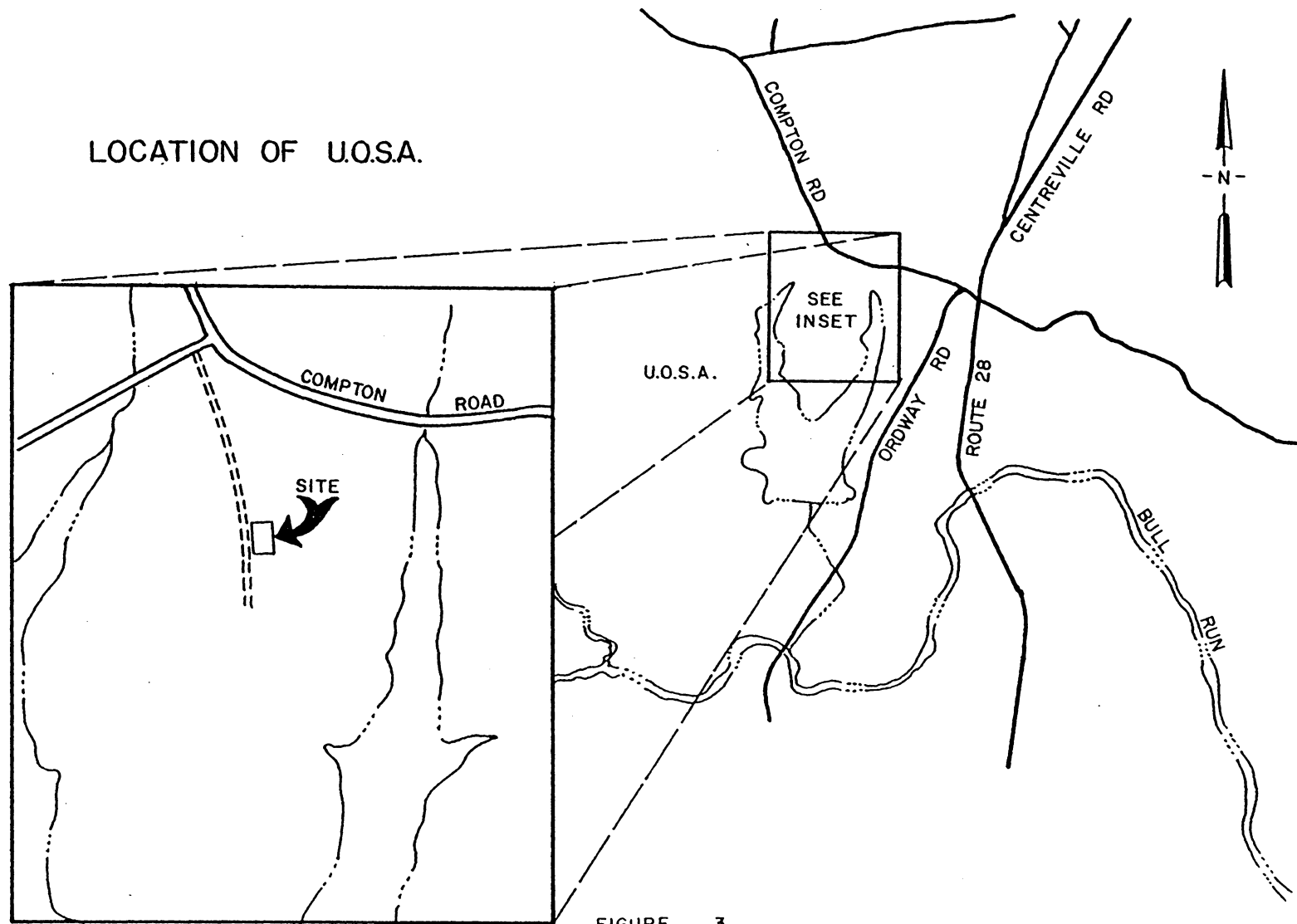


FIGURE 3

field, then fine graded the plots. Figures 4-7 show the as-built slopes and sizes of the three test plots. The survey data used to compute the Plot slopes and sizes are found in Appendix A. The plots were not significantly different in size from each other, though they were approximately 59 square feet less than the design area. Similarly, the slopes were not significantly different among the plots, but were on the average 2% greater than specified in the design. The plots were sufficiently equal in size and slope that the runoff volumes could be assumed to be free of bias from that source. The developer's crew top dressed and seeded the plots on April 9, 1986, with the appropriate treatments according to the rates used in the field, as follows:

Plot 1:

- Top soil layered on top
- 20 pounds Falcon Fescue seed (5% rye)
- 40 pounds 10-20-20 fertilizer
- Straw layered on top

This plot was hydroseeded which applied the seed, fertilizer, and water simultaneously.

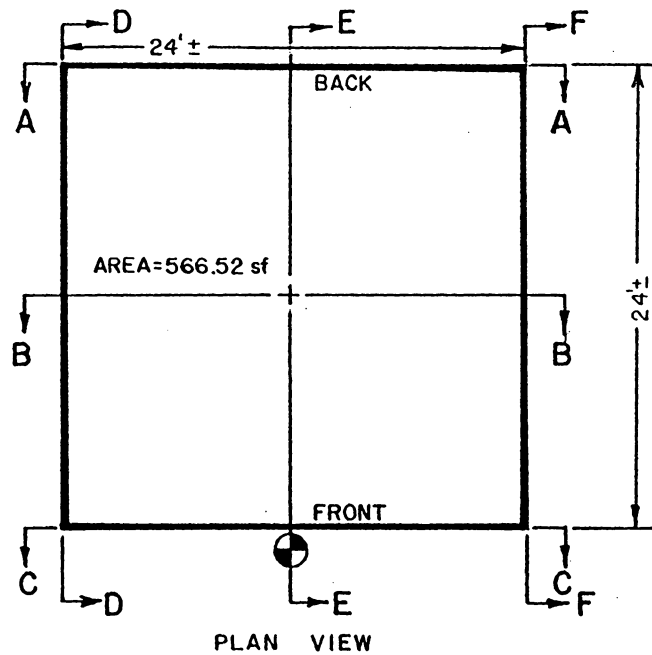
Plot 2:

- Top soil and compost mixed, 3 parts soil to 1 part compost (half inch of compost), compost disked in to 6" depth;
- 20 pounds Falcon Fescue seed(5% rye)
- 25 pounds 10-20-20 fertilizer
- Straw layered on top

After the compost had been disked into the top soil, this plot was hydroseeded similar to Plot 1.

Plot 3:

- Top soil and compost mixed, 3 parts soil to 1 part compost (half inch of compost), compost disked in to 6" depth;
- 20 pounds Falcon Fescue seed(5% rye)



 **SAMPLE COLLECTION:** MANHOLE/BARREL*
 (PROVIDED BY HAZEL-PETERSON) INTO WHICH
 CARBOY IS PLACED TO COLLECT RUNOFF.
 TOP LIP OF MANHOLE IS TO BE FLUSH
 WITH EXISTING GROUND AND FRONT CENTER
 EDGE OF PLOT.

PLAN & SIDE VIEWS
AS-BUILT PLOT 1
 (FERTILIZER)

* REPLACED WITH LARGE RUBBER
 TRASHCAN WHEN PLOTS WERE
 RECONSTRUCTED AT THE U.O.S.A.
 SITE.

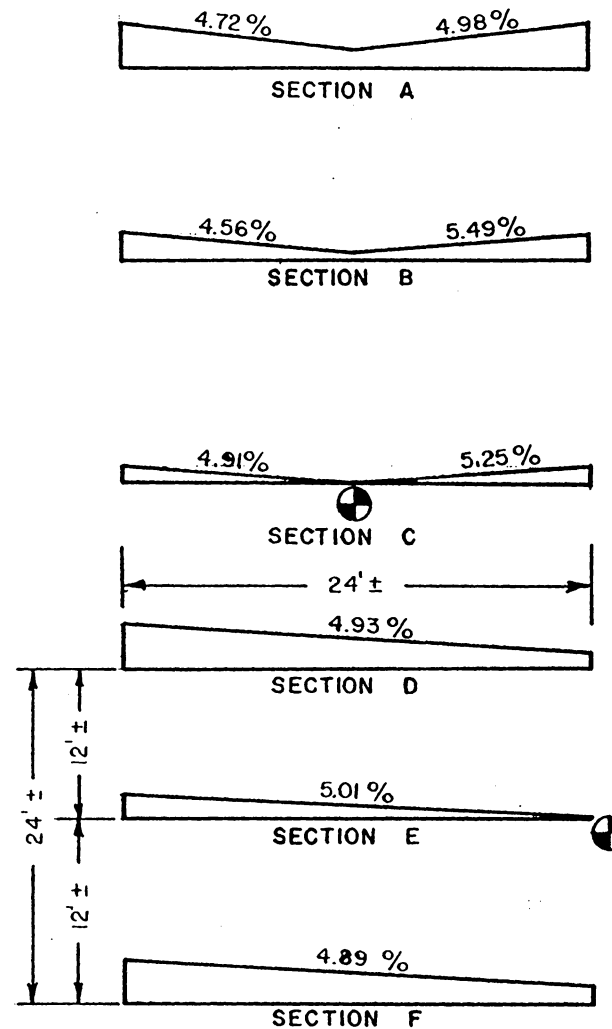
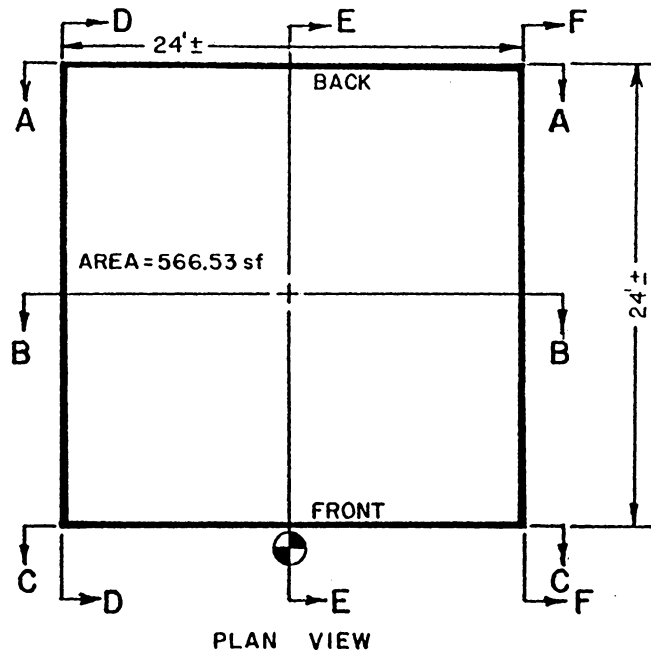


FIGURE 4



⊕ SAMPLE COLLECTION: MANHOLE/BARREL* (PROVIDED BY HAZEL-PETERSON) INTO WHICH CARBOY IS PLACED TO COLLECT RUNOFF. TOP LIP OF MANHOLE IS TO BE FLUSH WITH EXISTING GROUND AND FRONT CENTER EDGE OF PLOT.

PLAN & SIDE VIEWS
AS-BUILT PLOT 2
(FERTILIZER & COMPOST)

* REPLACED WITH LARGE RUBBER TRASHCAN WHEN PLOTS WERE RECONSTRUCTED AT THE U.O.S.A. SITE.

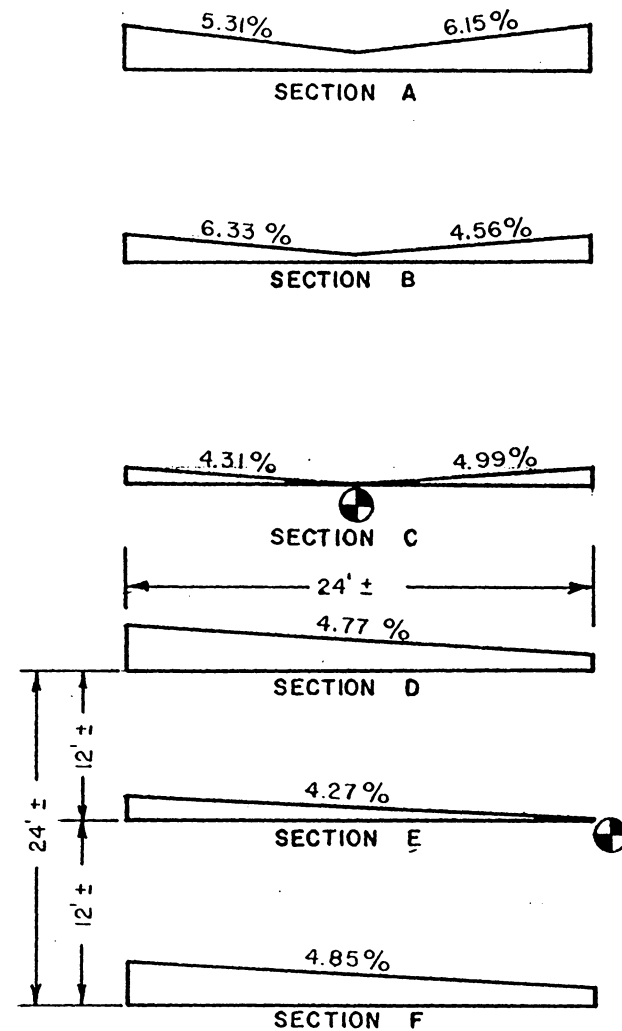
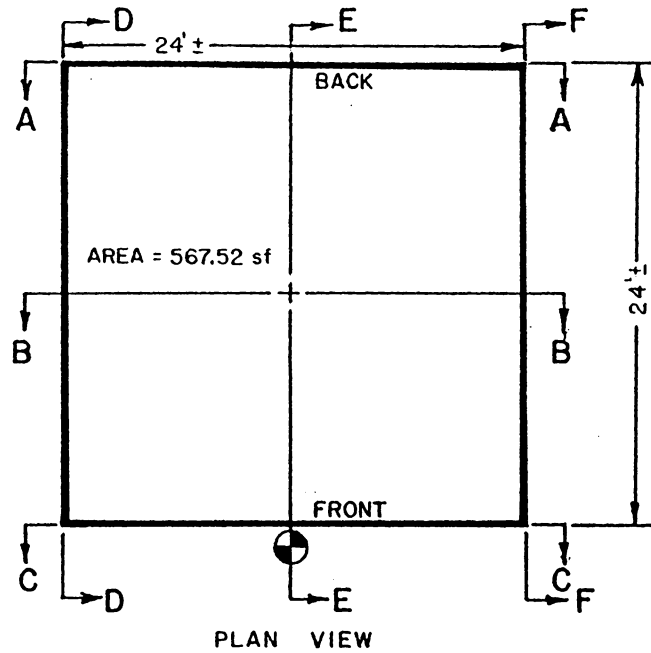


FIGURE 5



 **SAMPLE COLLECTION:** MANHOLE/BARREL*
 (PROVIDED BY HAZEL-PETERSON) INTO WHICH
 CARBOY IS PLACED TO COLLECT RUNOFF.
 TOP LIP OF MANHOLE IS TO BE FLUSH
 WITH EXISTING GROUND AND FRONT CENTER
 EDGE OF PLOT.

PLAN & SIDE VIEWS
 AS-BUILT PLOT 3
 (COMPOST)

* REPLACED WITH LARGE RUBBER
 TRASHCAN WHEN PLOTS WERE
 RECONSTRUCTED AT THE U.S.A.
 SITE.

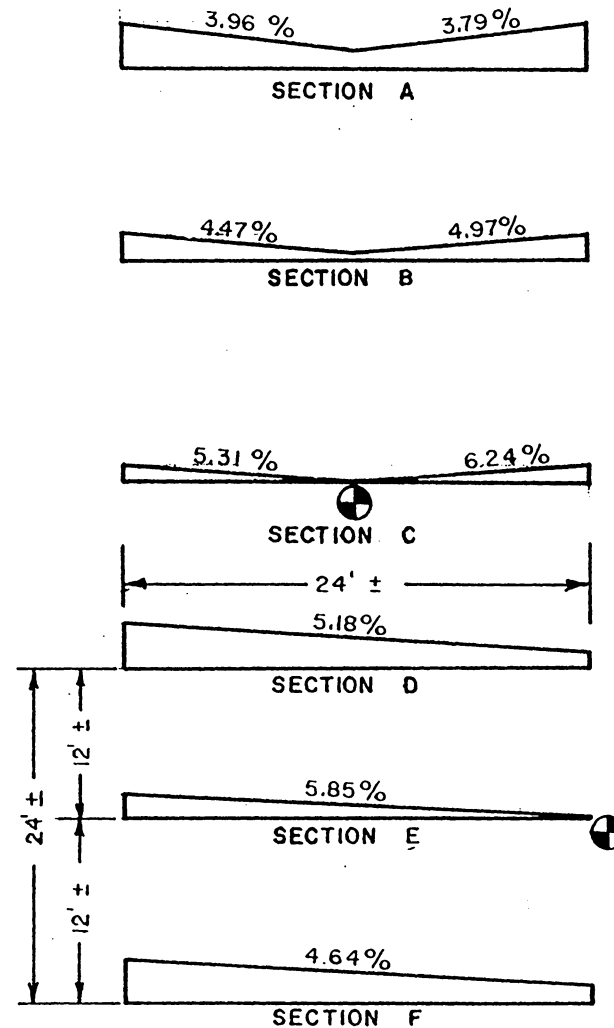


FIGURE 6

Slopes	Plot 1	Plot 2	Plot 3
1) - 7)	4.93%	4.77%	5.18%
2) - 8)	5.01%	4.27%	5.85%
3) - 9)	4.89%	4.85%	4.64%
1) - 2)	4.72%	5.31%	3.96%
3) - 2)	4.98%	6.15%	3.79%
4) - 5)	4.56%	6.33%	4.47%
6) - 5)	5.49%	4.56%	4.97%
7) - 8)	4.91%	4.31%	5.31%
9) - 8)	5.25%	4.99%	6.24%
Average Slope	4.97%	5.06%	4.94%

Plot Reference

Left				Right
- A	1	2	3	B - Back
	4	5	6	
- C	7	8	9	D - Front
	Front Center			

Collection Apparatus

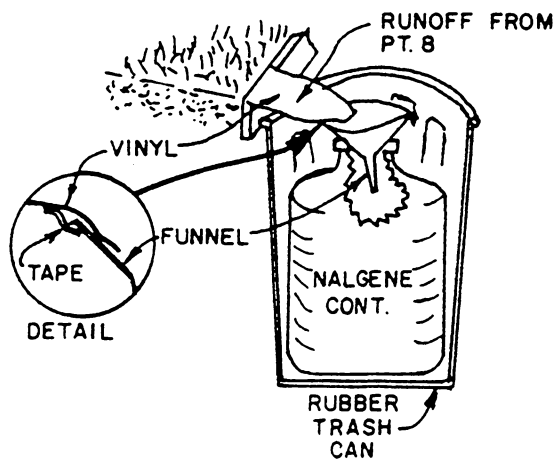


Figure 7: Plot Slopes and Collection Apparatus

Because the hydroseed machine had fertilizer in its mixture, the seed was fed by hand after the compost had been disked in.

The Falcon Fescue turfgrass is an improved variety of the tall fescue. It has a finer blade and is disease and drought resistant (Southern States, 1987). The fertilizer used contained largely inorganic N and no slow-release forms of N.

Note that in the Fair Lakes development, the developer had hydroseeded the areas that were composted and the hydroseed contained fertilizer. The fertilizer rates used in the field for the composted areas were used for Plot 2. The application rate for compost for Plots 2 and 3 were as recommended by UOSA, 1983: for new lawns, 1/2" depth compost should be rototilled to a depth of 6", or 1 1/2 cubic yards of compost per 1000 sf.

In order to continue to replicate actual field conditions, the test plots were limed, reseeded and fertilized according to the rates used in the field in September, 1986 by the developer:

Plot 1 and Plot 2:

- 29 pounds lime (application rate 50 lbs/1000 sf)
- 3 pounds Falcon Fescue seed (5 lbs/1000 sf)
- 1.5 pounds 10-10-10 fertilizer (2.5 lbs/1000 sf)

Plot 3:

- 29 pounds lime (application rate 50 lbs/1000 sf)
- 3 pounds Falcon Fescue seed (5 lbs/1000 sf)

Lime was applied on September 16, 1986 by a manual

push-type dispenser, and each plot was then watered with 0.284 inches equivalent rain. The plots were then seeded by hand on September 18, 1986. Fertilizer was applied to plots 1 and 2 by a manual push-type dispenser immediately after seeding. All plots were again watered with 0.284 inches equivalent rain. The following is a summary of the plot treatments:

<u>April 1986</u>	<u>Fertilizer</u>	<u>Compost</u>	<u>Seed</u>	<u>Lime</u>
Plot 1	40 lbs		20 lbs	
Plot 2	25 lbs	1423 lbs	20 lbs	
Plot 3		1423 lbs	20 lbs	

September 1986

Plot 1	1.5 lbs	3 lbs	29 lbs
Plot 2	1.5 lbs	3 lbs	29 lbs
Plot 3		3 lbs	29 lbs

Sampling Protocol

A Nalgene container was placed at the mouth of each plot to collect the runoff. These containers sat in a manhole placed in the ground to provide a stable place for the containers to rest below ground level and collect any runoff that exceeded the containers. The Nalgene containers were new, and thus each container was acid rinsed, followed with a distilled water triple rinse prior to use in the field. Likewise, the funnels used to direct the runoff into the Nalgene containers were acid and triple rinsed. Figure 7 depicts the runoff collection apparatus.

The Nalgene containers were calibrated in the Laboratory so that reasonably accurate volumes could be measured in the field. Known volumes of water were placed in the containers and corresponding depths measured. In this manner, a field measurement of depth in the container could be converted to volume using a calibration curve. A typical calibration curve is shown in Figure 8. In actual field circumstances, however, it was often the case that the entire volume of runoff was collected, measured in the Laboratory, then composited to a 1 liter sample for the analyses work.

An attempt was made to capture all of the runoff from each individual storm event that was monitored. By doing so, expensive flow measuring and sample compositing devices were not required. The runoff volume may be used to calculate loads (lbs/acre) and yields (lbs/acre/inch of rainfall) that discharge from the plots.

At the site, a Taylor 5 inch Clear-Vu Rain and Sprinkler gage was installed on a post that was carefully placed away from any trees or obstructions. Approximate rain measurements were recorded based on this gage. More accurate rain measurements were obtained directly from UOSA, which records rainfall daily by using a tipping bucket rain gage. Care was taken to reset the site rain gage after each rain so that the rainfall for each runoff event could

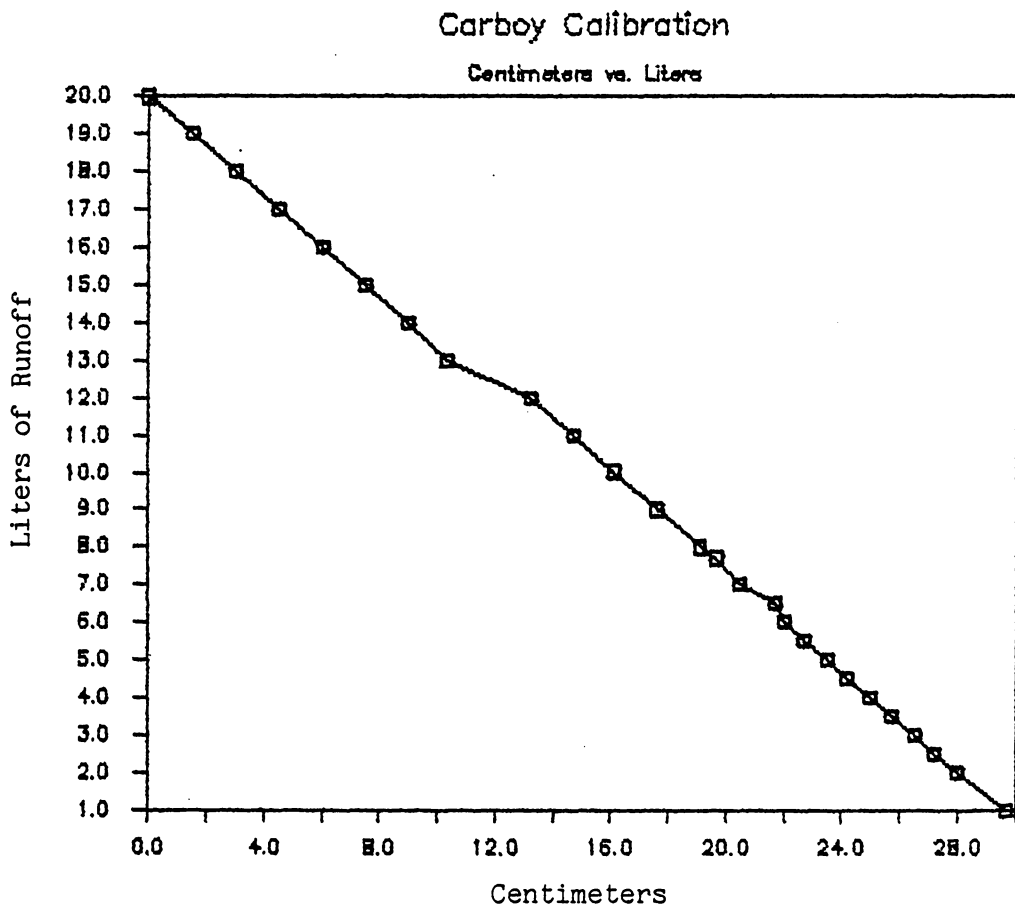


Figure 8: Carboy Calibration Curve

be recorded with reasonable accuracy, then later matched with UOSA data.

Description of Typical Sampling Occasion

After a rainfall, the rain gage located at the test plot site was read and the rain amount recorded. The rain gage was then emptied and reset on the post. Next, the containers for each plot were examined for runoff. If the container had over 500 ml of runoff, the container was pulled from the manhole, its volume measured and recorded, then shaken to mix the contents, and a sample poured into a reuseable or disposable plastic bottle. The reuseable bottles were also prepared by an acid rinse followed by a triple distilled water rinse. Midway through this project, the Laboratory switched to disposable containers that required no preparation. After a sample was taken from a container, the remaining contents were discarded, and the container and funnel rinsed with distilled water. The container was then reset into the manhole and the funnel was placed in the container so as to capture the next runoff event.

The samples were either taken directly to the OWML facility, or were refrigerated until they could be delivered to OWML. Once at OWML, the samples were logged in and refrigerated until staff was able to begin analyses. As

noted previously, if the entire volume of runoff was small enough to transfer to the Laboratory, the volume would then be measured at OWML and a composite sample would be made for analyses. The remaining runoff volume was then discarded.

Simulated Rainfall Events

By the end of September, 1986, eight storm events had been monitored where runoff was collected, measured, and analyzed. The summer rainfall was low and near-drought conditions occurred. For this reason, the plots were watered periodically throughout the summer and early fall of 1986. Because of the remote location of the plots, water was obtained from a Fairfax County Water Authority hydrant and transported in a 500 gallon fiberglass tank to the plots. Water was pumped from the tank onto the plots in metered amounts so that equivalent rainfall could be calculated. This apparatus was also used to simulate a storm event so that runoff could be generated.

On October 7, 1987, an equivalent 0.57 inches of rainfall were sprayed evenly over each plot. Runoff generated from all three plots was collected, measured, and analyzed. On October 16, 1987, an equivalent 0.28 inches were sprayed evenly over each plot. Runoff was generated from Plots 1 and 2 and was collected, measured, and analyzed, then reset for the next event. The runoff from

Plot 3 was less than 1 liter which was not enough for sample analyses. An additional 0.10 inches of equivalent rain was applied to each plot, and runoff was collected from all three plots. Note that the runoff from Plot 3 included that from the 0.28 inch rainfall plus the 0.10 inch rainfall.

Four natural storm events were monitored from October through November, when field work was discontinued.

Analytical Procedures

All chemical analyses on the runoff were performed at the OWML (Lab) facility by OWML staff. The cation exchange capacity was determined by the Fairfax County Environmental Laboratory, Wastewater Treatment Division. All phosphorus and nitrogen analyses were performed using the Technicon Automated Analyzer II according to the methods found in Methods for Chemical Analysis of Water and Wastes (USEPA, 1979).

Soluble Orthophosphate (OP)-- Filtered, Automated Ascorbic Acid, Colorimetric

Soluble orthophosphate was determined using the Automated Ascorbic Acid Reduction Method 365.1. Orthophosphates are those phosphates that "respond to the colorimetric tests without preliminary hydrolysis or oxidative digestion of the sample " (APHA, 1975). This

method reports the dissolved forms of OP, because the sample is filtered through a 1.5 micron glass fiber filter (934-AH, Whatman microfiber filter). The results were reported as P.

Total Phosphorus (TP) -- Semi-Automated Persulfate Digestion, Colorimetric

Total phosphorus was determined using the Semi-Automated Block Digestion Method 365.4. This method is also referred to as the persulfate digestion procedure. The total phosphate content of a sample includes all forms of orthophosphates and condensed phosphates, organic and inorganic, both soluble and insoluble. The results were reported as P.

Total Soluble Phosphorus (TSP) -- Filtered, Semi-Automated Persulfate Digestion, Colorimetric

The total soluble phosphorus was measured by filtering a sample through a 1.5 micron glass fiber filter, then analyzing the filtrate by the methods described above for TP and OP. The results were reported as P.

Soluble Ammonia as N (NH₃-N) -- Filtered, Automated Phenate, Colorimetric

Soluble ammonia was analyzed as described in Method

350.1. The sample was first filtered through a 1.5 micron glass fiber filter. The results were reported as N.

Total Kjeldahl Nitrogen (TKN) -- Semi-Automated Block
Digestion

TKN is the sum of free ammonia and organic N compounds. Method 351.2 was used to convert TKN to ammonium sulfate. The amount of ammonium sulfate found in the sample, measured as ammonia, is equal to the TKN. After conversion to ammonium sulfate, the sample was analyzed by the methods described above for NH₃-N by the automated phenate procedure. The results were reported as N.

Soluble Kjeldahl Nitrogen (SKN)-- Semi-Automated Block
Digestion

The soluble portion of the sum of free ammonia and organic N compounds was measured by filtering a sample through a 1.5 micron pore size filter and digesting the filtrate per Method 351.2 . Next, the ammonia content was analyzed by the methods described above for NH₃-N. The results were reported as N.

Oxidized Nitrogen as N (OXN)

-- Automated Cadmium Reduction, Colorimetric

Oxidized nitrogen (nitrite and nitrate) was measured

using Method 353.2. A sample was filtered through a 1.5 micron glass filter to reduce turbidity that may interfere with the analysis. The results were reported as N.

Total Suspended Solids (TSS) -- Total Nonfiltrable Residue

Total suspended solids is a measure of the residue that remains on a standard glass fiber filter after filtration through a 1.5 micron glass fiber filter. TSS was determined according to Section 209C, Standard Methods for the Examination of Water and Wastewater, 16th edition (APHA, 1985).

Chemical Oxygen Demand (COD) -- Open Reflux Method

COD was determined according to Standard Methods (1985), Section 508A. COD is a measure of the "oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant" (APHA, 1975).

Metals -- Atomic Absorption, Direct Air Acetylene

All metal determinations were made using the Perkin Elmer 403 Atomic Absorption (AA) unit. The AA measures the amount of atoms absorbed by a particular wavelength for each metal. The amount of absorbed metals is compared to metal absorption from known standards to determine the amount of

metal in the sample. Each metal has its own lamp that produces a specific wavelength. The detection limit is taken to be the "concentration of the element which will produce a signal/noise ratio of 2. Thus, the detection limit considers both the signal amplitude and the baseline noise and is the lowest concentration which can be clearly differentiated from zero" (Perkin-Elmer, 1982). These values, in ug/l, for the various metals tested are as follows:

Cd=6, Cu=10, Pb=50, Ni=21, Zn=5, Cr=20, Fe=20.

Cation Exchange Capacity (CEC)-- Ammonium Acetate Method

The CEC of the plots before and after amendment were determined by the Fairfax County Environmental Laboratory staff according to the Ammonium Acetate Method, 9-3.1, from Methods of Soil Analysis (ASA, 1982). The CEC is defined as the number of centimoles of cations per kilogram of soil. The cations of interest are Ca^{2+} , Mg^{2+} , K^{+} , and Na^{+} .

Quality Assurance (QA)

The QA program at the OWML is based on charting techniques that can be used to determine whether the precision and accuracy of analyses are acceptable (EPA, 1972; OWML, 1987). Precision, a measure of the reproducibility of the analysis, is determined by analyzing

replicate samples. A minimum of 15 replicate sets are recommended by EPA (1972) to determine analytical precision. The ranges (i.e., the absolute difference in the analyses results) for each set are calculated and plotted. The plot of ranges is compared to an upper control and warning limit calculated by adding three and two standard deviations, respectively, to the mean range value. If the plot falls below these limits, the analyses are then considered precise.

Accuracy, a measure of how close the analysis is to the actual value, is determined by measuring the recovery of known additions of analyte. A plotting procedure similar to that used for precision determination is used to ascertain whether analyses results may be considered accurate.

The QA analyses accounts for 25-30% of the analytical work in the OWML.

IV. Results and Discussion

Runoff was collected and analyzed for 18 runoff events that occurred between May 20, 1986 and November 20, 1986. The site log kept by the author and raw data are presented in Appendix A. Normally, the runoff volume was measured and recorded so that weighted average concentrations, storm loads (lbs/acre) and normalized storm loads (lbs/acre/inch of rainfall) could be computed from the concentration data. It should be noted that when referring to normalized storm loads, the term "yield" will be used. The concentration data collected for each constituent are tabulated in Appendix B. It may be noted by examining the raw data and the data tabulations (Appendices A and B) that data from certain events have been eliminated in the data tabulations. This was done to facilitate comparison of the three plots on an equal basis. For those events where the volume was not measured, the concentration data were not included in the data tabulations and subsequent calculations for any constituent. This is because the weighted average concentrations, loads, and yields for those events could not be calculated without knowledge of the associated runoff volumes. Similarly, there were instances where concentration data for 1, 2, or all 3 plots were not available for one or more constituents. Therefore, for each

constituent, any event which had at least one plot runoff concentration missing was not included in the data tabulation and subsequent calculations for that constituent. There were three reasons why the concentration data for a particular sample would be missing:

- (1) the analysis failed Lab quality control;
- (2) the analysis could not be performed because of equipment problems; or
- (3) the integrity of the sample was in doubt because of sample age.

As may be noted in the review of the tabulated data, there were events where Plot 1 had measurable runoff, whereas there was zero runoff from Plots 2 and 3. For these events, the concentrations, load, and yield were reported as zero for Plots 2 and 3.

There was a notable exception concerning the events of October 14, 1986 through November 20, 1986. The volume of runoff for Plot 2 was not all collected during these events due to a small leak in the plastic liner that was used to channel the runoff into the funnel and sample container. The leak was noticed while collecting the runoff from the October 14 event. This problem was repaired for the October 16, 1986 simulated event and thus valid volume and concentration were measured for that event. For other events in the time period, the leak returned and although samples were retrieved and analyzed, the concentrations of the runoff collected were suspect because not all of the

runoff had been collected. The average loads and yields for each plot were thus calculated up to the October 14 event for Plots 1, 2, and 3, and through the remaining events for Plots 1 and 3. As will be discussed in a later section, the average loads and yields were ultimately not used in the comparison of the results. Instead, the median loads and yields were determined and used for comparison.

Soil Analyses

Soil analyses was performed by the Virginia Cooperative Extension Service in Blacksburg, Virginia on soil samples taken prior to amendment in April, 1986. The constituents tested were pH, Phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg); the results were as follows:

	Parameter				
	pH	P	K	Ca	Mg
		lb/ac	lb/ac	lb/ac	lb/ac

Plot 1	6.1	20	200	2330	240
Plot 2	6.0	10	220	2140	240
Plot 3	5.9	10	235	2090	240

According to the Extension Service, the phosphorus levels in Plots 2 and 3 were considered "low". The phosphorus level in Plot 1 was "moderately low". The

potassium, calcium, and magnesium were all considered "high" to "very high". The Extension Service recommended the application of a 1-2-1 fertilizer with 2.5 lbs of available nitrogen per 1000 sf. According to Table 3 in "Soil Test Notes" (Soil Testing Laboratory, 1985), if adding a 5-10-5 fertilizer, which is equivalent to a 1-2-1 ratio fertilizer, 50 lbs would be required. This assumes that all of the nitrogen in the fertilizer is water soluble and thus "quickly available" (Soil Testing Laboratory, 1985). When determining the fertilizer equivalence for first year compost application, the USDA (Hornick et al., 1983) and the EPA Process Design Manual for Land Application of Municipal Sludges (USEPA, 1983b) recommend that 10% of the total nitrogen in the compost be assumed to be available nitrogen, equivalent to the water soluble, quickly available fertilizer nitrogen. For Plots 2 and 3, due to the low available phosphorus content, the Extension Service recommended the application of 2-3 lbs of superphosphate per 100 sf. Superphosphate is a water soluble form of phosphorus which is also quickly available. The Extension Service also recommended that lime should be applied at 60 lbs/1000 sf and disked in to 6" depth to achieve the ideal soil pH between 6.2 and 6.5.

The plots were not fertilized as recommended by the Extension Service, but instead were treated exactly like the

Fair Lakes soils were treated. Originally, the project was designed to model actual fertilizer application rates in the Fair Lakes subdivision. The fertilizer rates used in the Fair Lakes subdivision were representative of those used by the development community in Fairfax County. As previously detailed in the Materials and Methods section of this paper, Plot 1 received 40 lbs of 10-20-20 fertilizer, Plot 2 received 25 lbs of 10-20-20 fertilizer plus 1422 lbs of compost (1/2 inch over the entire surface), and Plot 3 received only 1422 lbs of compost. Lime was added in the fall at 50 lbs/1000 sf; additional fertilizer was also added in the fall. Table 6 shows various recommendations for nutrient application for turfgrass establishment, and the actual nutrient applications made to each plot.

Cation Exchange Capacity

The cation exchange capacity (CEC) is an important soil parameter for soils with substantial metal concentrations. The higher the CEC, the less available are metals to plants for uptake. Amendment with sludge or compost has been found to increase the CEC of a soil as much as 3 times (Epstien et al., 1976). In this study, the CEC in cmol/kg of the soils prior to the fertilizer and compost applications were 237, 220, and 210 for Plots 1, 2 and 3, respectively. After fertilizer and/or compost addition, the CEC in cmol/kg of

Table 6 Nutrient Application for Turfgrass Establishment

Recommended Nutrient Application for Turfgrass Establishment lbs/acre (lbs/plot)			
Source	Available N lbs/acre	Available P lbs/acre	Available K lbs/acre
(1) VA Tech	109 (1.42)	218 (2.84)	109 (1.42)
(2) Hornick	80-241 (1.06-3.19)	27-36 (.35-.47)	NA
(3) UOSA	160 (2.1)	NA	NA
Nutrient Application Made by Fertilizer and/or Compost, April 1986 lbs/acre (lbs/plot)			
(4) Plot 1 Fertilizer only	308 (4)	616 (8)	616 (8)
(5) Plot 2 Fertilizer and Compost	273* (3.55)	829** (10.76)	439*** (95.7)
(6) Plot 3 Compost only	81* (1.05)	444** (5.76)	54*** (0.7)
Nutrient Application Made by Fertilizer, September 1986 lbs/acre (lbs/plot)			
(7) Plot 1 and Plot 2	11 (.14)	11 (.14)	11 (.14)
Total Nutrient Application lbs/acre (lbs/plot)			
Plot 1	319 (4)	627 (8)	627 (8)
Plot 2	284 (3.55)	840 (10.76)	450 (95.7)
Plot 3	81 (1.05)	444 (5.76)	54 (0.7)

Table 6 continued: Notes and Sources

(1) Recommendation of 2.5 lbs available N/1000 sf in a 1-2-1 fertilizer made by Virginia Cooperative Extension Service, Blacksburg, VA from soils analysis run Oct.86. The P and K applications are based on a 1-2-1 ratio.

(2) Recommendation made by Hornick et al (1983) for turfgrass. Based on 99-298 mt/ha appl. rate, 1.5% Total N dry wt in compost, 60% solids and 10% available nitrogen.

(3) UOSA recommendation based on 20% availability of Total N in compost, 60% solids, 1.23% Total N, and wet wt. compost 1600 lbs/cy.

(4) Based on 10-20-20 fertilizer, 40 lbs/plot.

(5) Based on 10-20-20 fertilizer, 25 lbs/plot, and compost at 1422 lbs/plot.

(6) Based on 1422 lbs compost/plot, 1.23% Total N, 10% availability of Total N, 61% solids.

* Assumes 10% N available based on Hornick et al. (1983)

** Assumes 40% P available based on Hornick et al. (1983)

*** Assumes 100% K availability based on EPA Land Application of Municipal Sludge (1983)

the fertilized Plot 1 was 216, compared to the CEC of the compost-amended plots at 594 and 531 for Plots 2 and 3, respectively. The CEC of Plots 2 and 3 increased 2.7 and 2.5 times, respectively, which confirm the results reported in Epstein et al. (1976). The CEC and individual cation contributions of the soil prior to this study, after study completion, and the net change of each are presented in Figures 9-11, respectively. The values are tabulated in Appendix C.

pH

The pH of the unamended soil in plot 1 was 6.1 prior to fertilizer application in April 1986. The pH of the soil measured after the field monitoring had been completed was 5.7. The effective raise in pH, if any, due to the lime addition to all three plots in September, 1986, had quickly dissipated. The pH of the soil in Plot 2 and 3 prior to compost amendment was 6.0 and 5.9, respectively. The pH of the amended plots measured after the field monitoring had been completed was 7.5 and 7.2, respectively. The pH of Plot 1 remained in the desirable range for P availability 5.5-7.0 (Tisdale and Nelson, 1975), but below that required for control of metal uptake. Chaney (1981) reported that as the pH increased, the metal concentration in the soil solution decreased. As observed in the runoff, the higher

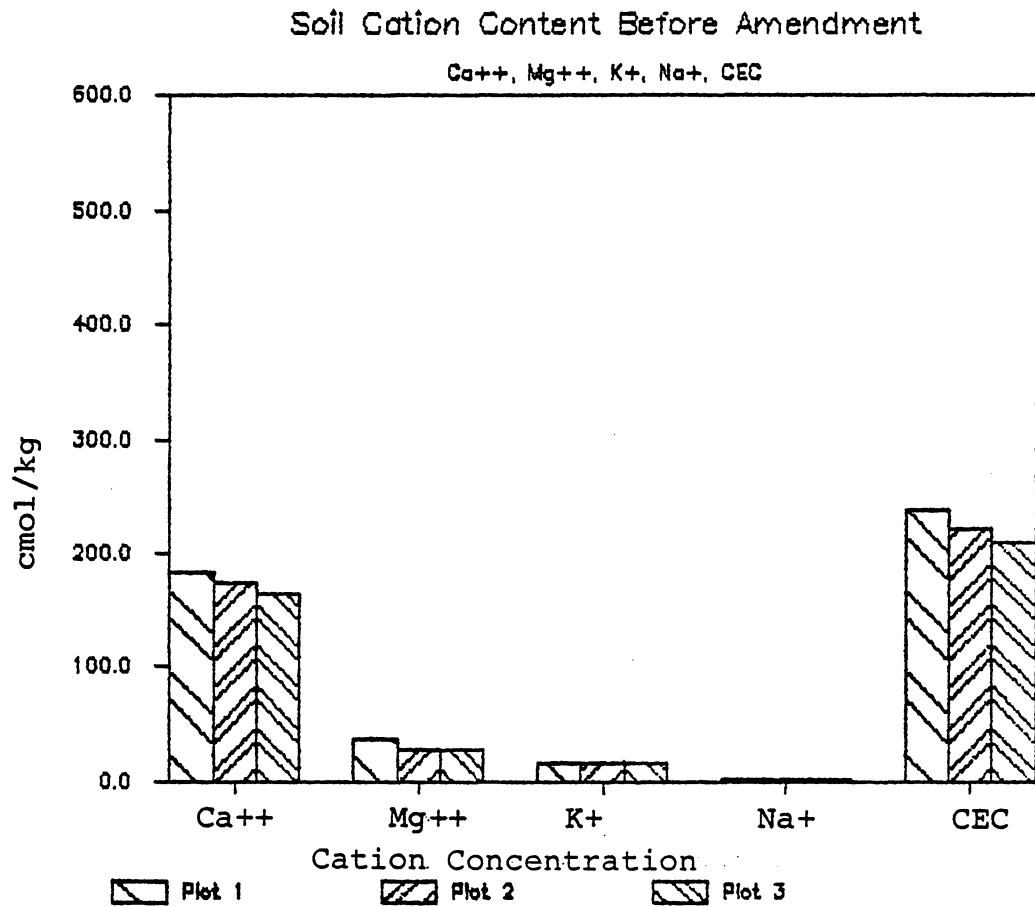


Figure 9: CEC and Individual Cation Contributions Prior to Amendment

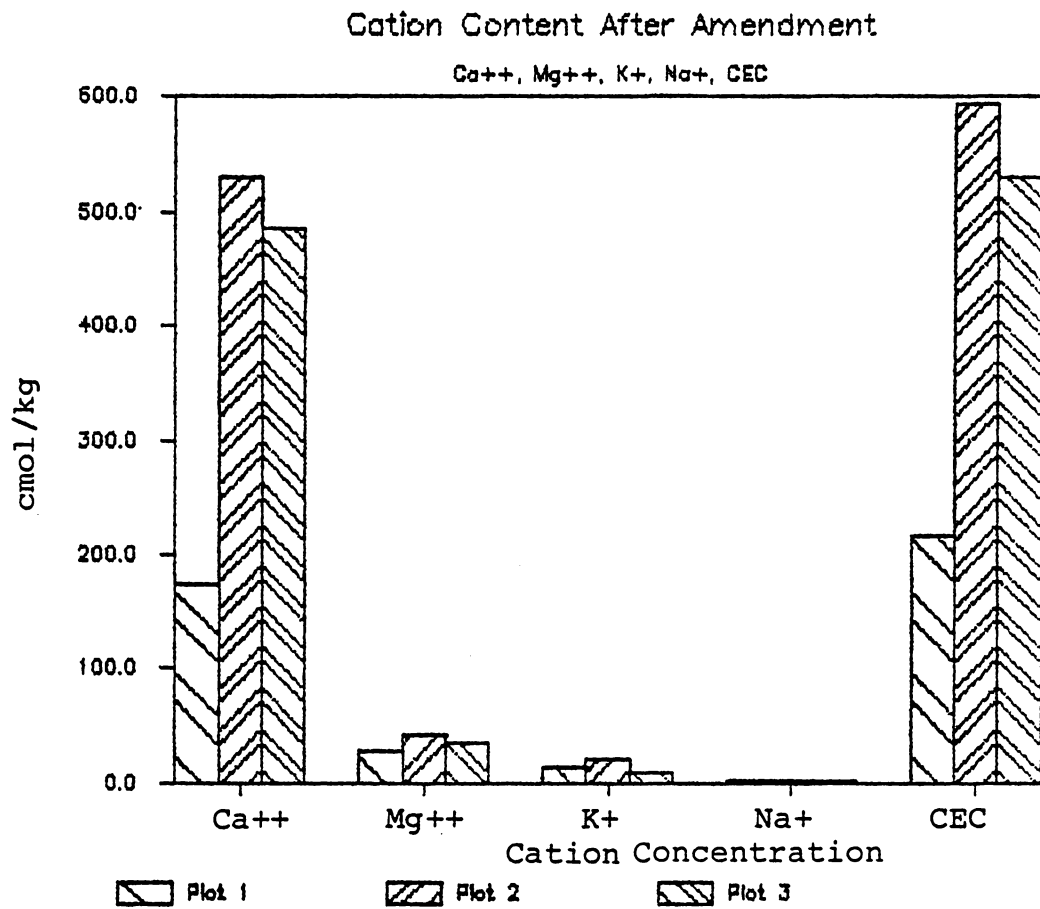


Figure 10: CEC and Individual Cation Contribution After Amendment

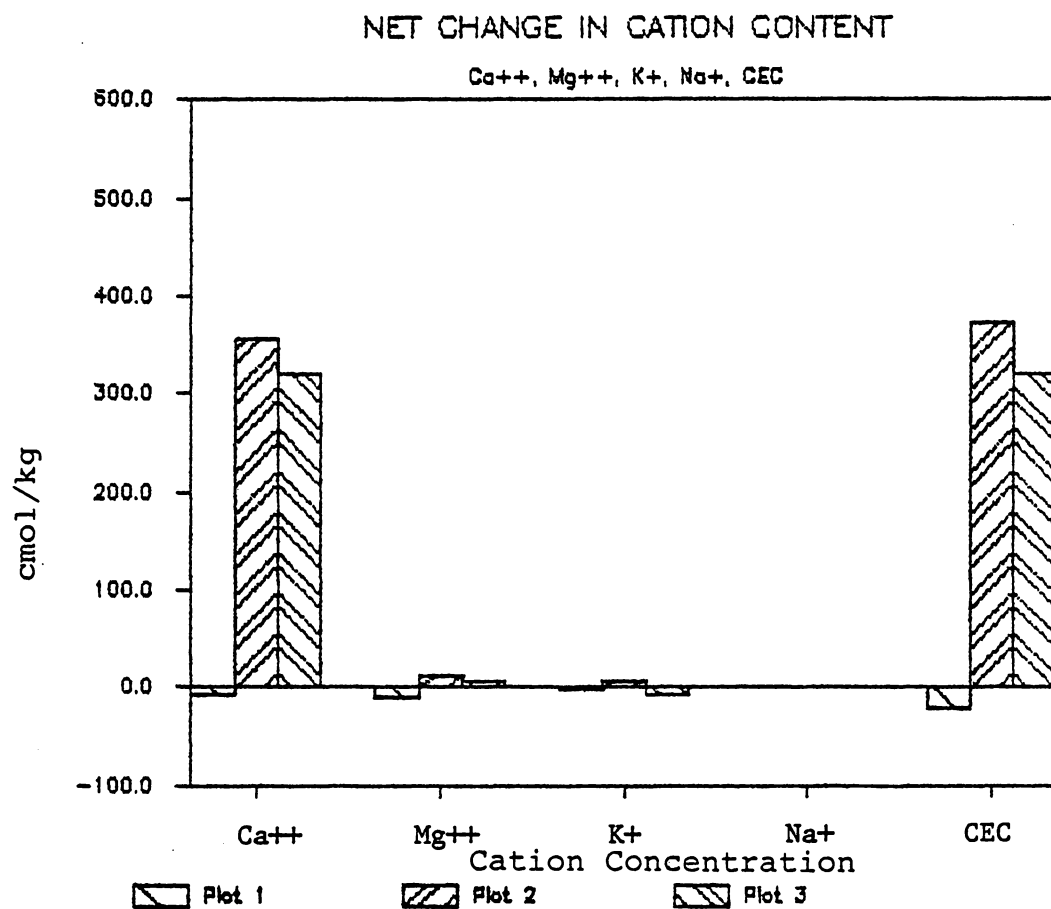


Figure 11: Net Change in CEC and Individual Cation Concentrations

pH of Plots 2 and 3 contributed to the reduced availability of metals in the soil solution. The pH of Plots 2 and 3 was slightly above the desired range for P availability, and thus phosphate precipitation with calcium or magnesium may have occurred more readily in these plots. Because exchangeable P was not measured in the study, conclusions regarding the effects of pH on P availability to plants cannot be made.

Rainfall

Figure 12 presents the frequency diagram and box plot of the rainfall received for all monitored events from April through November, 1986. Figure 13 is a schematic which interprets the box plot. To construct the box plot distribution diagram, the 25th percentile, median, and 75th percentile were calculated using Statistical Package for the Social Sciences (SPSS-X) using an IBM 3090-200E computer. SPSS-X is a statistical program commonly used by the business and academic communities.

The average rainfall was 0.39 inches; the median rainfall was 0.38 inches. Because the mean and median are approximately equal, either may be used to represent a typical rainfall event.

Runoff/Rainfall Ratio

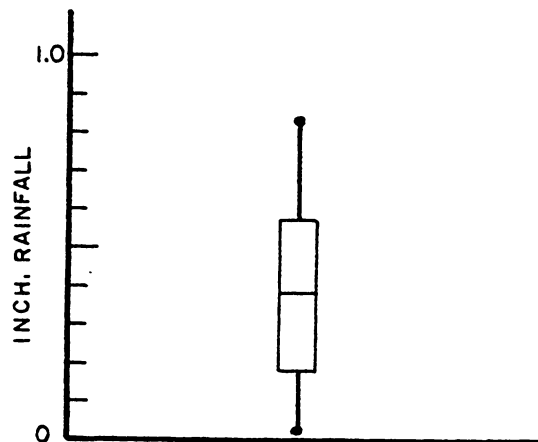
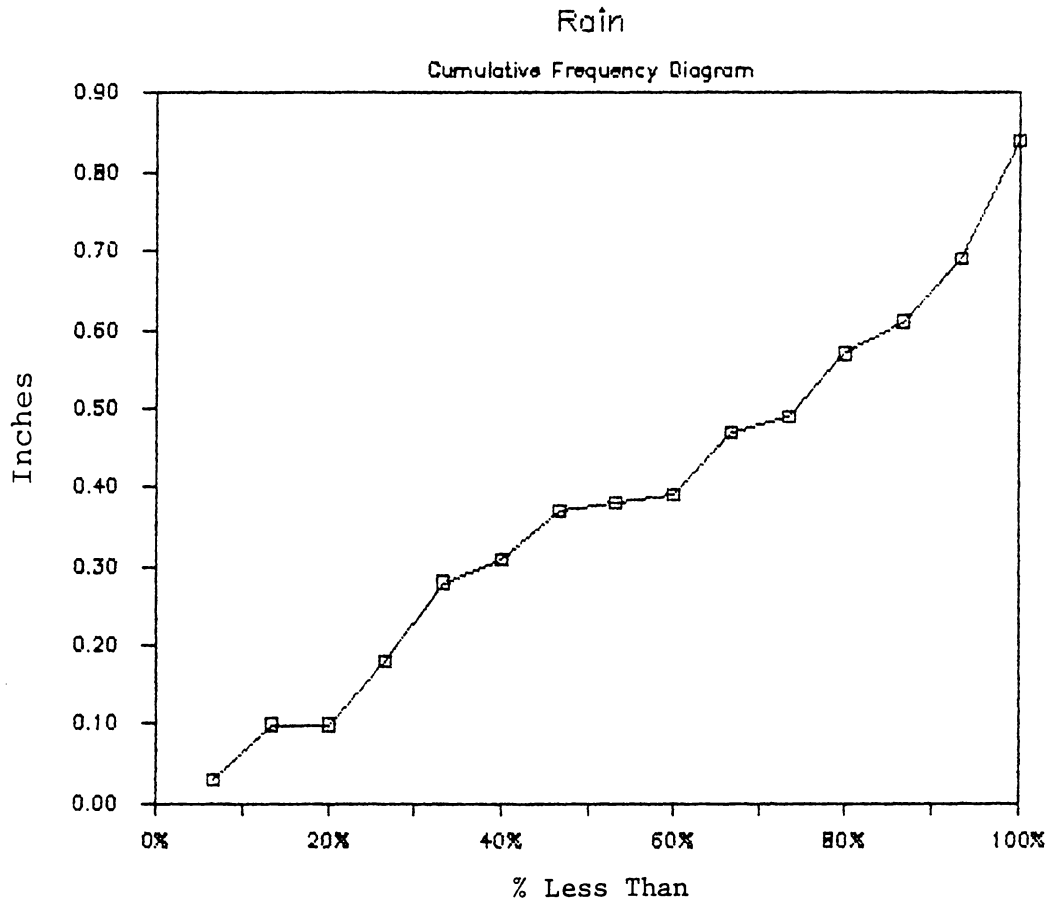
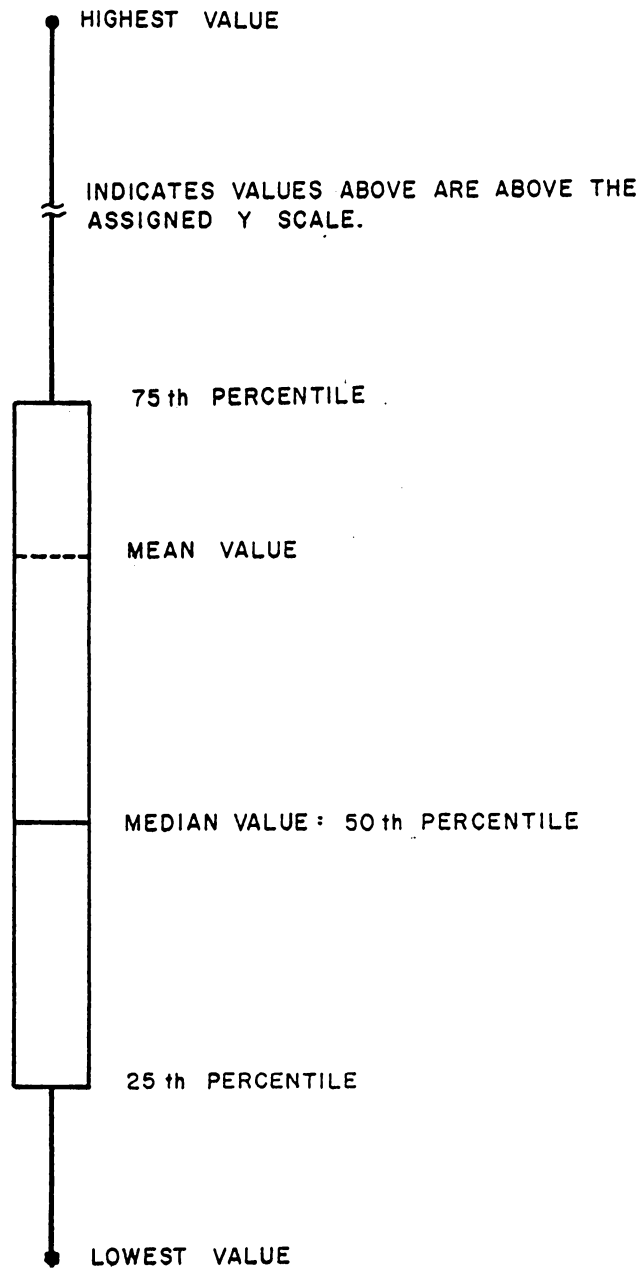


Figure 12: Rainfall for All Monitored Events:
Cumulative Frequency Diagram and
Distribution

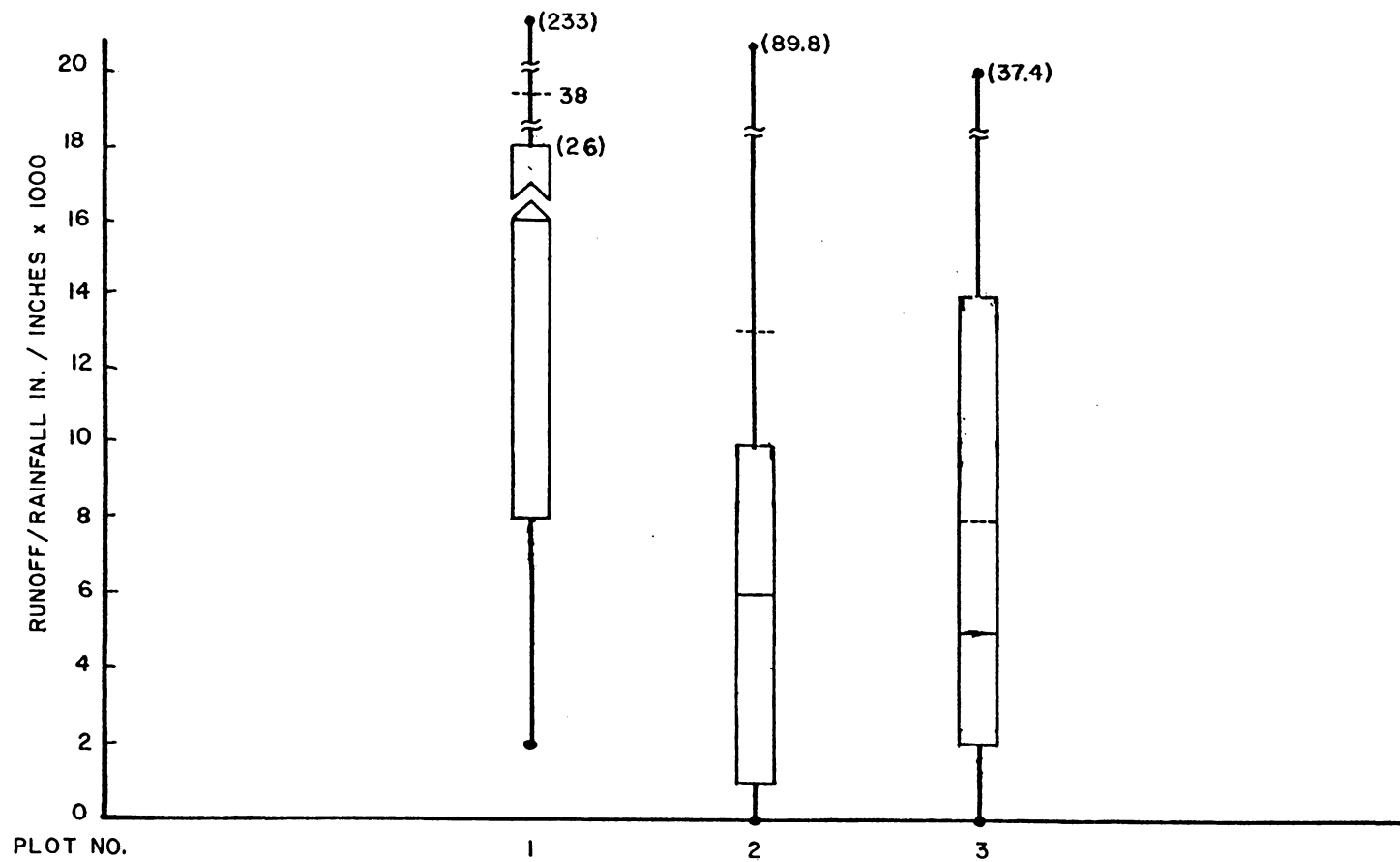


SCHEMATIC OF BOX PLOT

FIGURE 13

The cumulative frequency curves plotting the runoff/rainfall ratios for the three plots are found in Appendix D. This ratio may also be interpreted as normalized runoff volume. Figure 14 is the box plot for these distributions. The median and mean runoff/rainfall ratio were highest for Plot 1. The median runoff/rainfall ratio for Plot 1 was approximately 3 times higher than that for Plots 2 and 3. The mean and median values for Plot 2 were slightly higher than those for Plot 3, but not significantly higher. This confirms compost-amended plots allow higher water infiltration and retention.

The mean ratio for each plot is higher than the median. This indicates that the runoff/rainfall ratio distribution is not normally distributed, but is positively skewed (tail on the right). "In this sense, the mean does not seem a good indicator of the middle of the distribution. With highly skewed distributions..., the median is often reported, because it seems to represent people's concept of an average better than the mean" (Snedecor and Cochran, 1967). Unusually high runoff events inflated the means well above the medians. If the mean values were used as the average in interpreting the data, the results would be viewed at an artificially high level. The median value should therefore be used to represent the typical event instead of the mean.



RUNOFF/RAINFALL RATIO DISTRIBUTION

N = 15 10 14
 WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN.
 FIGURE 14

Flow Weighted Average Concentration

The flow weighted average concentration, averaged over the rainfall events for which runoff was collected and measured, was calculated by the following formula:

$$\text{Flow Wtd Avg Conc} = \frac{\sum_{i=1}^n \text{runoff conc (mg/L)} \times \text{runoff vol (L)}}{\sum_{i=1}^n \text{runoff volume (L)}}$$

where n = number of runoff events.

Table 7 shows the flow weighted average concentrations, to be referred to as "average concentrations", for each constituent by plot number. In Table 8, the ranges of concentrations from all events and the flow weighted average concentrations are compared to the ranges cited in the NURP study (USEPA, 1983a).

The results from this study may be seen to fall within the ranges cited in the NURP study for the metals. It should be noted that the ranges of metals cited from NURP are the low and high data points of all the reported events.

The NURP ranges reported for nutrients, TSS, and COD are event mean concentrations (EMC) of all reported events. The average concentrations of this study may be seen to fall above the EMC ranges reported in NURP. The ranges for all events for this study are much wider than those reported in

Table 7
Pollutant Concentration by Plot
Flow Weighted Average

Parameter	Units	Plot 1	Plot 2	Plot 3
OP	mg/l	0.41	0.64	0.44
TSP	mg/l	0.43	1.0	0.55
TP	mg/l	2.7	1.5	1.7
NH3	mg/l	0.60	0.60	0.74
SKN	mg/l	2.5	7.0	3.6
TKN	mg/l	9.4	8.6	8.6
OXN	mg/l	1.8	6.3	2.3
TSS	mg/l	1750	575	1090
COD	mg/l	360	175	485
Cd	ug/l	12	10	10
Cu	ug/l	115	65	70
Pb	ug/l	105	105	85
Ni	ug/l	65	40	45
Zn	ug/l	175	85	110
Cr	ug/l	125	40	90
Fe	ug/l	26800	NA	6900

Table 8 Comparison of Runoff Concentration Ranges

Constituent	NURP (1) Site Mean EMC* (mg/l)	Flow Wtd Avg Conc. (mg/l)	Conc., All Events (mg/l)
OP	NA	0.41-0.64	0.03-1.1
TSP	0.13-0.17	0.43-1.00	0.07-2.0
TP	0.37-0.47	1.5-2.7	0.24-7.6
NH3	NA	0.60-0.74	0.03-4.5
SKN	NA	2.5-7.0	0.75-15
TKN	1.68-2.12	8.6-9.4	1.0-25.5
OXN	0.76-0.96	1.8-6.3	0.01-77.0
TSS	144-224	575-1750	85-4160
COD	73-92	175-485	80-990
Metals	NURP, All Events (ug/l)	Flow Wtd Avg Conc. (ug/l)	Conc., All Events (ug/l)
Cd	0.1M-14	10-12	**6-40
Cu	1L-100	65-115	12-215
Pb	6-240	85-105	**50-304
Ni	1-182	40-65	**21-120
Zn	10-2400	85-175	13-340
Cr	1-140	40-125	**20-155
Fe	NA	6900-26800	650-28400

(1) Source EPA, 1983.

M = Presence of material verified but not quantified.

L = Actual value is known to be greater than value given.

* = Event Mean Concentration

** = Actual values may be lower; the concentration was determined to be below the detection limit, but the detection limit is cited as the value.

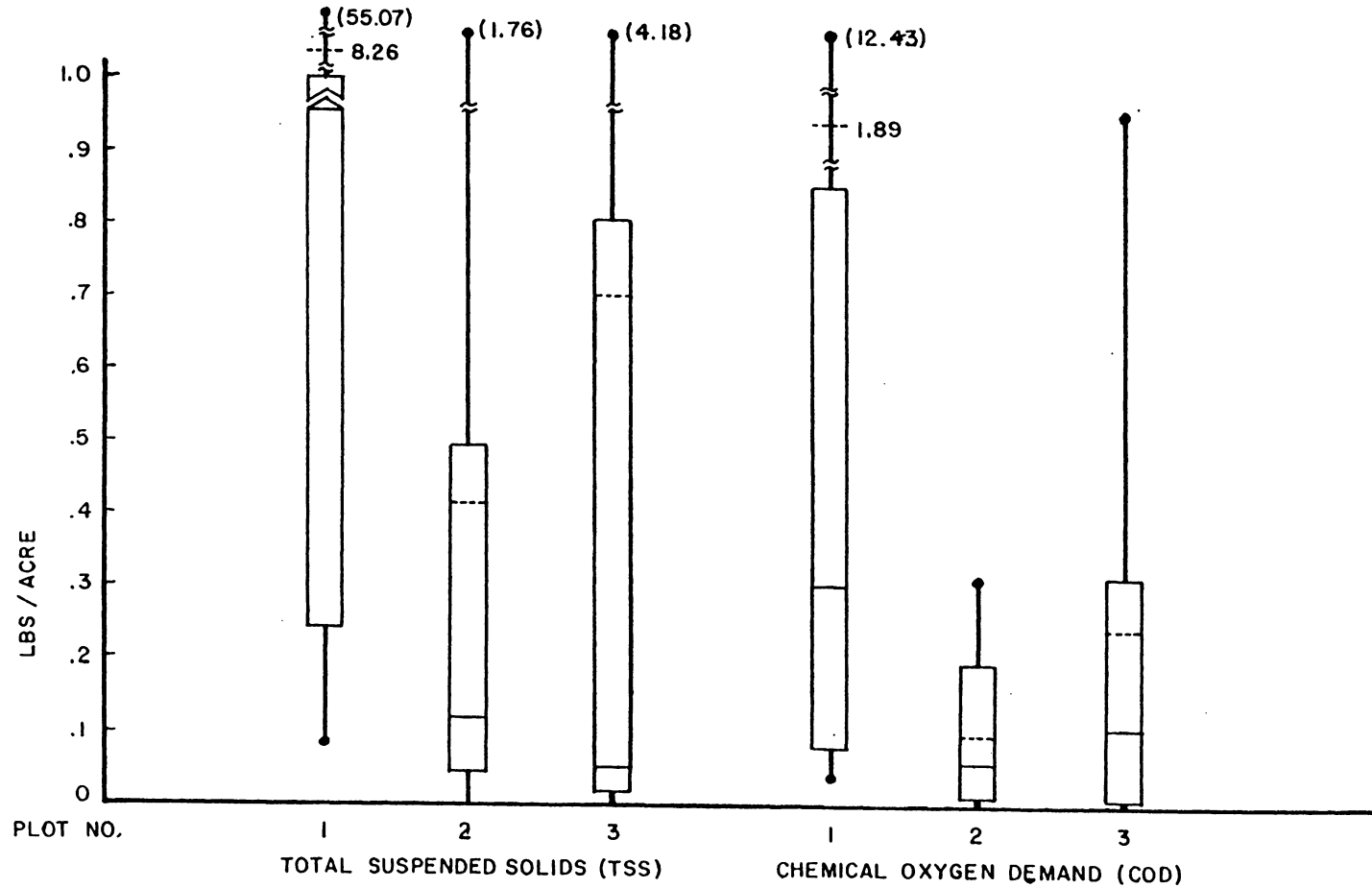
NURP. The reason for the wider ranges reported in this study may be found in the nature of the discrete land use and subsequent material application practices. Relatively large applications of nutrients were made to Plot soils, and runoff was analyzed for six months immediately following application. The NURP study analyzed runoff from residential, commercial, and mixed-use land areas under general conditions where the runoff was not correlated to a specific material application practice such as fertilization or compost amendment.

Storm Loads and Normalized Storm Loads

The storm loads (loads) for each constituent were calculated by the following formula:

$$\text{Load (lbs/acre)} = \frac{\text{runoff conc (mg/L)} \times \text{runoff volume (L)} \times 43560 \text{ sf/acre}}{453,600 \text{ mg/lb} \times 566.52 \text{ sf (plot area)}}$$

The normalized storm loads (yields) were calculated by dividing the storm load (lbs/acre) for each event by the inches of rainfall for that event. The loads and yields are tabulated for each parameter for each monitored event in Appendix B. Box plots for each parameter are shown in Figures 15-24. The values to construct the box plots were

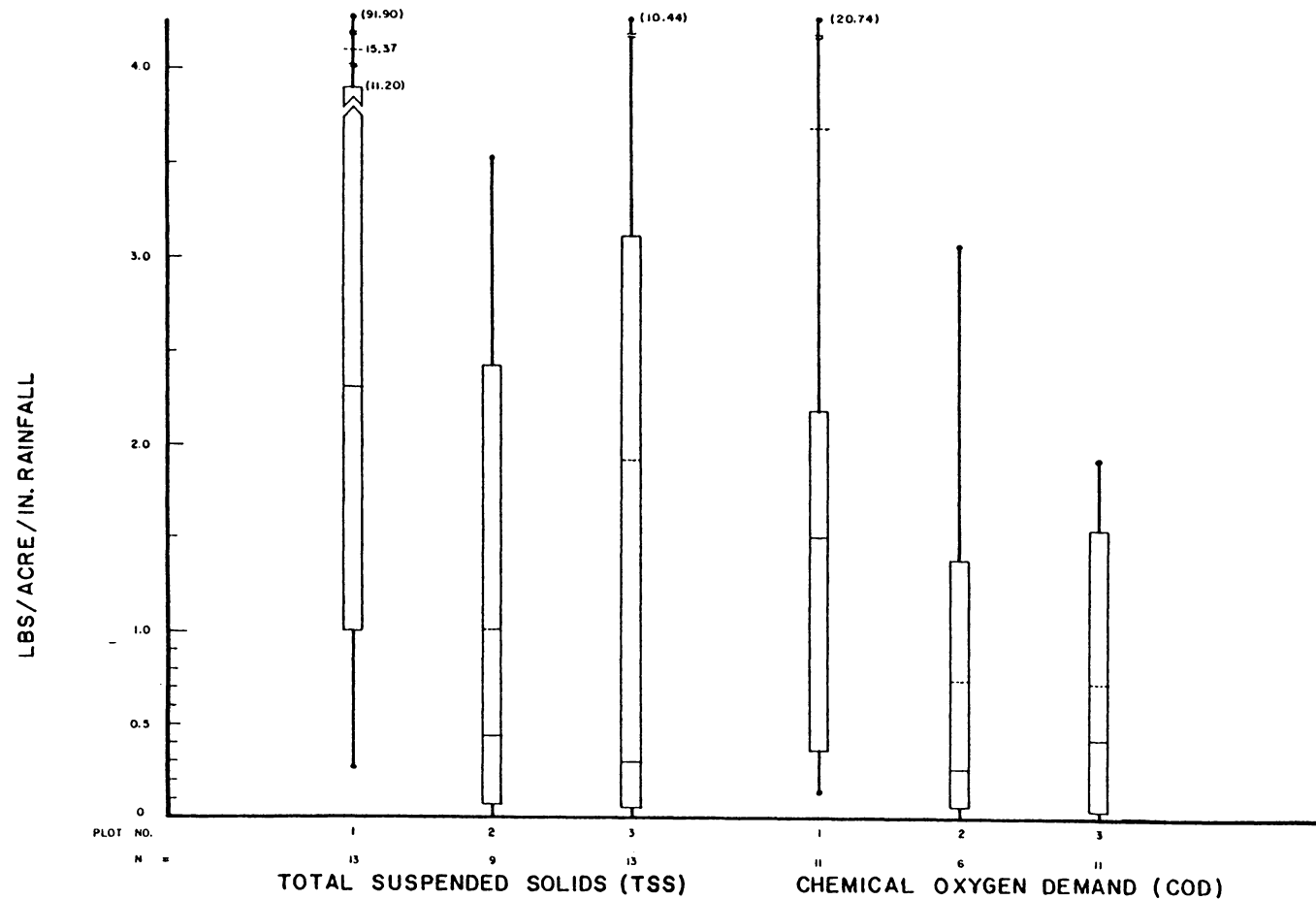


LOAD DISTRIBUTION OF TOTAL SUSPENDED SOLIDS AND CHEMICAL OXYGEN DEMAND IN RUNOFF

N = 13 9 13 11 6 11

WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN.

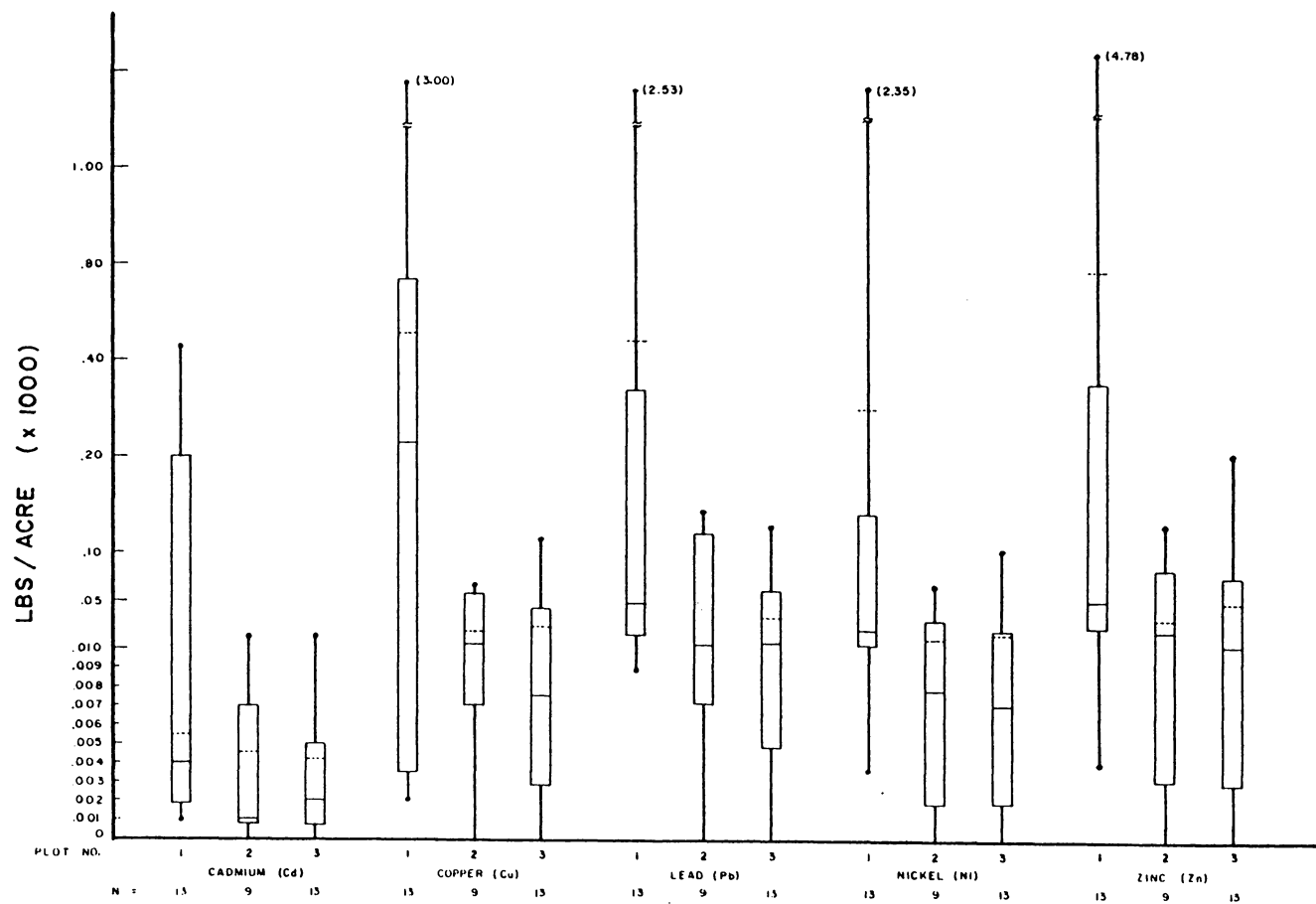
FIGURE 15



YIELD DISTRIBUTION OF TOTAL SUSPENDED SOLIDS AND CHEMICAL OXYGEN DEMAND IN RUNOFF

WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN.

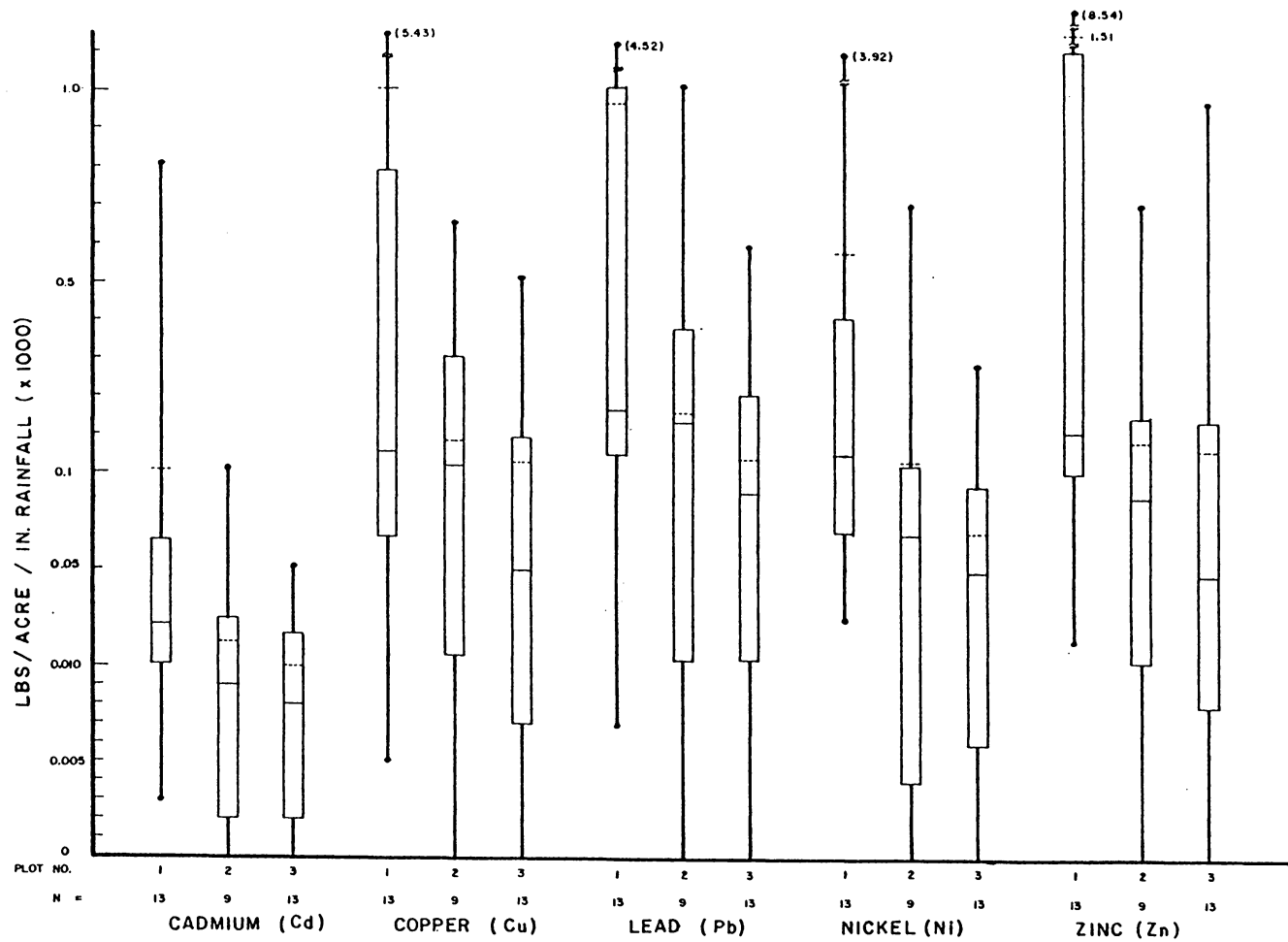
FIGURE 16



LOAD DISTRIBUTION OF METALS IN RUNOFF

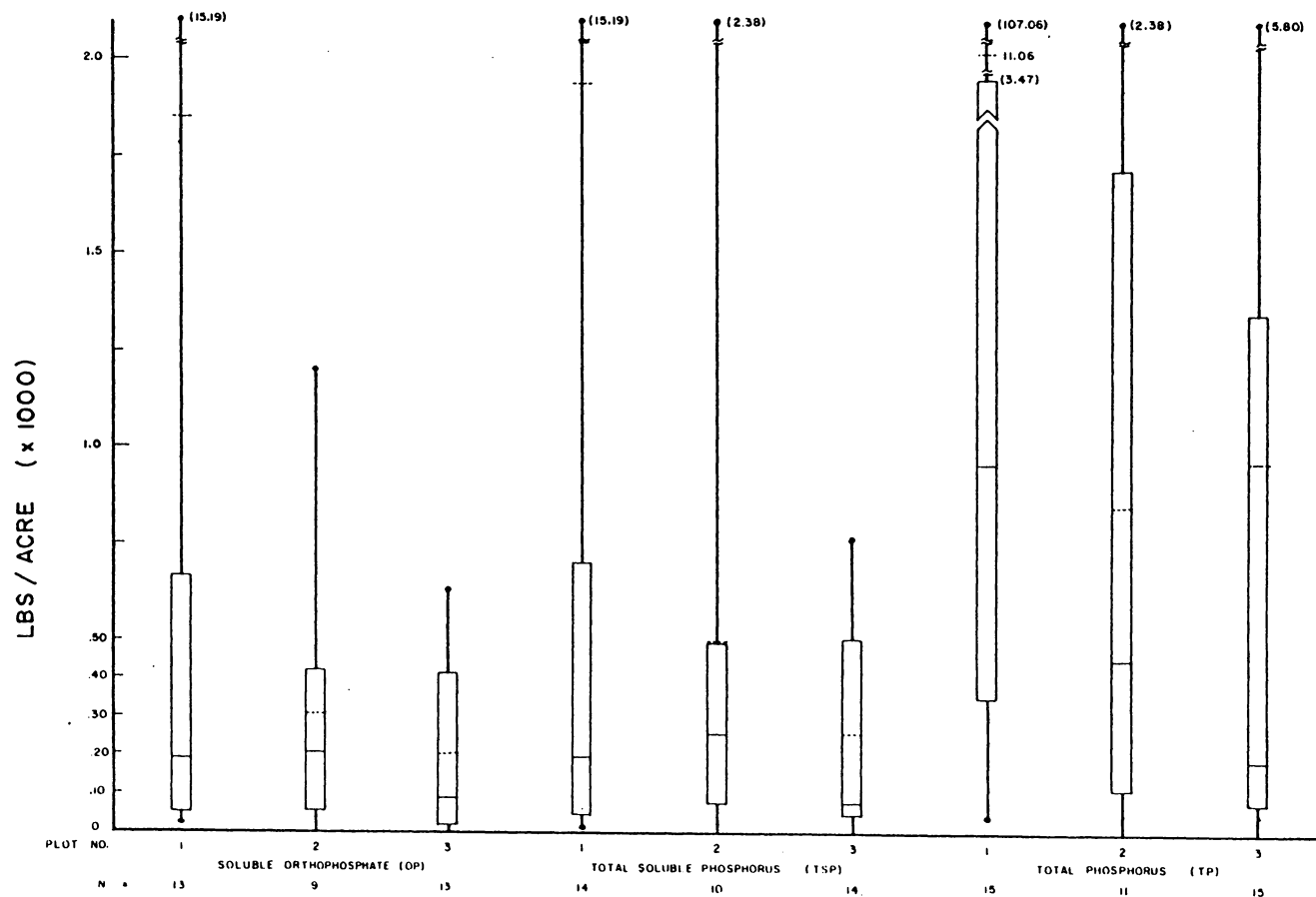
WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN

FIGURE 17



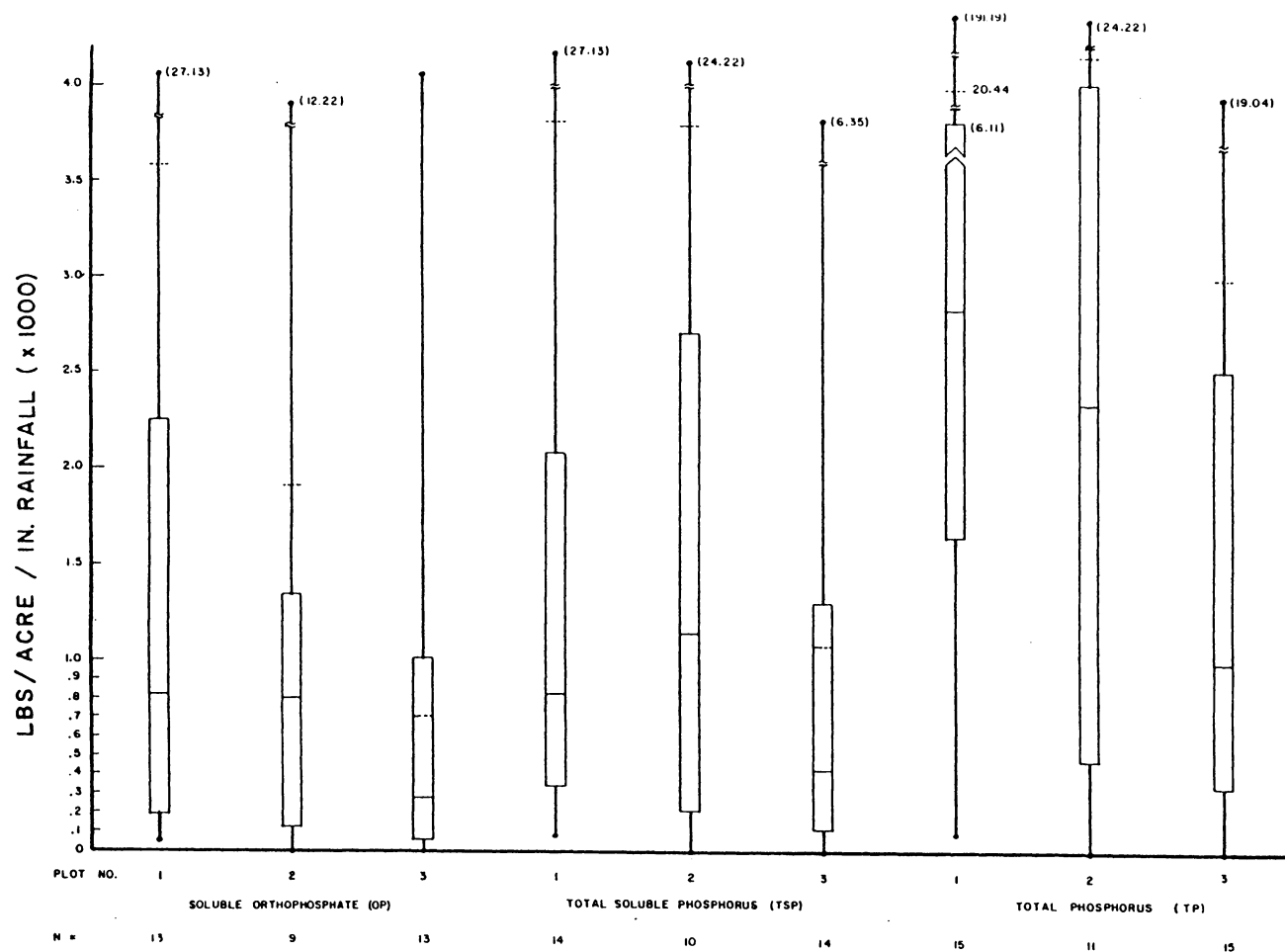
YIELD DISTRIBUTION OF METALS IN RUNOFF

WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN
FIGURE 18



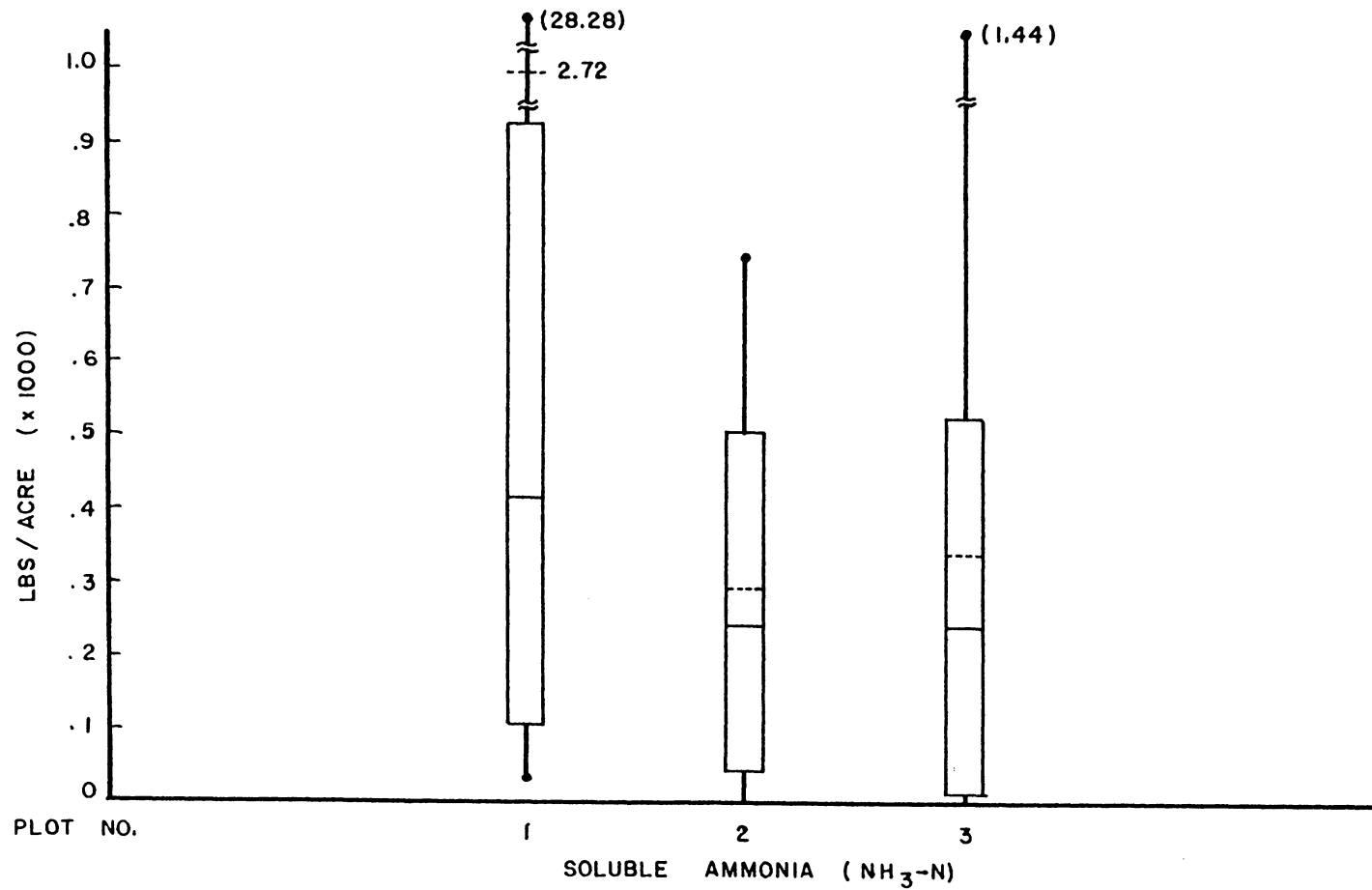
LOAD DISTRIBUTION OF SOLUBLE ORTHOPHOSPHATE, TOTAL SOLUBLE PHOSPHORUS, TOTAL PHOSPHORUS IN RUNOFF

WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN
FIGURE 19



YIELD DISTRIBUTION OF SOLUBLE ORTHOPHOSPHATE,
TOTAL SOLUBLE PHOSPHORUS, TOTAL PHOSPHORUS
IN RUNOFF

WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN
FIGURE 20



LOAD DISTRIBUTION OF SOLUBLE AMMONIA IN RUNOFF

N = 13 9 13
 WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN

FIGURE 21

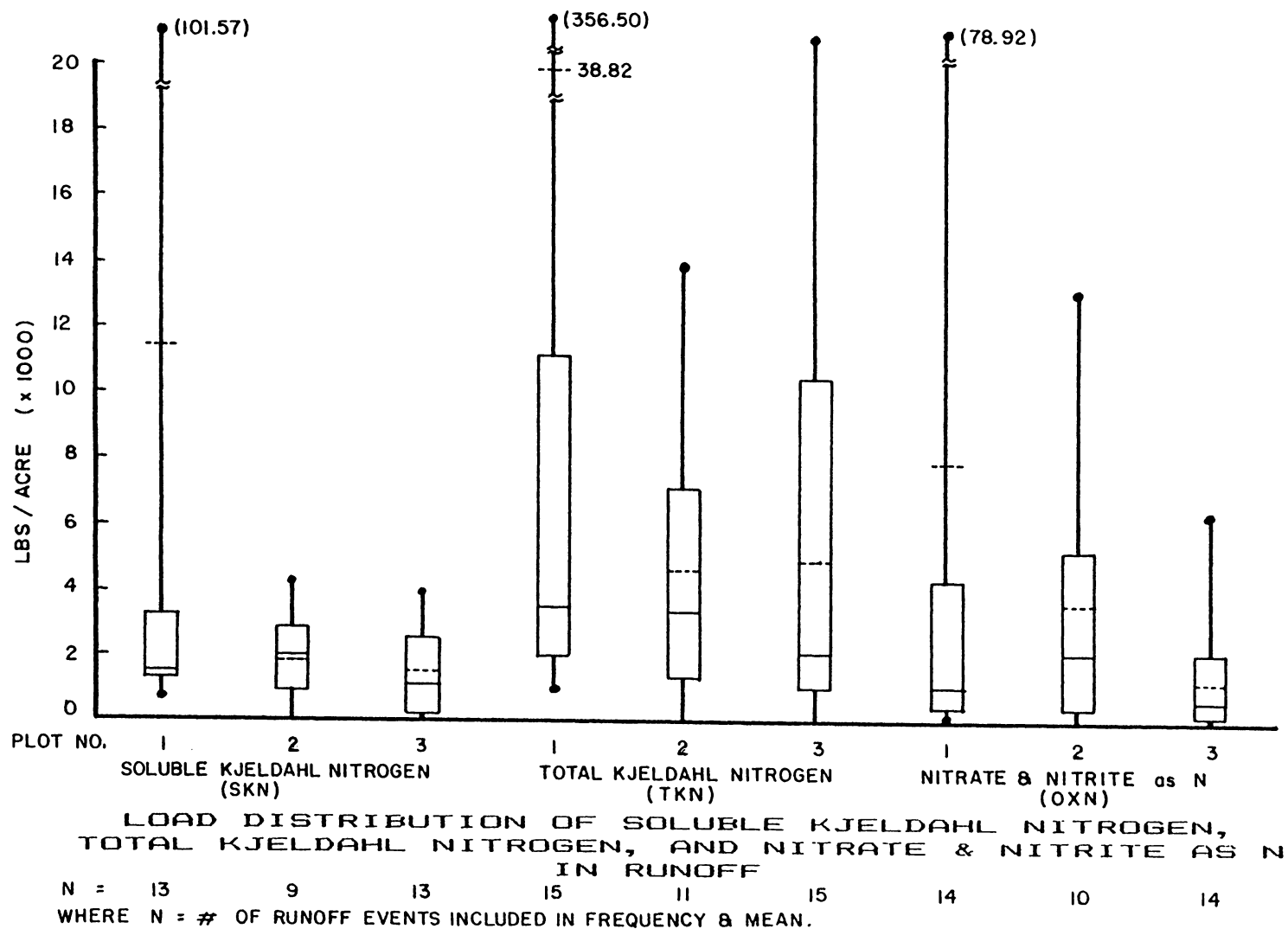
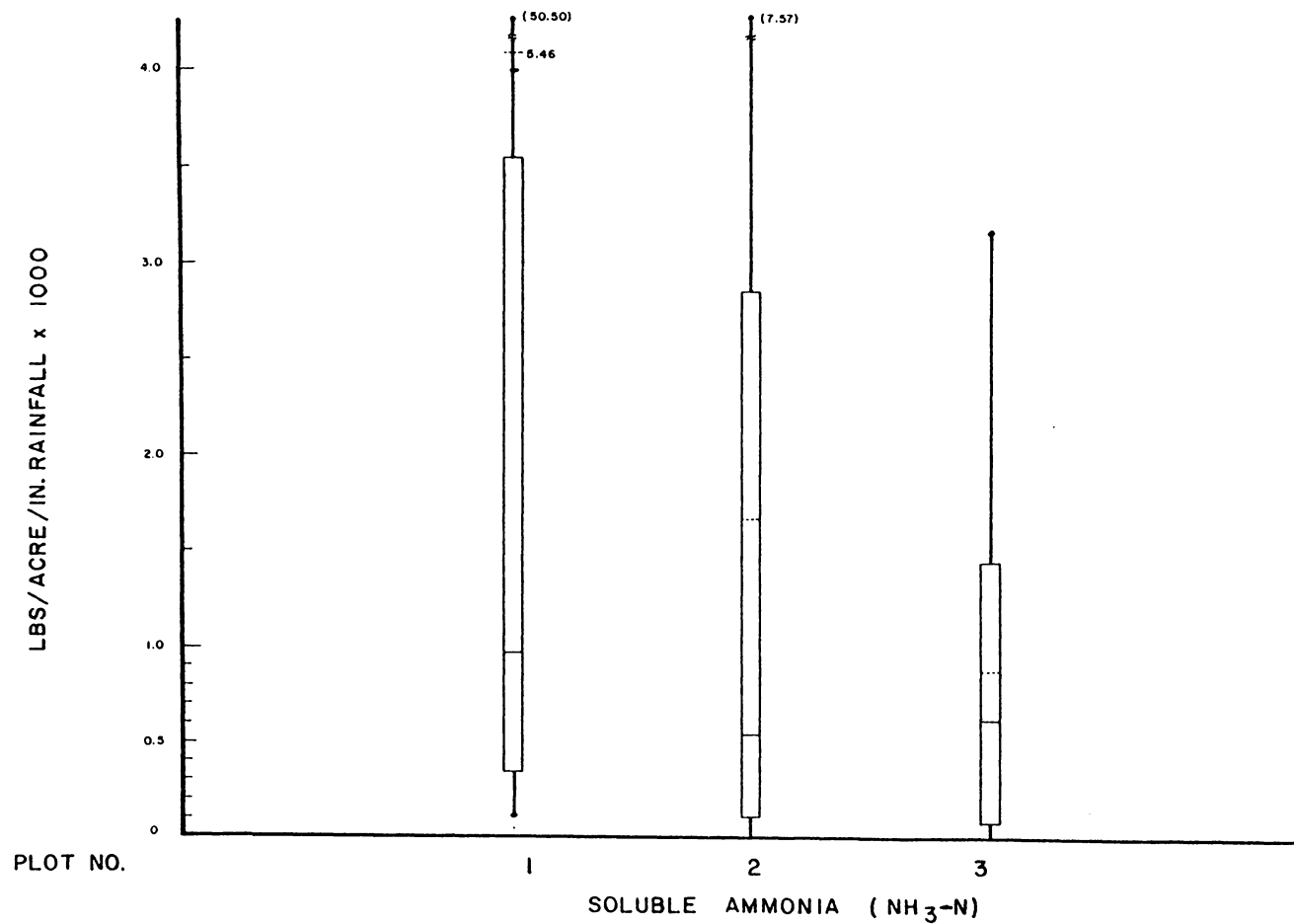


FIGURE 22



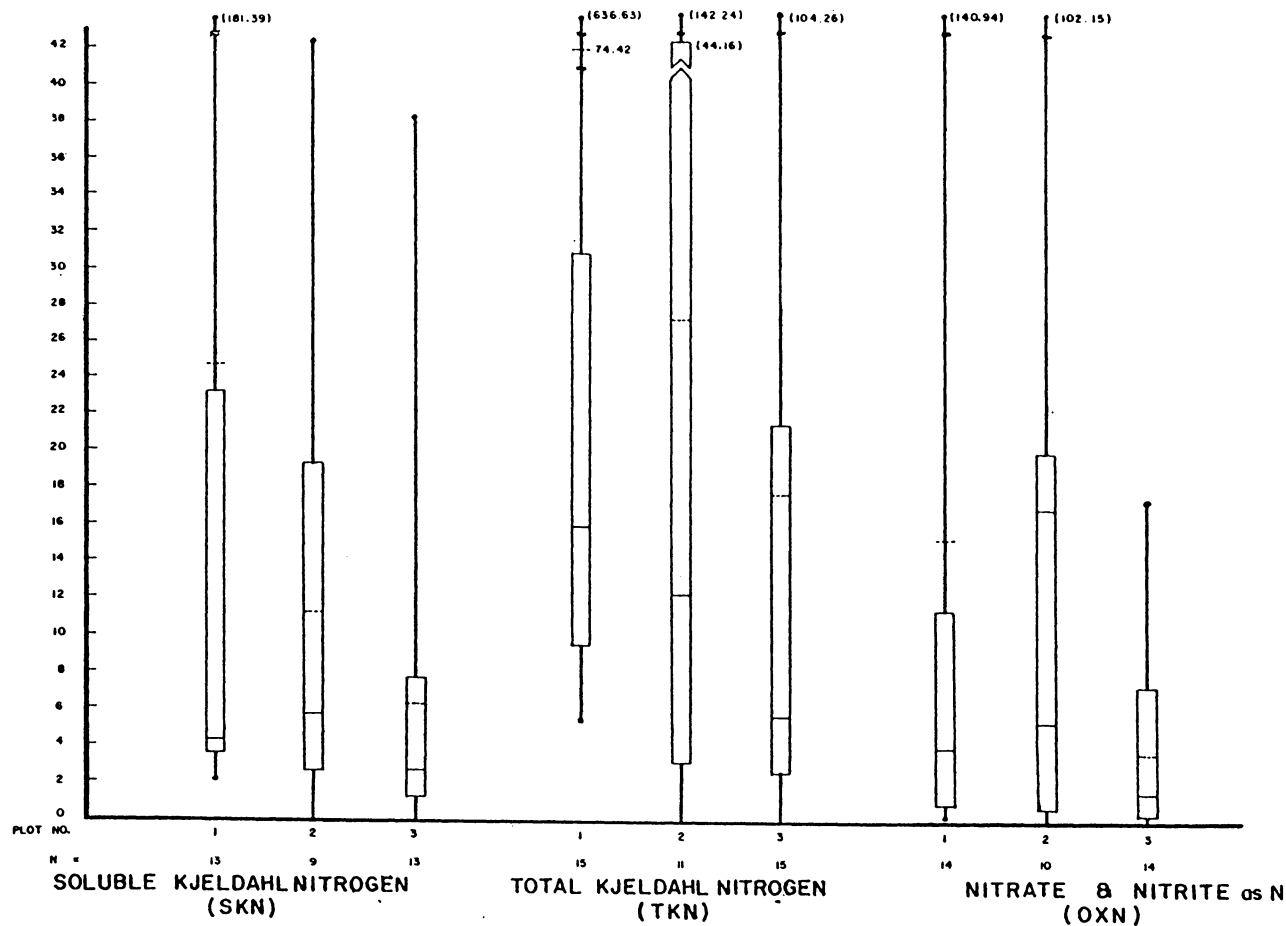
YIELD DISTRIBUTION OF SOLUBLE AMMONIA IN RUNOFF

N = 13 9 13

WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN.

FIGURE 23

LBS/ACRE/IN. RAINFALL x 1000



YIELD DISTRIBUTION OF SOLUBLE KJELDAHL NITROGEN, TOTAL KJELDAHL NITROGEN, AND NITRATE & NITRITE AS N IN RUNOFF

WHERE N = # OF RUNOFF EVENTS INCLUDED IN FREQUENCY & MEAN.

FIGURE 24

calculated using the SPSS-X computer program (SPSS-X). The median loads and yields are used instead of the mean to represent the average. As indicated by the box plots for each constituent, the means were substantially higher than the median, indicating the sample population was not normally distributed. As previously discussed, under these circumstances, the median is a better representative of the average of the population than is the mean. The median loads and yields are tabulated in Tables 9 and 10, respectively. The ratios among the median loads and yields for the three plots are also presented for reference in discussing the results.

Total Suspended Solids in Runoff

The cumulative frequency diagram for TSS yield is shown in Figure 25. Plot 1 TSS yields were consistently higher than those for Plots 2 and 3. TSS concentrations ranged from 86 to 4,163 mg/L.

The average concentrations are shown graphically for all three plots in Figure 26. The total suspended solids concentration found in Plot 1 runoff was observed to be approximately 3 times that of Plot 2 and 1.5 times that of Plot 3. Plot 2 runoff was found to be half that of Plot 3 runoff. The amended soil appeared to retain more of the particulate matter.

Table 9
Median Storm Loads by Plot
lbs/acre (x 1000)

	Plot 1	Plot 2	Plot 3	Plot 1/ Plot 2	Plot 1/ Plot 3	Plot 2/ Plot 3
OP	0.18	0.20	0.08	0.9	2.1	2.4
TSP	0.20	0.25	0.08	0.8	2.6	3.4
TP	0.96	0.45	0.18	2.1	5.3	2.5
NH3	0.42	0.24	0.24	1.7	1.7	1.0
SKN	1.5	2.0	1.2	0.8	1.3	1.7
TKN	3.5	3.4	2.1	1.0	1.6	1.6
OXN	1.0	2.0	0.65	0.5	1.6	3.1
TSS	960	140	60	6.9	16.0	2.3
COD	300	50	100	6.0	3.0	0.5
Cd	0.004	0.001	0.002	3.0	2.0	0.7
Cu	0.02	0.02	0.01	1.4	3.1	2.2
Pb	0.05	0.02	0.02	3.1	2.9	0.9
Ni	0.03	0.01	0.01	3.6	3.9	1.1
Zn	0.05	0.02	0.01	2.1	4.3	2.1
Cr (1)	0.11	0.04	0.05	2.8	2.5	0.9
Fe (2)	20.4	NA	2.3	NA	8.7	NA

(1) Includes only 3 events.

(2) Concentration data not available for Plot 2.

Table 10 Median Normalized Storm Load (Yield) by Plot
 lbs/acre/inch rainfall (x 1000)

Parameter	Plot 1	Plot 2	Plot 3	Plot 1/ Plot 2	Plot 1/ Plot 3	Plot 2/ Plot 3
OP	0.82	0.80	0.27	1.03	3.04	2.94
TSP	0.82	1.15	0.43	0.72	1.93	2.70
TP	2.8	2.3	0.99	1.21	2.87	2.36
NH3	0.98	0.55	0.63	1.78	1.55	0.87
SKN	4.3	5.7	2.6	0.75	1.64	2.19
TKN	16.0	12.3	5.6	1.53	3.35	2.19
OXN	4.0	5.3	1.5	0.74	2.59	3.49
TSS	2300	450	300	5.56	8.33	1.50
COD	1500	260	410	5.90	3.81	0.65
Cd	0.02	0.01	0.01	4.00	4.00	1.00
Cu	0.16	0.12	0.05	1.27	3.18	2.50
Pb	0.27	0.24	0.09	1.13	3.00	2.67
Ni	0.15	0.07	0.05	2.46	3.08	1.25
Zn	0.21	0.09	0.05	2.33	4.38	1.88
Cr (1)	0.41	0.14	0.16	3.25	2.60	0.80
Fe (2)	44.2	NA	5.0	NA	NA	NA

(1) Includes only 3 events.

(2) Concentration data not available for Plot 2.

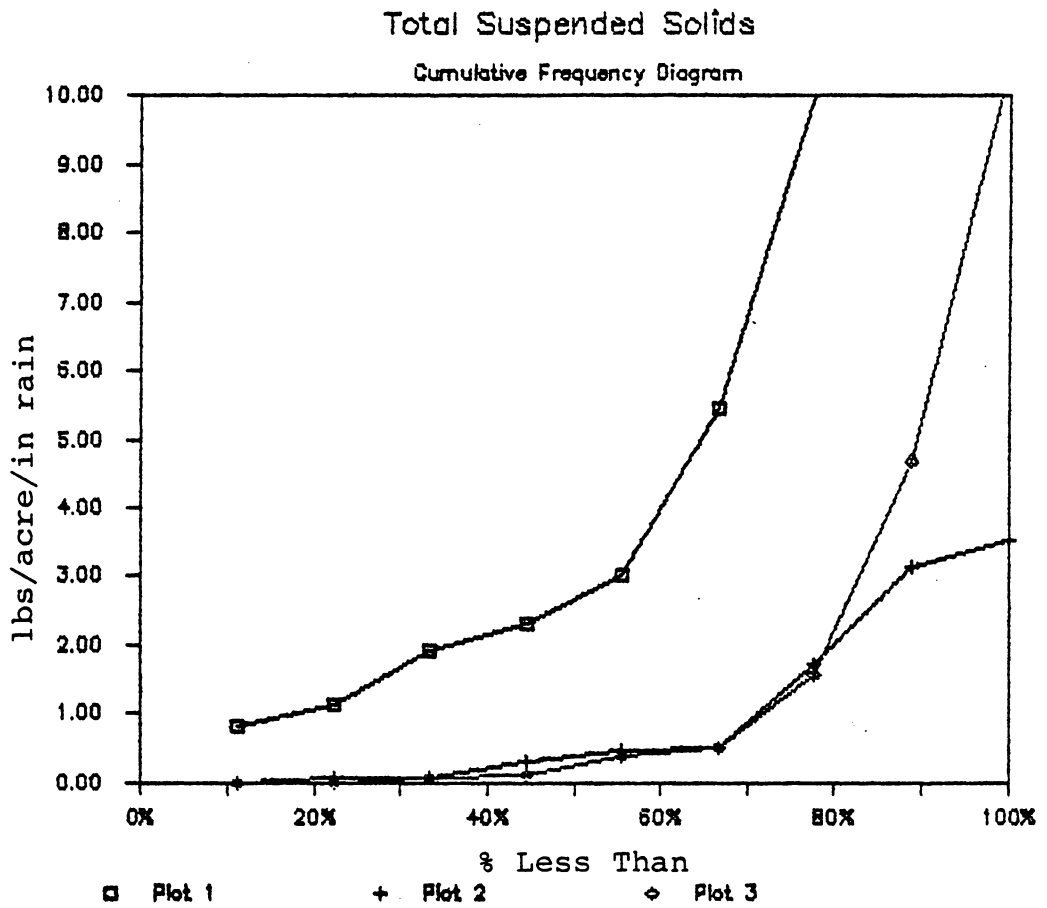


Figure 25: Cumulative Frequency Diagram of TSS Yields

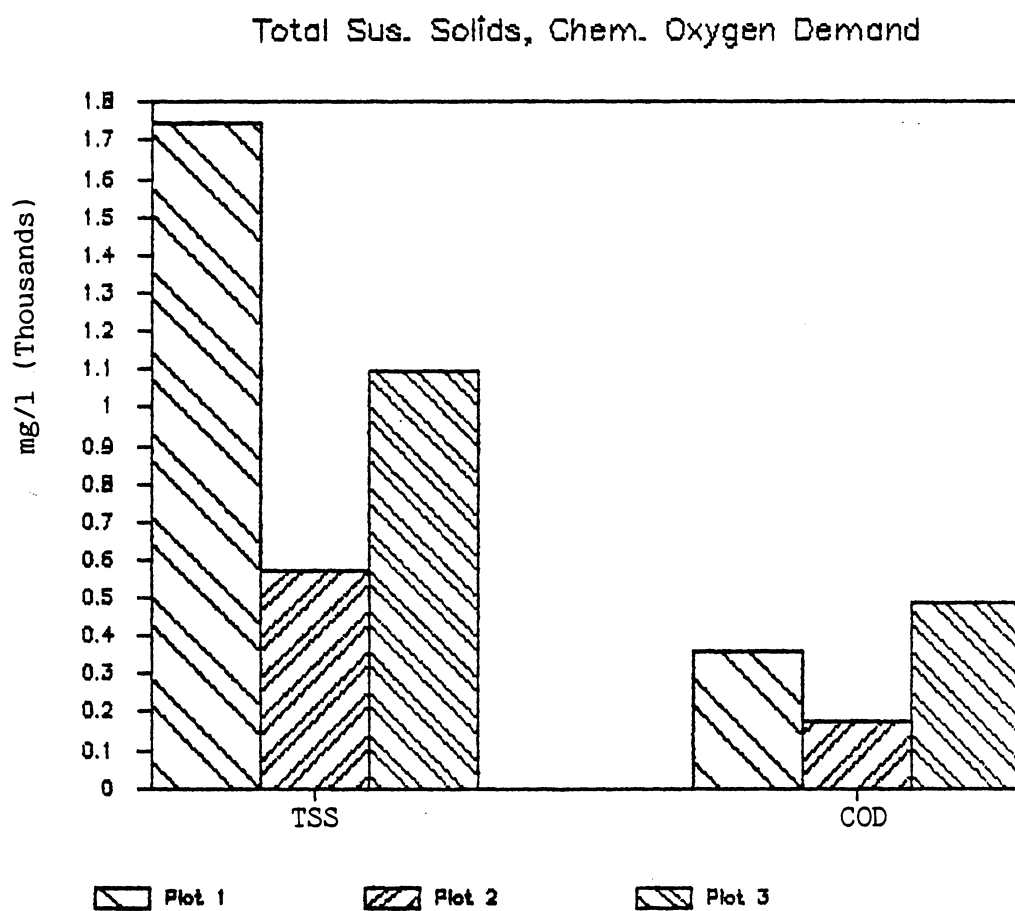


Figure 26: Flow Weighted Average Concentration of TSS and COD

The median storm load from Plot 1 was approximately 7 times that of Plot 2 and 17 times that of Plot 3 as shown in Figure 27. Plot 2 median load was 2.5 times Plot 3 median load. A similar pattern was observed for yield. When normalized, Plot 1 median load was over 5 times that of Plot 2 and almost 8 times that of Plot 3, illustrated in Figure 28. Plot 2 median yield was 1.5 times Plot 3 median yield. This is in contrast to the average concentration pattern observed which showed Plot 2 TSS to be almost half that of Plot 3. The box plots in Figures 15 and 16 illustrate the similarity between the overall Plot 2 and 3 TSS load and yield distributions. The important observation to note, however, is the substantially higher Plot 1 TSS exported compared to Plots 2 and 3.

The data illustrate and confirm the literature (Barbarika et al., 1980; Parr et al., 1978) which reported that decreased soil erosion occurred from compost-amended soil. The unamended Plot 1 discharged significantly more TSS per inch of rainfall than did amended Plots 2 and 3. Further, fertilizer application to compost-amended soil had no observable effect on the export of particulate matter.

Referring to Table 8, TSS average concentration was lowest and the OP, TSP, and SKN concentrations were highest for Plot 2. Biggar and Corey (1969) suggested that soluble N and P concentrations could be reduced in runoff due to

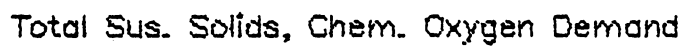


Figure 27:- Median Storm Load of TSS and COD

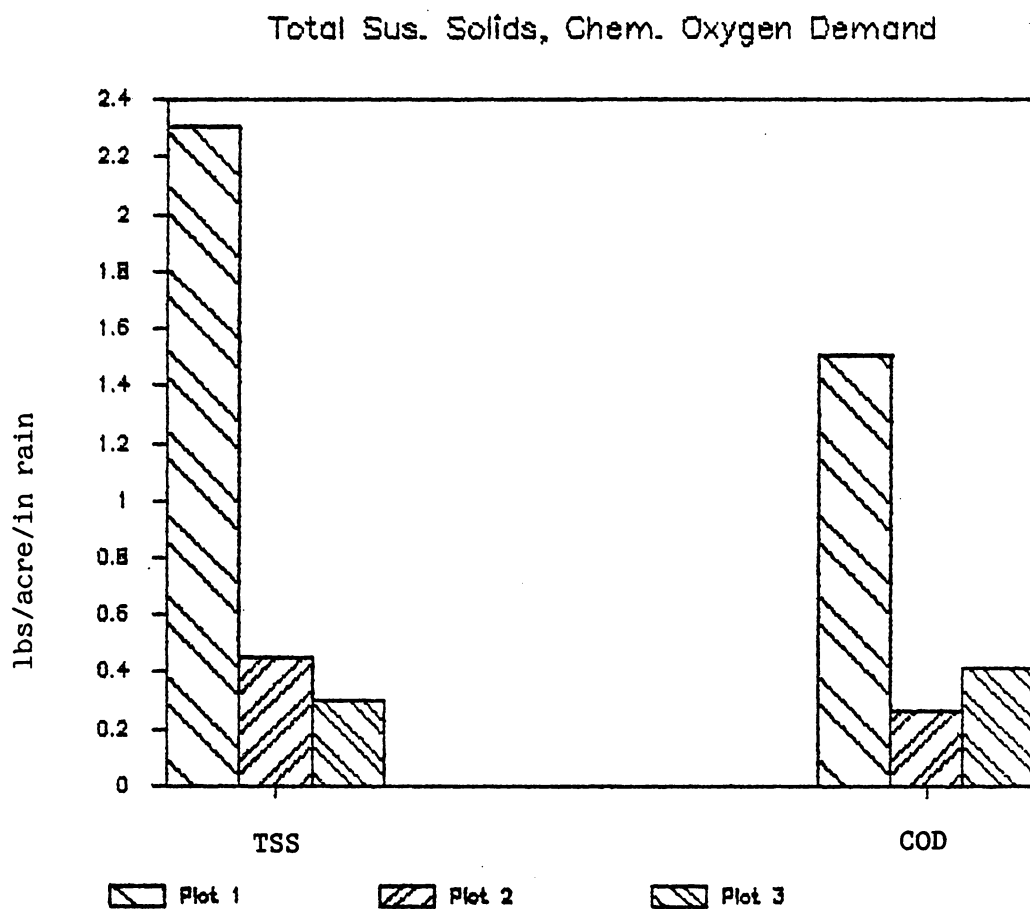


Figure 28: Median Yield of Total Suspended Solids and Chemical Oxygen Demand

adsorption in suspended material. The observations appear to support this conclusion; OP, TSP, and SKN concentrations in the runoff were relatively high when the TSS was relatively low.

Chemical Oxygen Demand in Runoff

The cumulative frequency diagram for COD yields is shown in Figure 29. Plot 1 COD yields were consistently higher than those for Plots 2 and 3. Plots 2 and 3 had similar yields. COD concentrations ranged from 78 to 988 mg/L.

The average concentrations are presented graphically in Figure 26. The chemical oxygen demand found in the Plot 3 runoff was 35% greater than Plot 1 and 300% greater than Plot 2. Because organic matter content was increased in the soil due to the addition of compost, the COD concentration in the runoff was expected to be higher from the amended Plots 2 and 3. The extreme difference observed between the COD concentrations of Plots 2 and 3 was not expected because equal amounts of compost were incorporated into each plot. The average concentration of Plot 2 appears to have been depressed because of one exceptionally low concentration value obtained on October 7, 1986.

The box plot diagrams in Figures 15 and 16 better reflect the trend among the Plots. COD exported from Plot 1

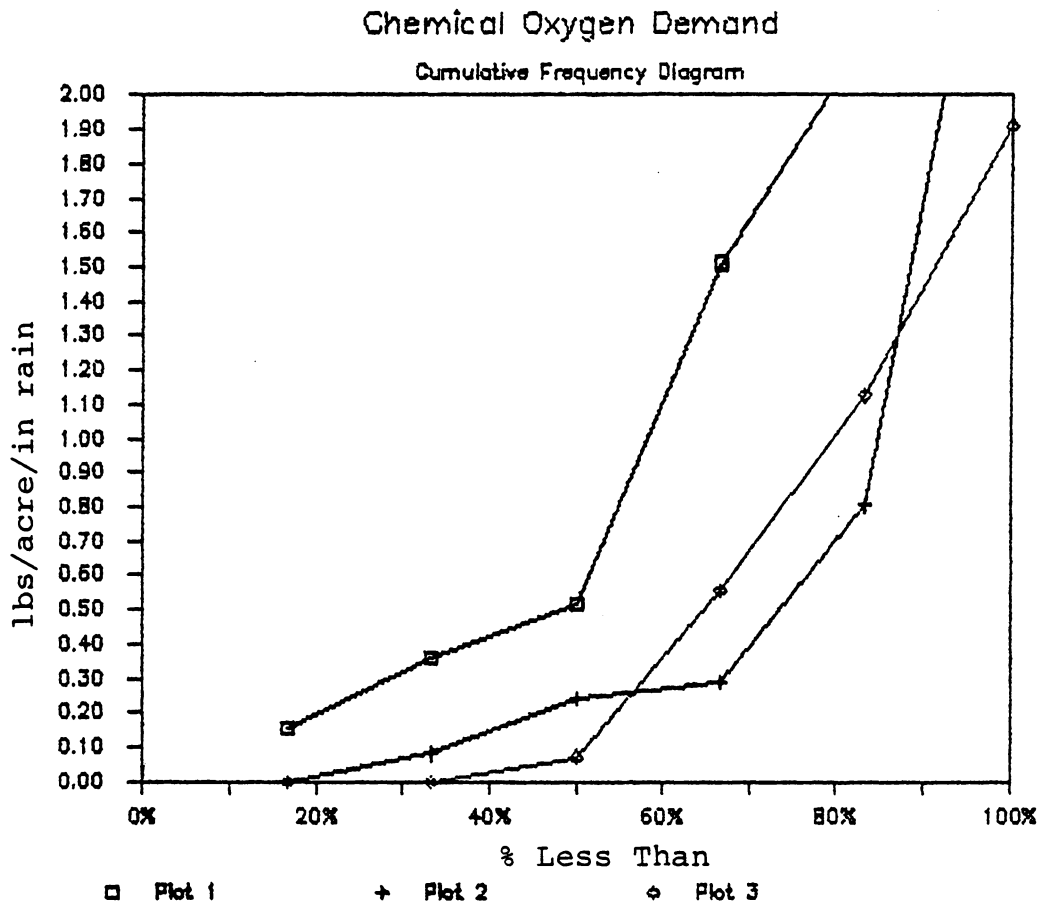


Figure 29: Cumulative Frequency Diagram of COD Yields

was highest. The median COD loads and yields, presented graphically in Figures 28 and 29, from Plot 1 were almost 6 times as high as Plot 2. The COD median load from Plot 1 was nearly 3 times that of Plot 3, and the median yield from Plot 1 was over 3.5 times that of Plot 3. Plot 3 median load and yield were higher than those for Plot 2 by factors of 1.9 and 1.6, respectively.

The pattern between Plots 2 and 3 observed in the average concentrations is thus repeated for load and yield. However, the pattern between Plot 1 and 3 is not repeated. Instead, COD export from Plot 3 was substantially lower than Plot 1 export even though Plot 3 concentration was highest. It may be seen that the organic matter exported in the runoff, approximated in this study by the COD analyses, was significantly less in compost-amended soils. The application of fertilizer to compost-amended soil did not appear to increase export of COD.

Metals in Runoff

The cumulative frequency diagrams for the yields of the metals analyzes are shown in Figures 30-35. As for TSS and COD yields, Plot 1 yields were consistently highest, and Plots 2 and 3 were similar and often approximately equal.

The average concentrations for the metals, shown in Figure 36, from Plot 1 were observed to be higher than those

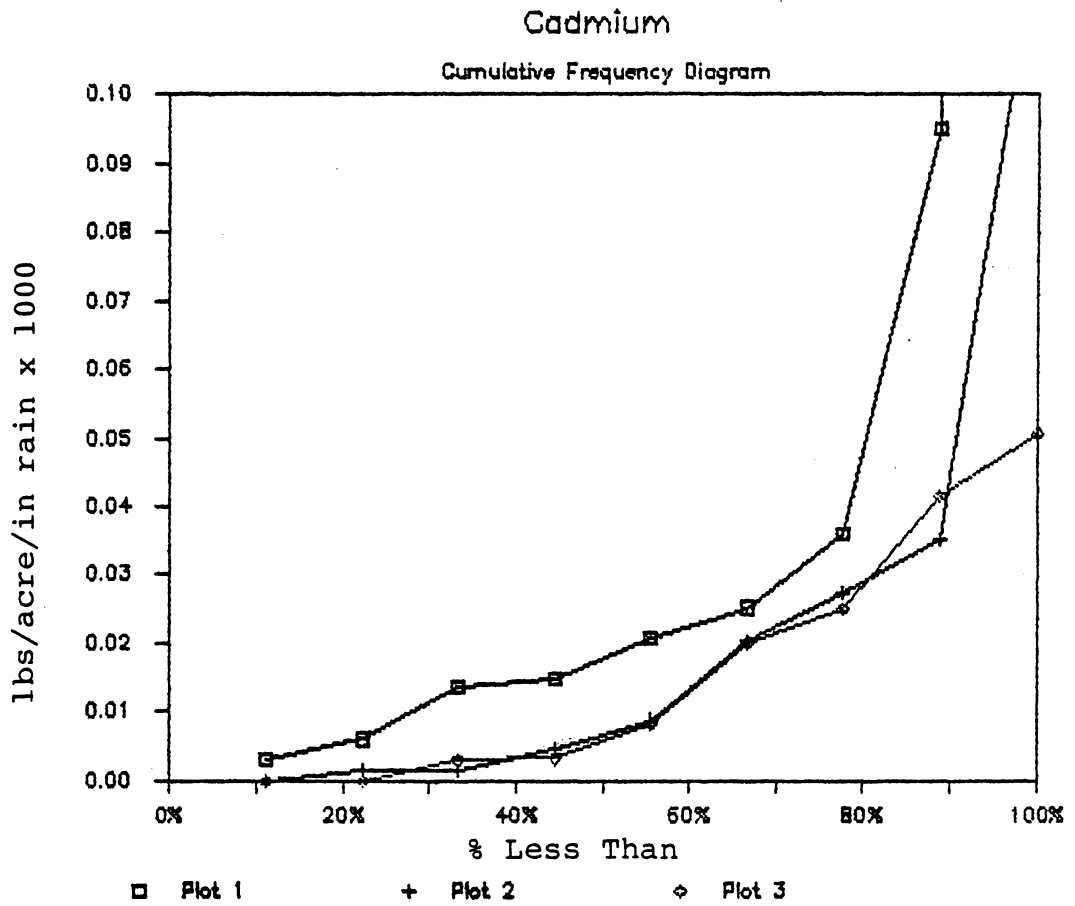


Figure 30: Cumulative Frequency Diagram of CD Yields

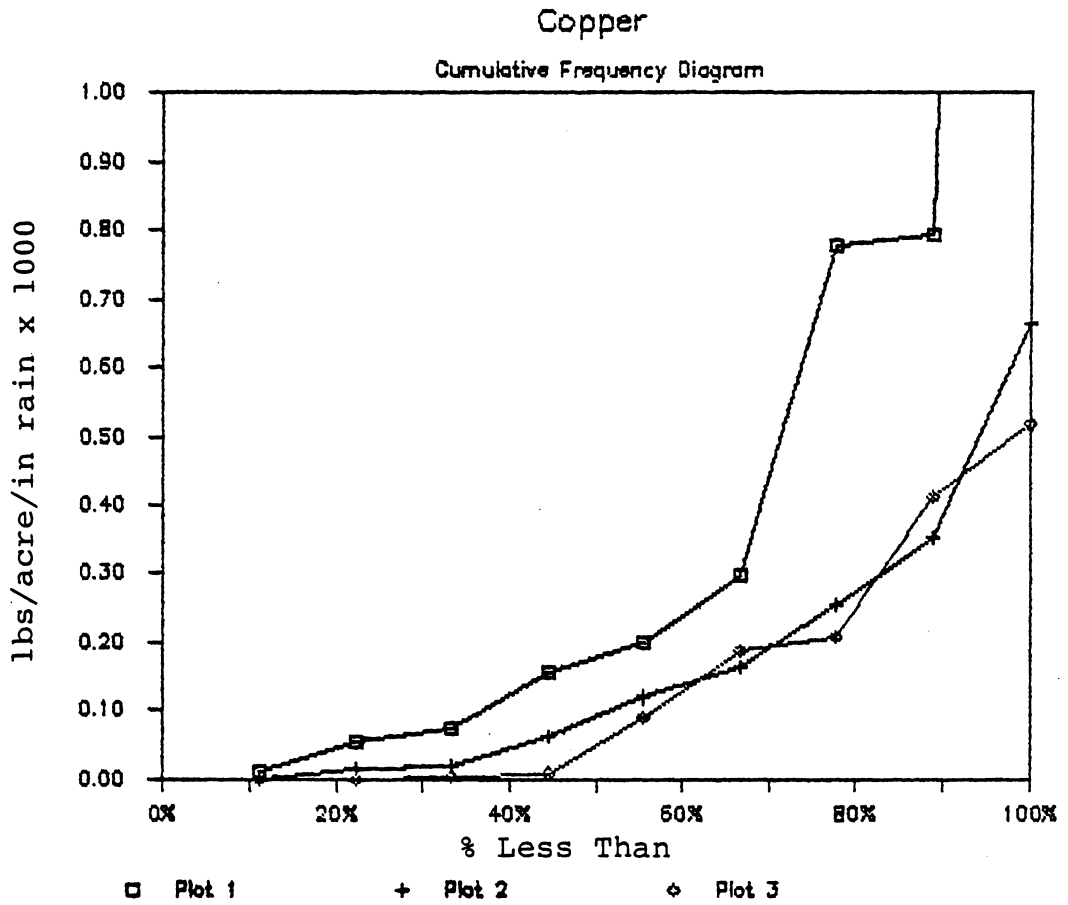


Figure 31: Cumulative Frequency Diagram of Cu Yields

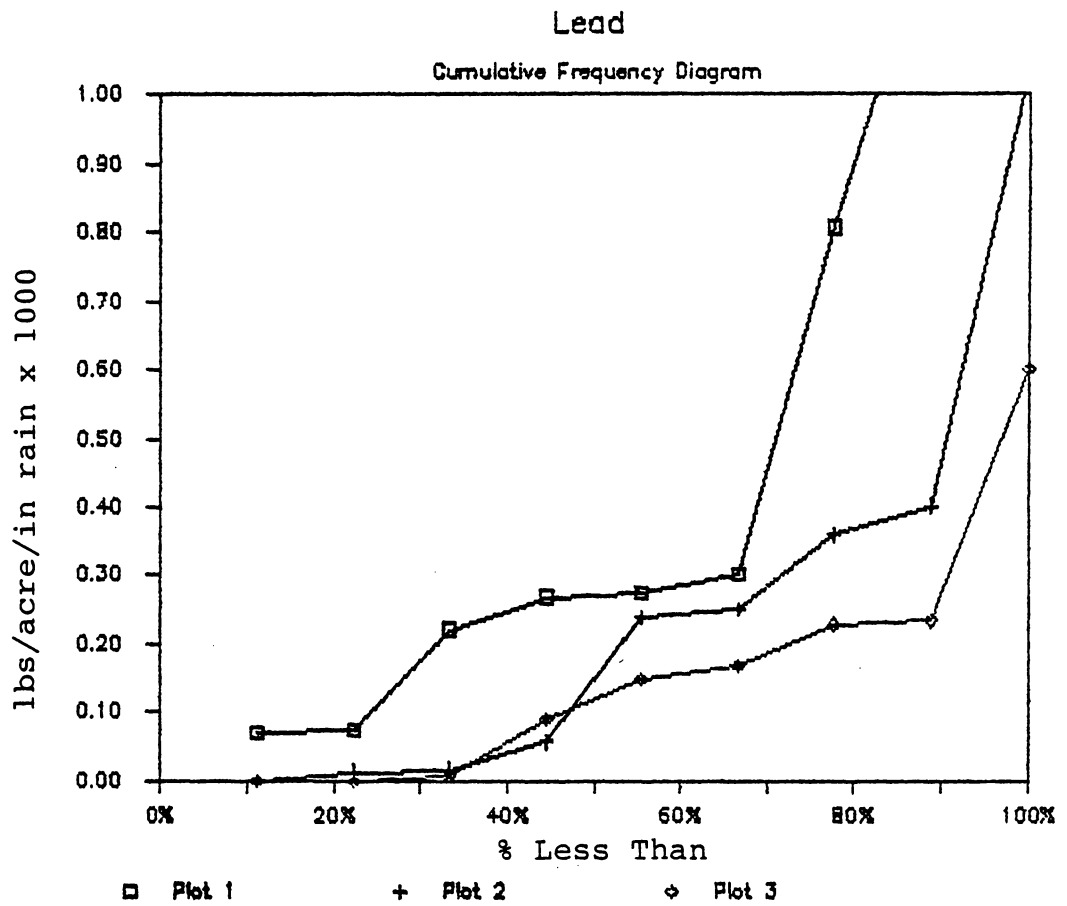


Figure 32: Cumulative Frequency Diagram of Pb Yields

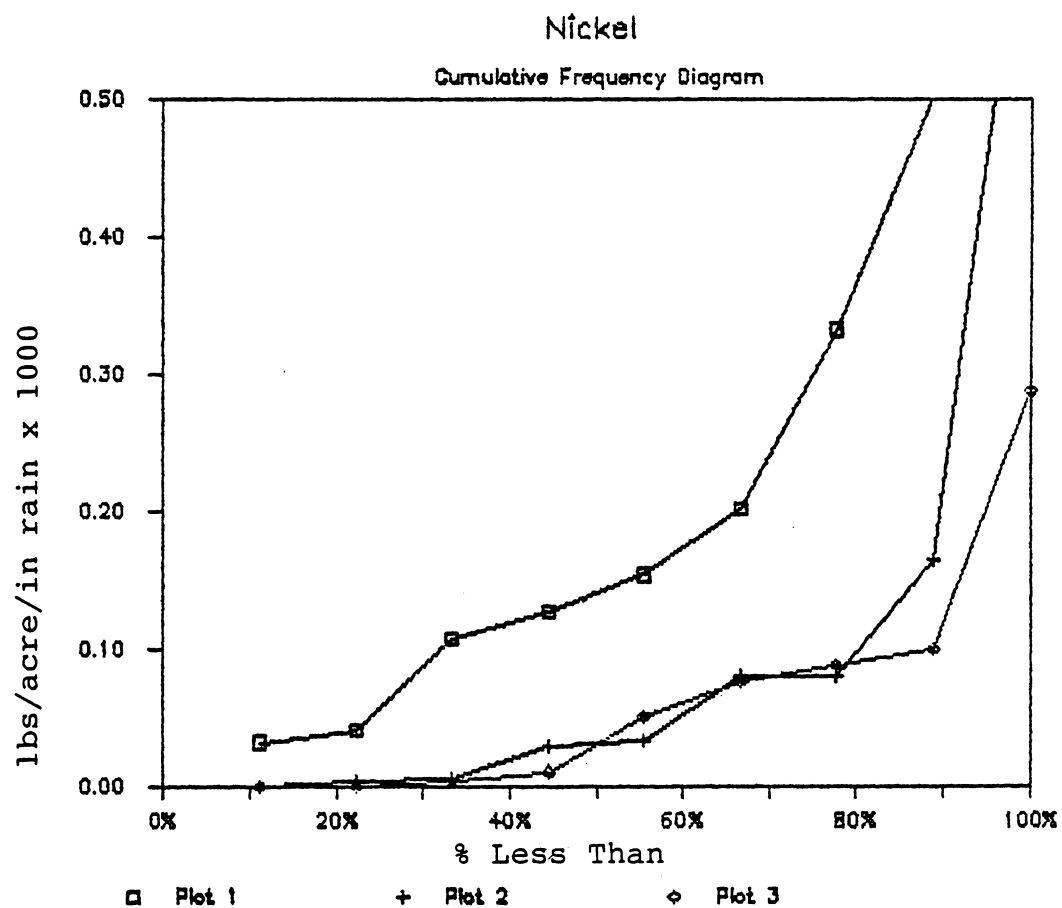


Figure 33: Cumulative Frequency Diagram of Ni Yields

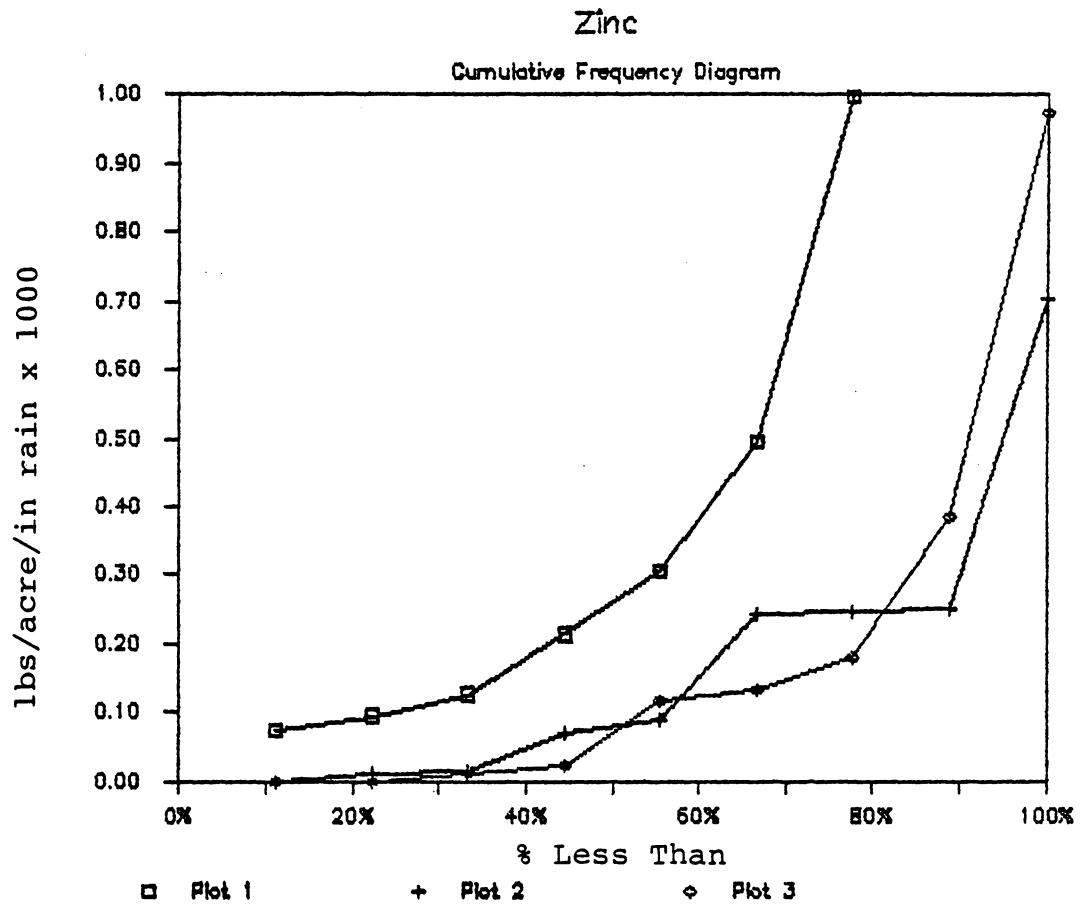


Figure 34: Cumulative Frequency Diagram of Zn Yields

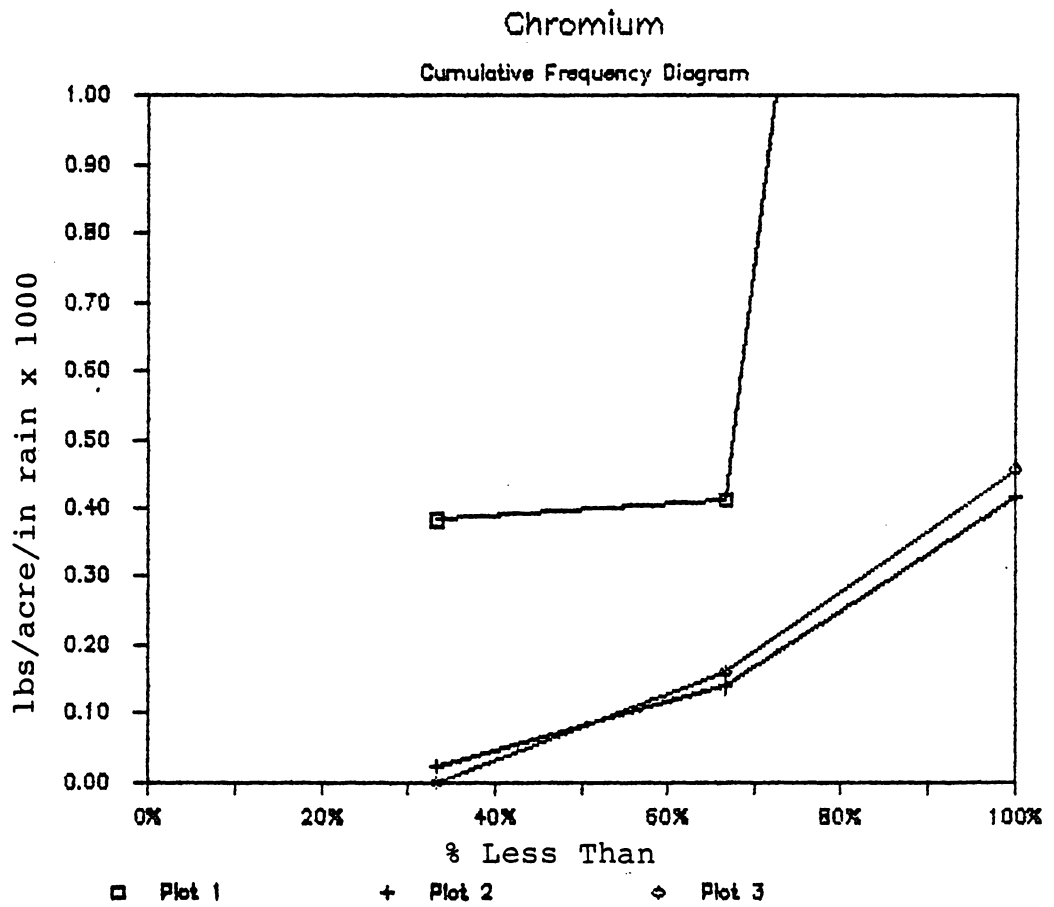


Figure 35: Cumulative Frequency Diagram of Cr Yields

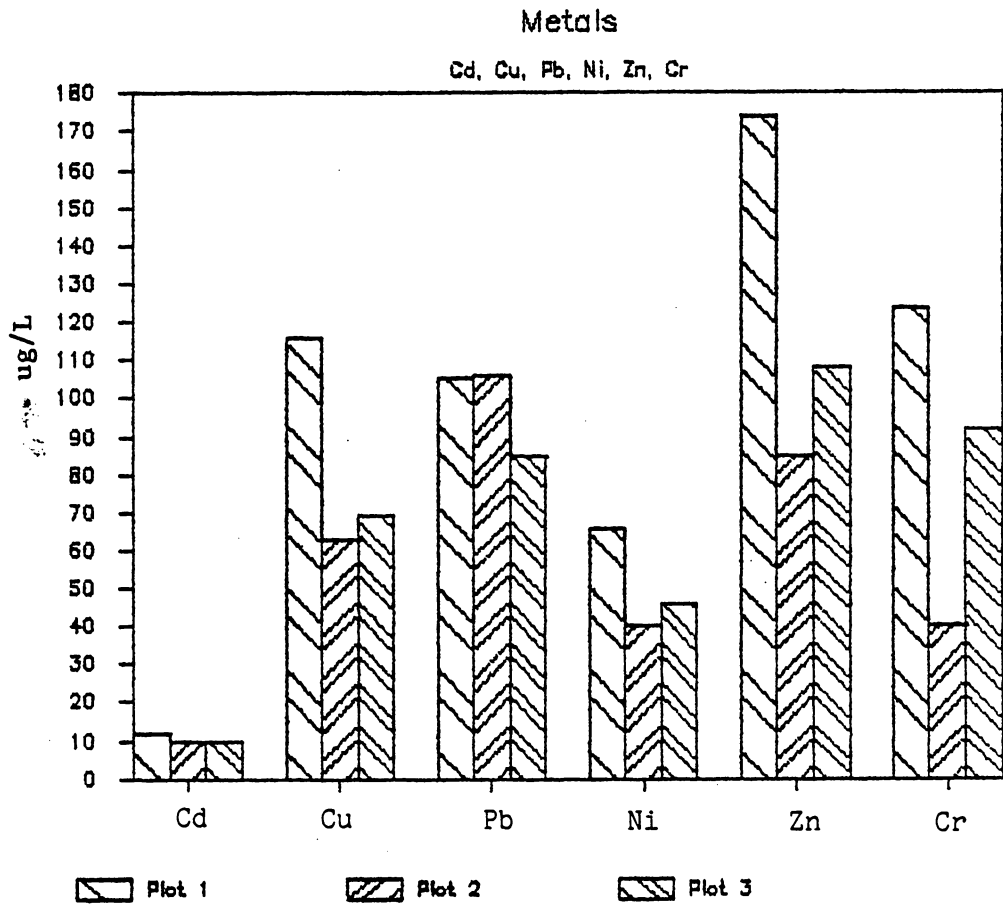


Figure 36: Flow Weighted Average Concentrations of Metals in Runoff

from Plots 2 and 3, except for lead, for which Plots 1 and 2 were approximately equal. The concentrations of Plot 2 metals were slightly less than those for Plot 3, except for cadmium where Plots 2 and 3 were equal, and lead where Plots 1 and 2 were equal. The lower CEC and pH of the unamended soil in Plot 1 allowed the metals to be more available for runoff. Soils with high CEC and/or pH above 6.5 are known to retain the metals and make them less available for plant uptake. Under these conditions, metals are less available in their soluble form in the soil solution for plant uptake (Parr et al. 1978). Therefore, under these same conditions which occur due to compost amendment, it follows that metals would be less available for runoff, also. The box plots in Figures 17 and 18 illustrate that metals export was reduced in the amended Plots.

The metals median loads and yields are presented graphically in Figures 37 and 38. As observed for flow weighted average concentrations, the median load and yield for each metal was highest for Plot 1. For median loads, the ratios between Plot 1 and Plot 2 ranged from 1.4 to 3.57. The ratios between Plot 1 and Plot 3 ranged from 2.0 to 4.3. Plot 2 median loads were slightly less than Plot 3 loads for Cd, Pb, and Cr, and slightly more for Cu, Ni, and Zn. This is in contrast to the pattern observed for average concentrations. For example, Plot 2 Cd load was equal to

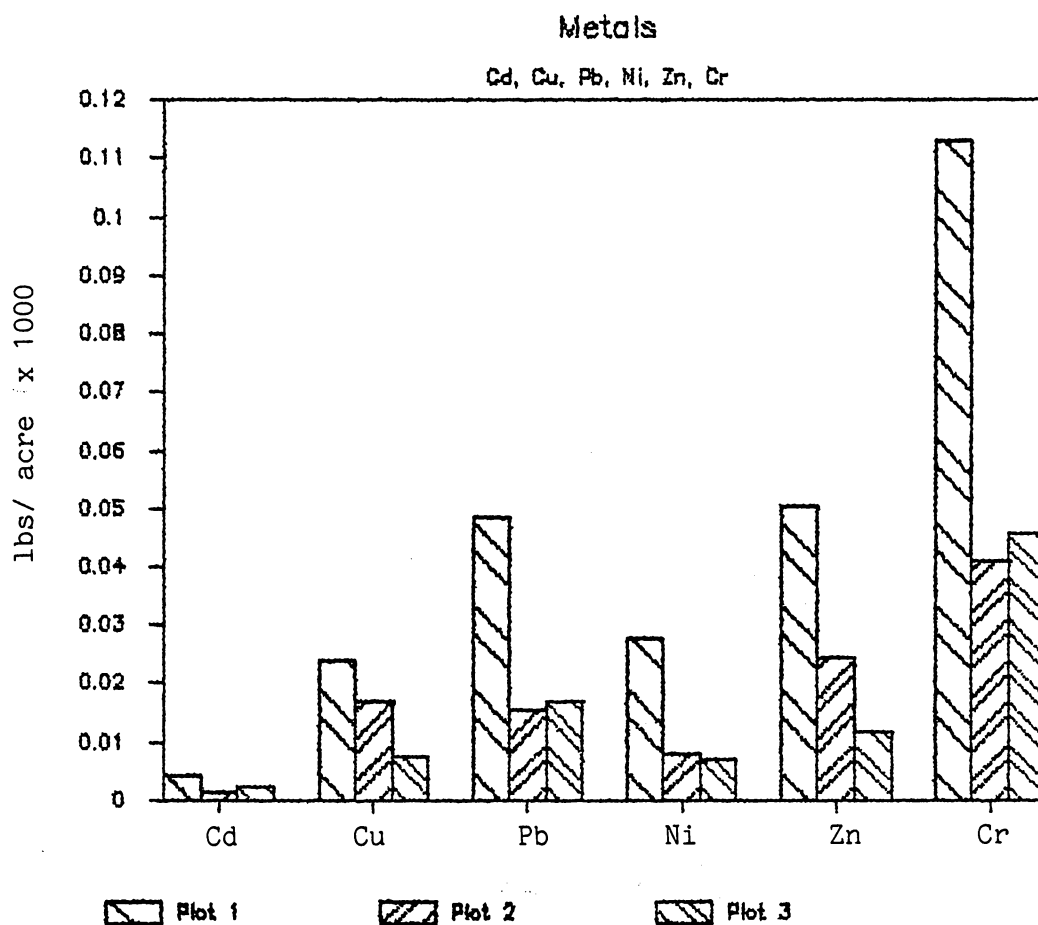


Figure 37: -Median Loads of Metals in Runoff

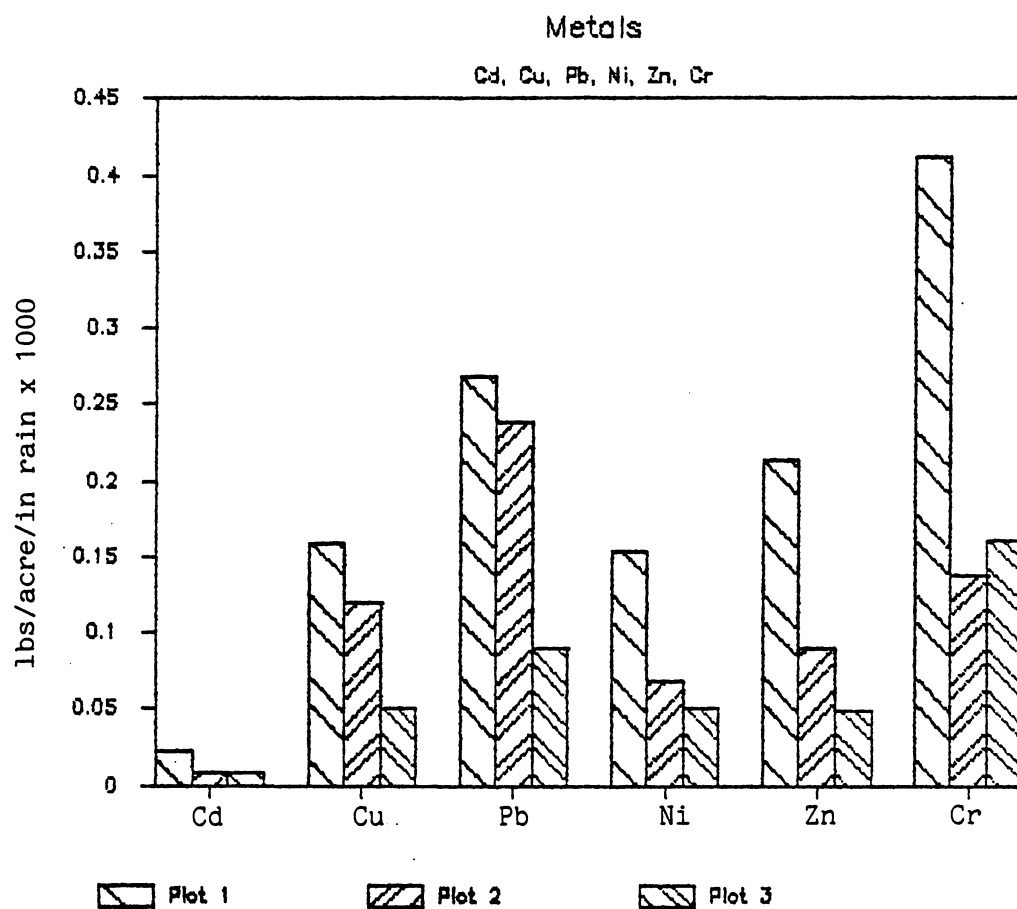


Figure 38: Median Yields of Metals in Runoff

Plot 3, Plot 2 Pb was equal to Plot 1 and higher than Plot 3, and all others were less for Plot 2 than for Plot 3.

Plot 2 median yields, compared to those from Plot 3, reflected the flow weighted average concentration pattern for Cd, Pb, and Cr. Otherwise, Plot 2 yields were observed to be higher than Plot 3 for Cu, Ni, and Zn.

The differences noted between Plots 2 and 3 for average concentrations, loads, and yields do not appear significant. The box plots show that for all metals, Plots 2 and 3 had similar export distributions. In comparison, Plot 1 had substantially greater export distributions in each case.

The metals of concern in urban runoff are usually copper, lead, and zinc (USEPA, 1983a). The unamended Plot 1 discharged these metals at median yields over 4 times those of the compost-amended plots. As no compost was added to Plot 1, and the fertilizer was assumed to be free of metals (Tisdale and Nelson, 1975), the source of these metals may be due to native levels in the soil. The compost applications to Plots 2 and 3 of metals to the soil ranged from approximately 1,800 to 26,000 times the exported quantity from Plot 2, and 2,300 to 47,000 times the exported quantity from Plot 3. Because export from the unamended Plot was larger than the export from either amended Plot, it can be said that compost-amended soils retain metals occurring naturally in the soil and compost, as well as that

which may be contributed by rain, and make them less available for runoff.

The metals applied to the soil from compost were well below the maximum recommended loads for metals, regardless of the soil CEC (Parr et al., 1978). Therefore, crops for food-chain or direct human consumption could be safely grown, with respect to metals content, in soil amended with this compost or compost with similar metal characteristics. The regulations for food-chain crop production (USEPA, 1979) state that the annual cadmium application rate cannot exceed 0.45 lbs/ac. The compost used in this project had an unusually high Cd concentration, 24.7 mg/kg; average UOSA compost Cd content is 3.9 mg/kg. For this study, 2 lbs/acre Cd were applied, based on the amount of compost needed to satisfy the nitrogen demand of the fescue. Had the compost used been average in Cd concentration, only 0.26 lb/ac would have been applied which meets the EPA regulation for food-chain crop production.

Cadmium Toxicity

In order to control cadmium toxicity to livestock and humans, Chaney (1981) reported that at a maximum Cd:Zn ratio (of the applied sludge or compost) of 1-1.5%, the phytotoxicity of Zn would limit the Cd accumulation in plants. The Cd:Zn ratio of the compost used in this project

was 4%, which exceeded the recommended levels. As noted above, the Cd levels in this compost were not representative; the Cd:Zn ratio calculated using the 3-year average Cd concentration of UOSA compost, 3.9 mg/kg, is 0.7%. Based on the average UOSA compost, the Cd:Zn ratio of 0.7% would limit cadmium intake by crops grown in compost-amended soil, and thus could make this compost compatible with vegetable gardens if the pH were maintained above 6.5.

Phosphorus in Runoff

The cumulative frequency diagrams for the yields of OP, TSP, and TP are presented in Figures 39-41. Unlike the parameters previously discussed, there is no clear pattern among the Plots from these diagrams. Generally, Plot 3 yields were lowest for OP and TP. For TSP, Plot 2 export was somewhat higher than Plots 1 and 3.

The soluble OP average concentration for Plot 2 runoff, shown in Figure 42, was observed to be approximately 1.5 times that of Plots 1 and 3. The TSP average concentration for Plot 2 runoff was found to be approximately 2 times that of Plots 1 and 3. OP and TSP appeared to have similar runoff concentration patterns among the Plots. For TP, Plot 1 was highest with approximately 1.7 times concentrations of Plots 2 and 3. The insoluble

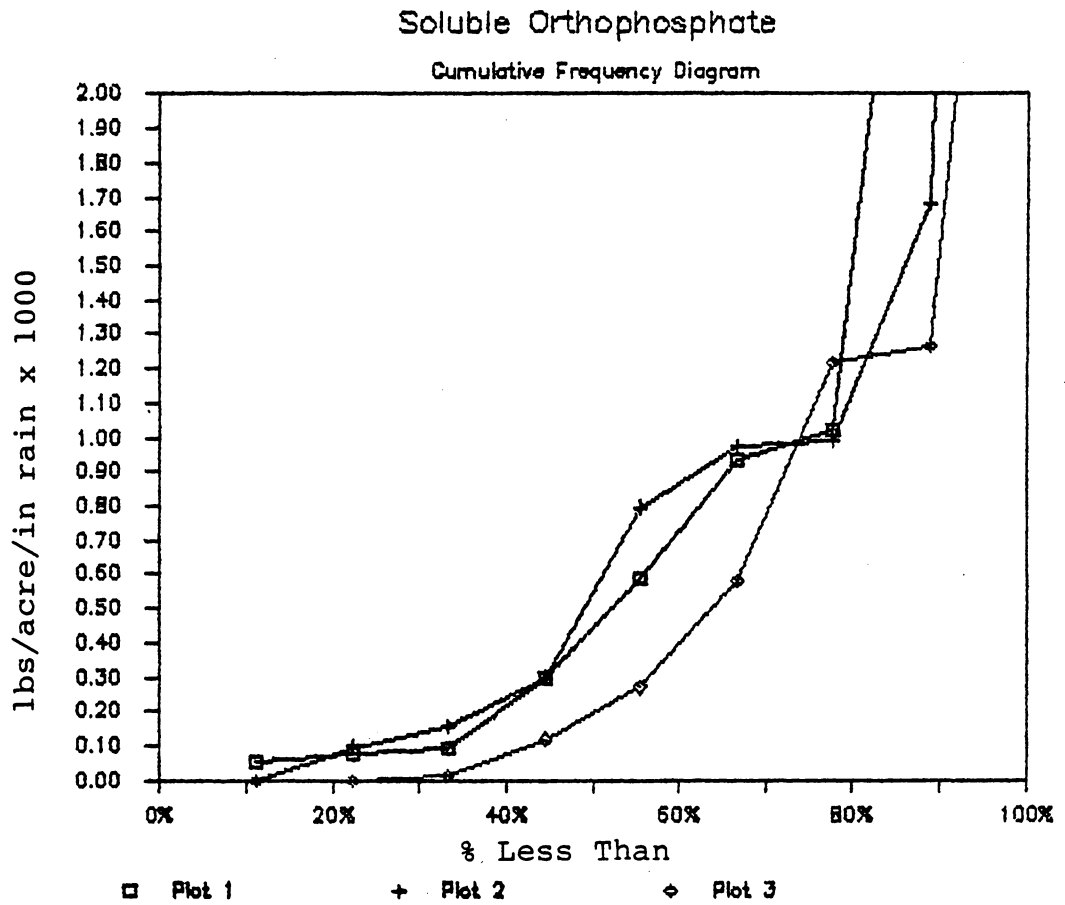


Figure 39: Cumulative Frequency Diagram of Orthophosphate Yields

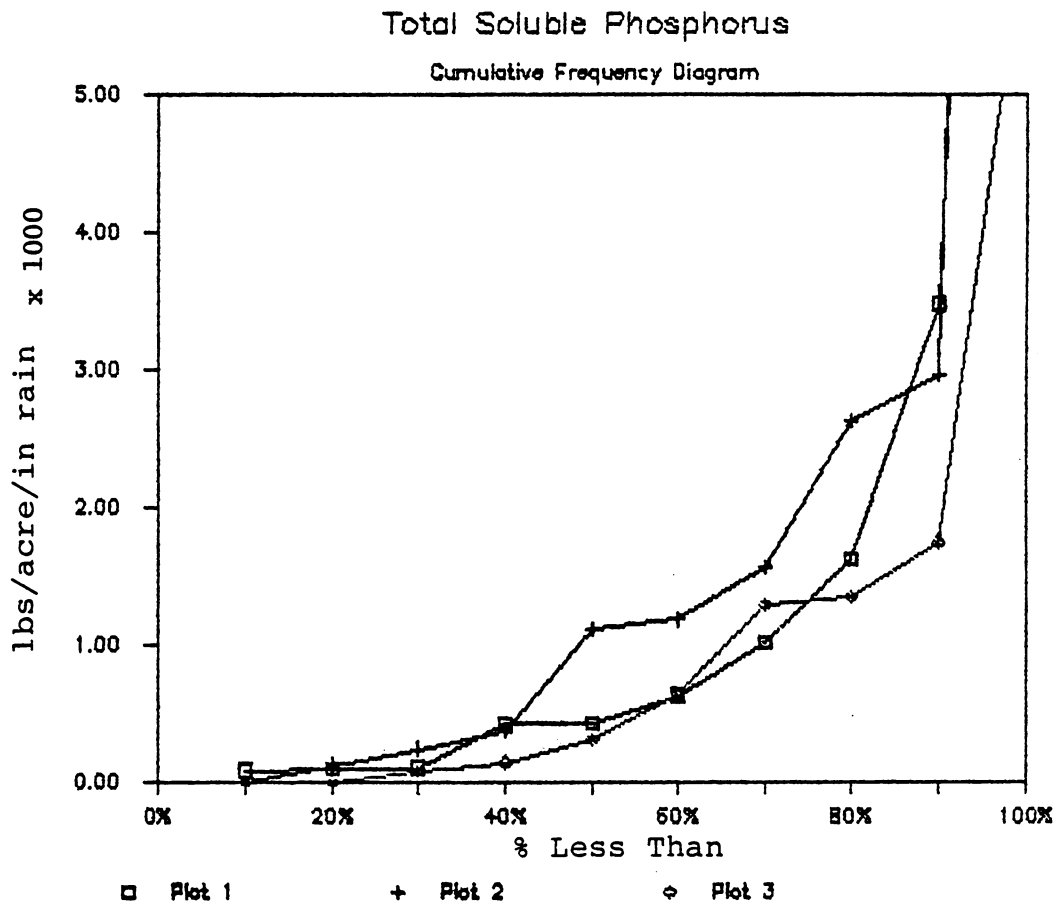


Figure 40: Cumulative Frequency Diagram of Total Soluble Phosphorus Yields

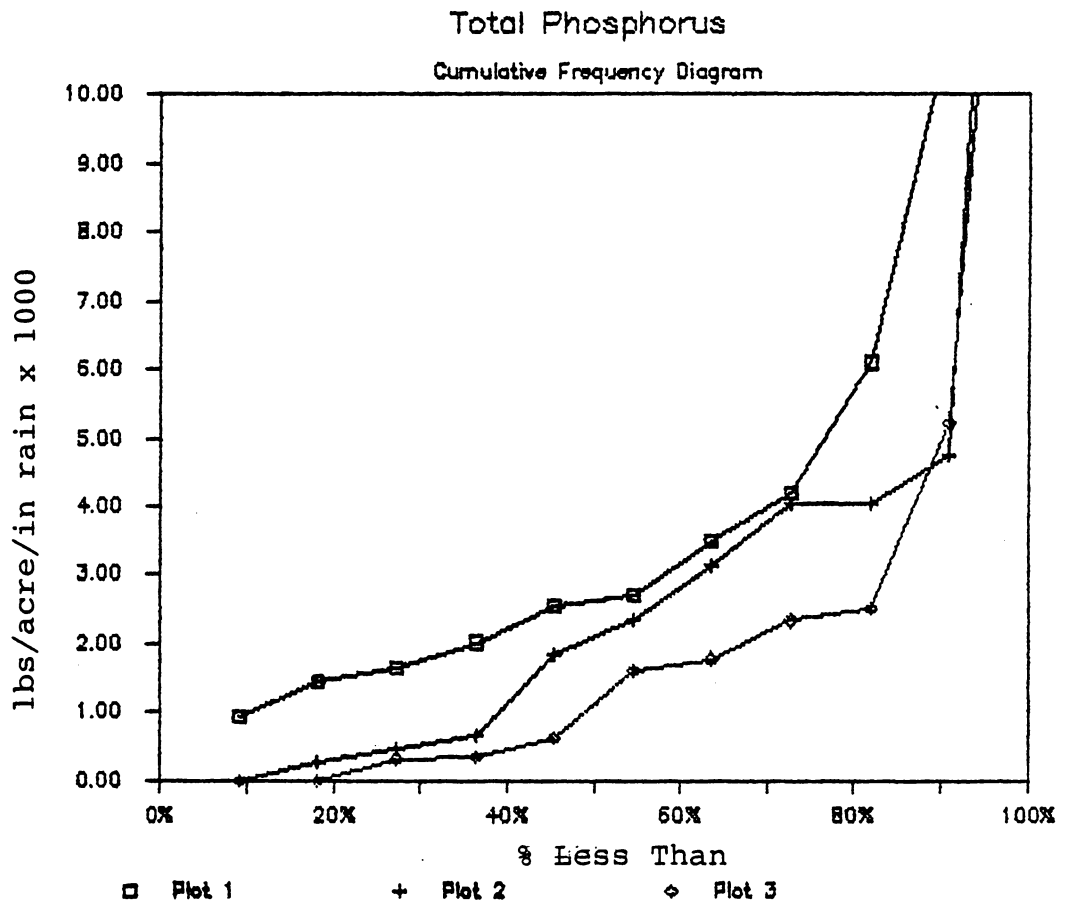


Figure 41: Cumulative Frequency of Total Phosphorus Yield

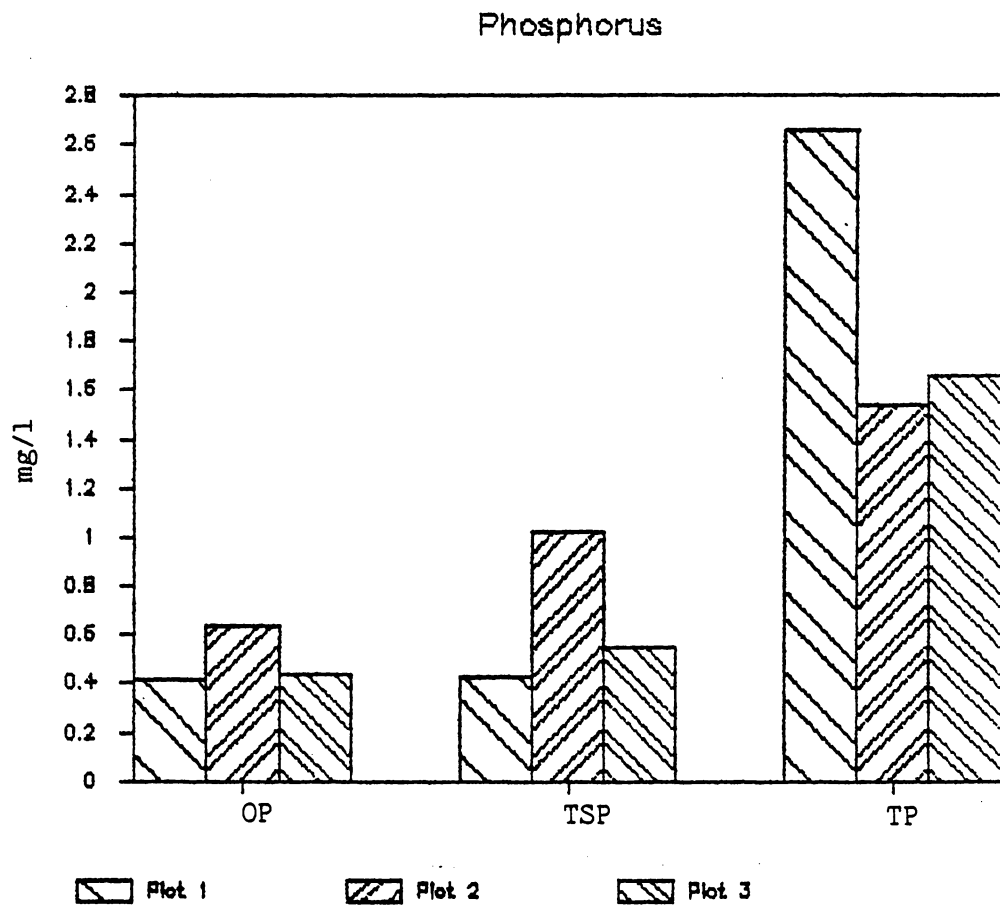


Figure 42: Flow Weighted Average Concentrations of Phosphorus Species
in Runoff

particulate P fraction, obtained by subtracting TSP from TP, was 2.23 mg/L, 0.52 mg/L, and 1.11 mg/L for Plots 1, 2, and 3, respectively. The particulate P appeared to be retained in the compost-amended soil (Plots 2 and 3) in contrast to the unamended soil.

Biggar and Corey (1969) found that P concentrations in runoff were usually less than 1.0 mg/L. The runoff concentrations observed in this study for TP ranged from 0.22 mg/L to 7.61 mg/L, and averaged 1.54 mg/L to 2.66 mg/L. The difference may be attributed to the variations in soil, land use and material application practices between the two studies.

The median loads and yields are illustrated in Figures 43 and 44. The median loads and yields were lowest for Plot 3 for OP, TSP, and TP. Export from Plots 1 and 2 were approximately 2 to 5 times higher than Plot 3 export. As observed for TSP average concentrations, the median load and yield exported from Plot 2 were highest. Similar to TP average concentrations, the median loads and yields exported from Plot 1 were highest. Plot 1 TP was observed to be 1.2 and 2.9 times that of Plots 2 and 3, respectively, for load and 2.1 and 5.3 times that of Plots 2 and 3, respectively, for yield. Plot 2 median load for TSP was found to be 1.3 and 3.1 times that of Plots 1 and 3, respectively. Plot 2 median yield for TSP was found to be 1.4 and 2.7 times that

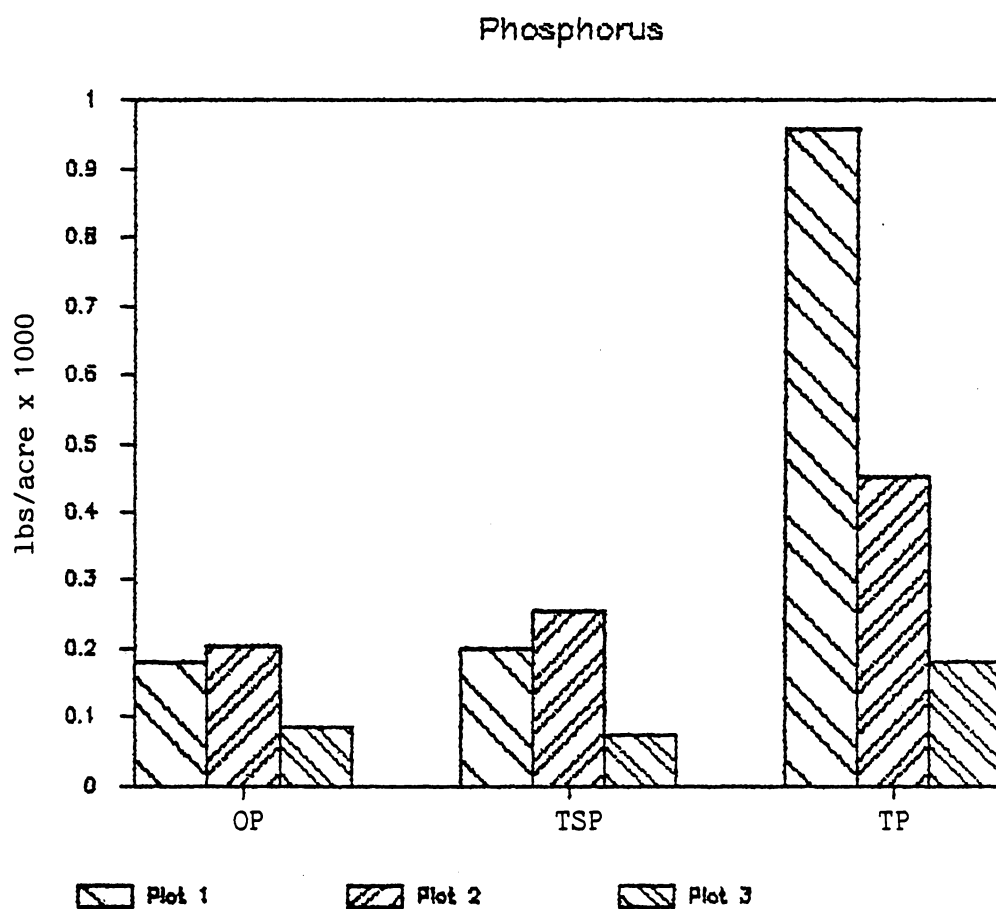


Figure 43: Median Loads of Phosphorus Species in Runoff

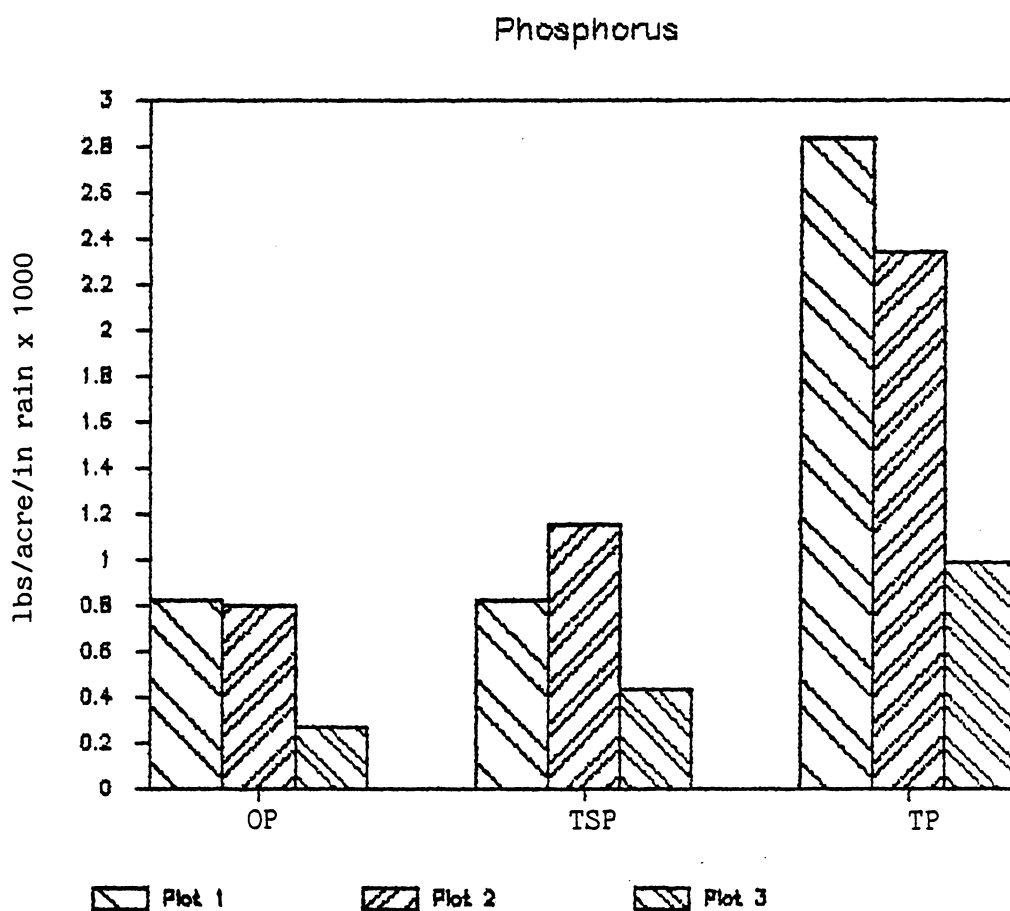


Figure 44: Median Yields of Phosphorus Species in Runoff

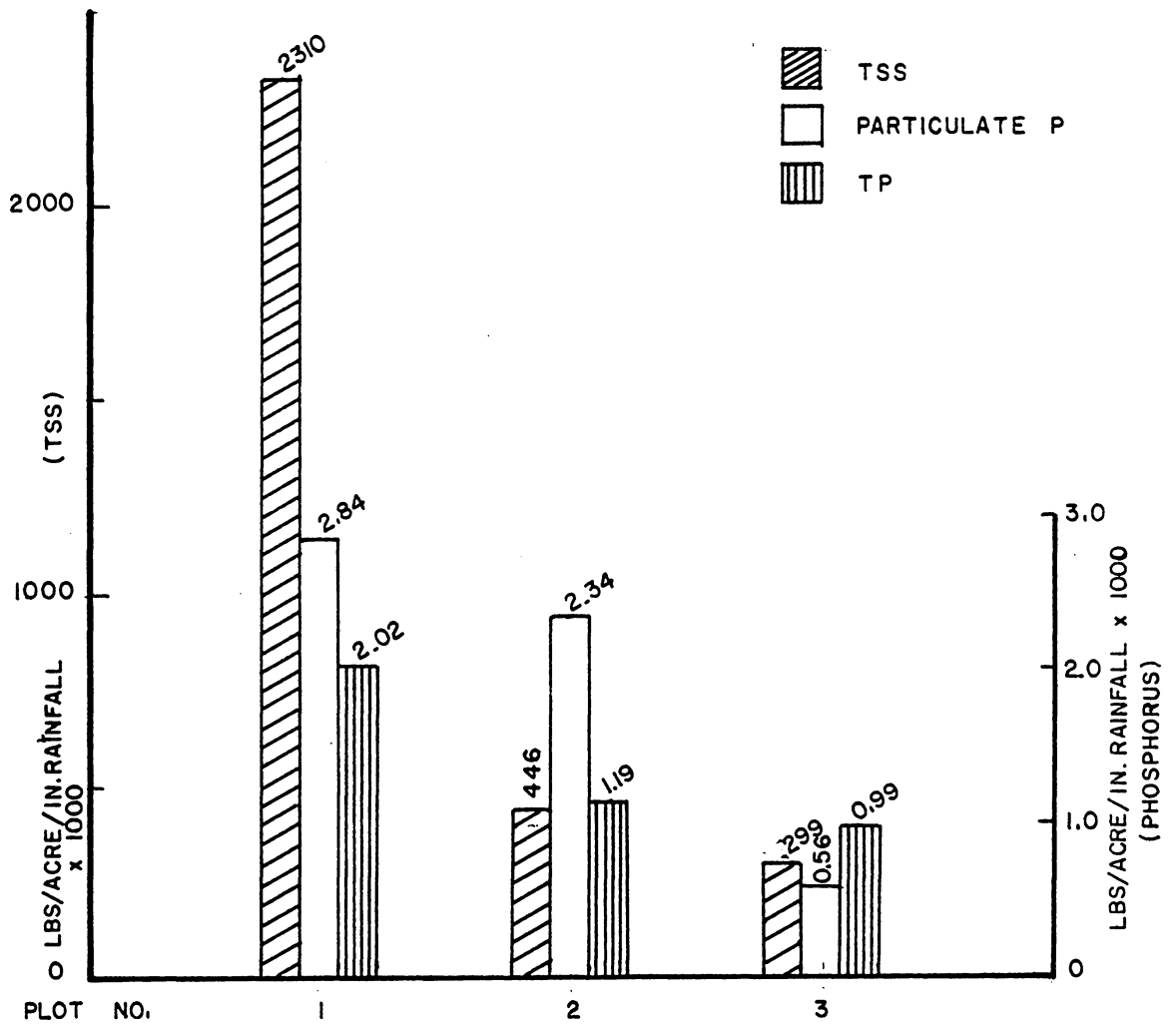
of Plots 1 and 3, respectively.

The OP median load and yield exported from Plots 1 and 2 were approximately equal, unlike the observed OP flow weighted average concentrations.

The relatively large differences between TP and the other soluble forms of P may indicate that insoluble P forms are more subject to runoff. Figure 45 illustrates the relationship observed between TSS, TP, and particulate (insoluble) P median yields. As TSS export increased, TP and particulate P export increased. Direct relationships between TSS and TP, and TSS and particulate P are indicated.

Because plants absorb most of their phosphorus in the OP form, it was expected that OP average concentration in the runoff would be relatively low compared to TSP and TP. Further, the higher OP concentration of Plot 2 runoff may indicate that the combination fertilizer and compost provided excessive OP for the crop. The high median yields of OP from Plots 1 and 2 compared to Plot 3 may also indicate that excessive OP was lost. This may be due to the lack of soil moisture retention in Plot 1, and to the excessive application of OP from the fertilizer in Plot 2.

The OP exported from Plot 3 was very low despite the fact that its average concentration was observed to be higher than Plot 1. This may be attributed to the moisture



MEDIAN YIELD OF
TOTAL SUSPENDED SOLIDS VS
TOTAL PHOSPHORUS &
PARTICULATE PHOSPHORUS IN RUNOFF

FIGURE 45

retention capabilities of the compost-amended soil.

The pH of the Plots after treatment indicated that Plot 1 was in the optimum pH range (5.5-7.0) for maximum P availability to plants. Plots 2 and 3 were slightly above the optimum pH range. From this study, it is not possible to determine the actual P uptake in the fescue.

Nitrogen in Runoff

The cumulative frequency diagrams for the yields of the N species analyzed are presented in Figures 46-49. The soluble ammonia as N ($\text{NH}_3\text{-N}$) and total Kjeldahl nitrogen (TKN) yields from Plot 1 were observed to be clearly above those of Plots 2 and 3. Plot 2 and 3 yields were similar. For SKN, the soluble portion of TKN, Plot 2 yields were observed to be above those from Plot 1. Plot 1 yields were generally above Plot 3. For nitrite plus nitrate as N (OXN) the yields from Plot 3 were below Plots 1 and 2. Plot 2 had a few exceptionally high yields. This may be a reflection of its relatively high flow weighted average concentration, shown in Figure 50.

The $\text{NH}_3\text{-N}$ and TKN average concentrations follow similar patterns among the Plots. Likewise, SKN and OXN average concentrations have similar patterns. The soluble ammonia concentration in the runoff from Plots 1 and 2 were equal. The soluble ammonia concentration for Plot 3 was

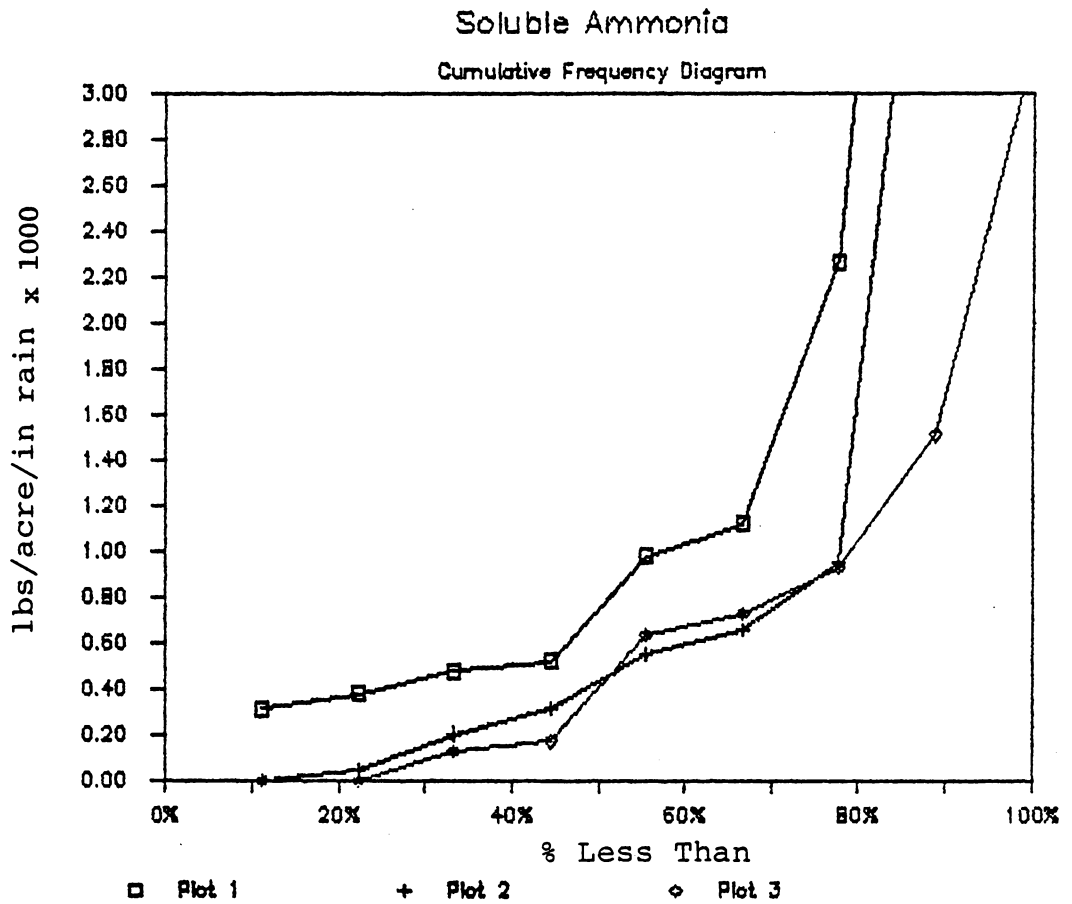


Figure 46: Cumulative Frequency Diagram of Soluble Ammonia Yields

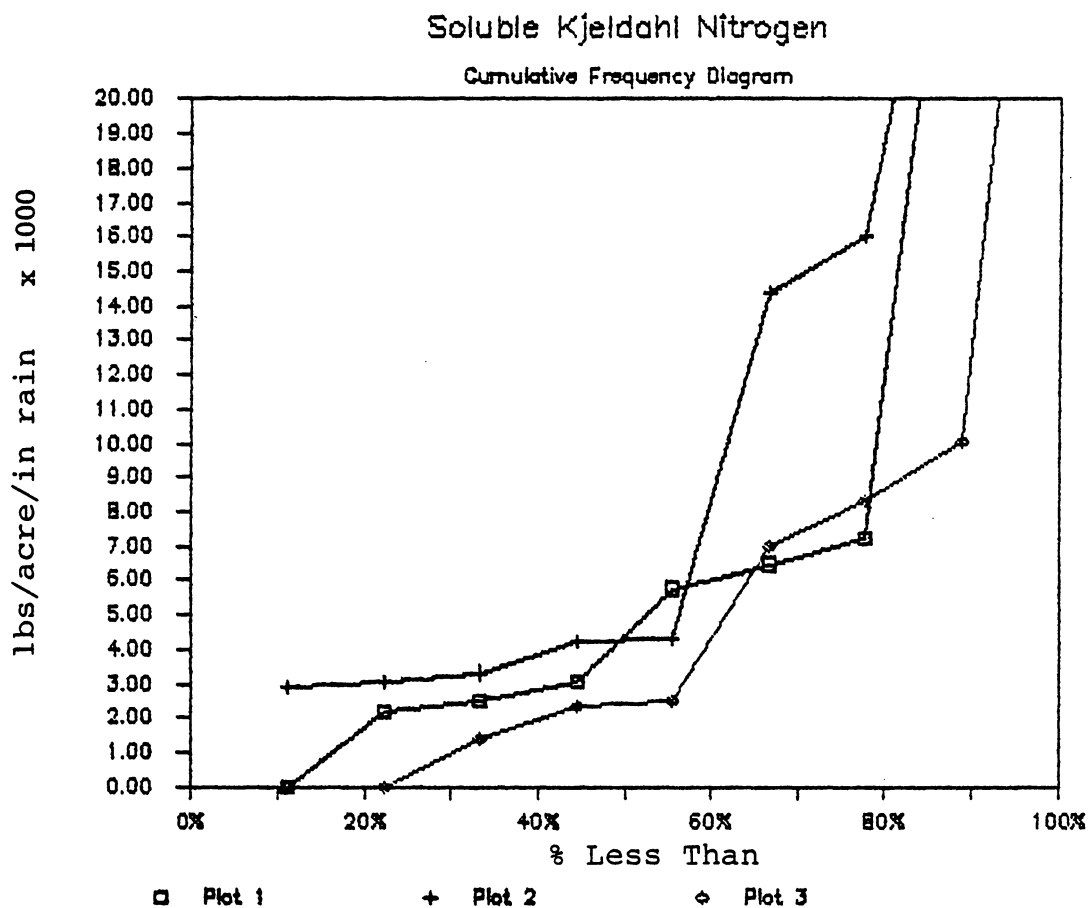


Figure 47: Cumulative Frequency Diagrams of Soluble Kjeldahl Nitrogen Yields

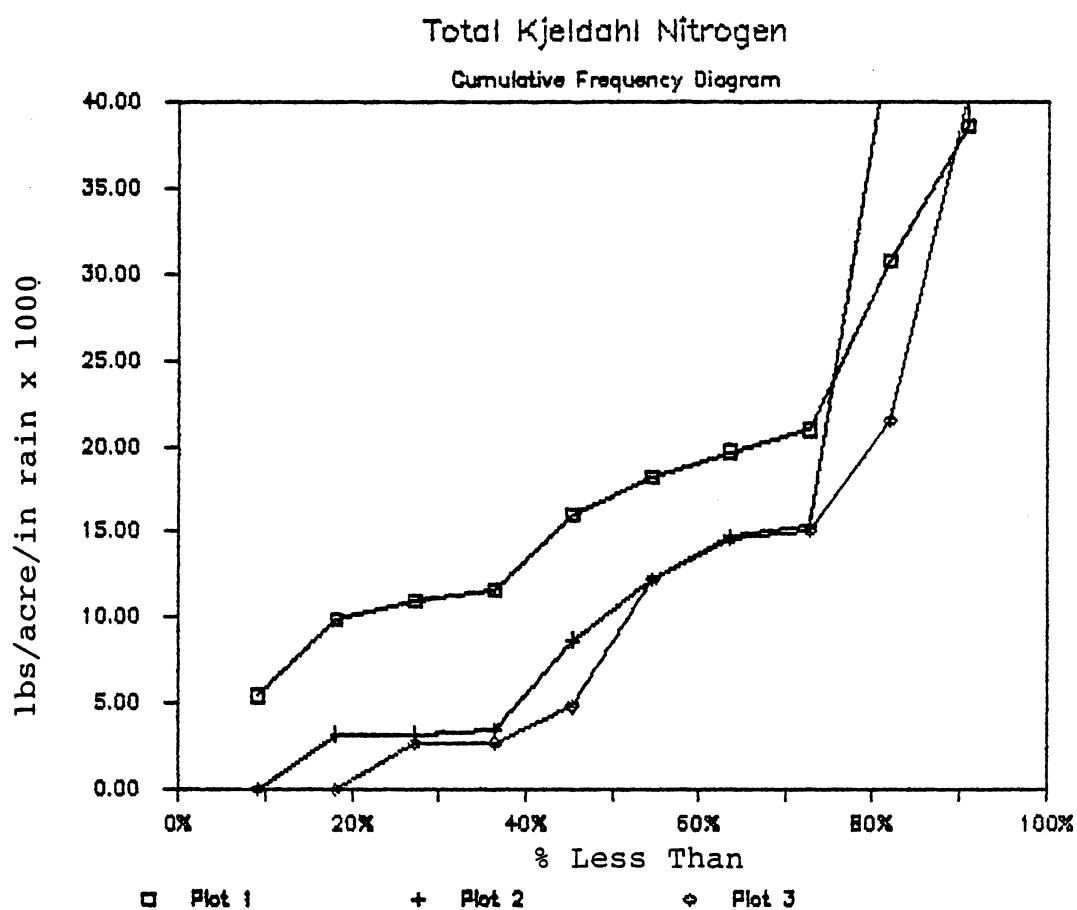


Figure 48: Cumulative Frequency Diagrams of Total Kjeldahl Nitrogen Yields

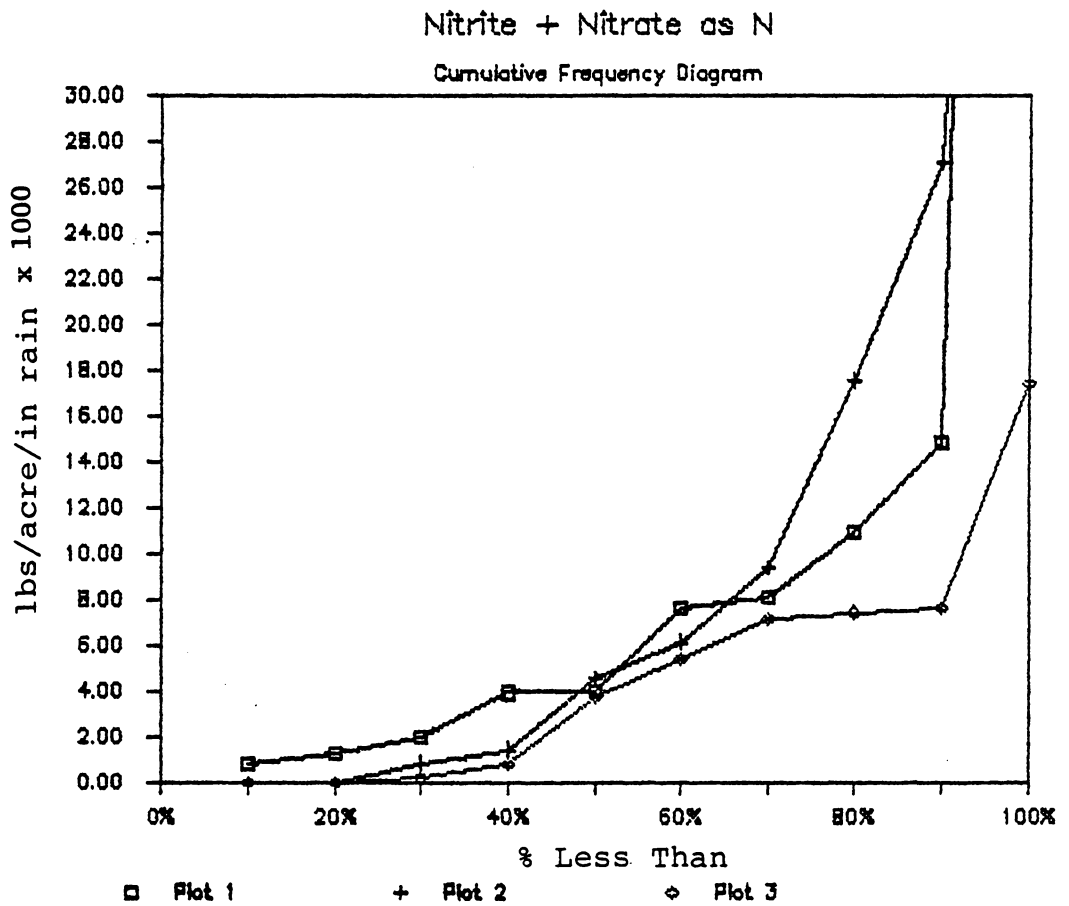


Figure 49: Cumulative Frequency Diagrams of Nitrite + Nitrate as Nitrogen Yields

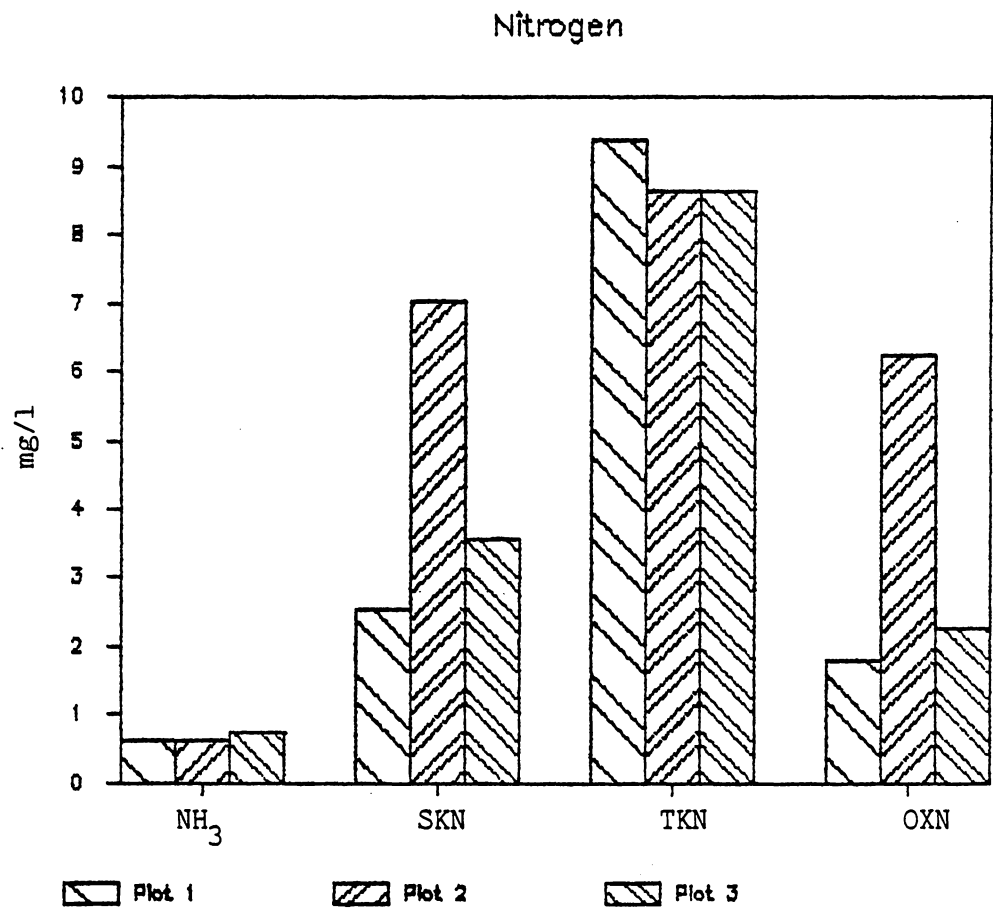


Figure 50: Flow Weighted Average Concentrations of the Nitrogen Species in Runoff

approximately 25% greater than those observed for Plots 1 and 2. The TKN average concentration for Plot 1 was almost 10% larger than those of Plots 2 and 3, which were equal. These differences are not significant, as the NH_3 and TKN runoff concentrations did not appear to be affected by the material application (i.e., fertilizer and/or compost). The SKN average concentration for Plot 2 was approximately 2.75 and 2.0 times that of Plots 1 and 3, respectively, with Plot 3 nearly 25% greater than Plot 1.

Nitrogen is typically absorbed by plants in the form of nitrate. The organic nitrogen in the soil is mineralized to form ammonium. The ammonium is first oxidized to nitrite, then to nitrate. The C:N ratio of the soil affects the mineralization rate. Below C:N of 20, organic N will mineralize readily and be available for plant uptake. The C:N ratio of the compost used for this project was below 20, so it can be assumed that organic N mineralization took place readily in the amended soil. This is important since the majority of the N source in compost is in the organic form.

The organic N concentration in the runoff was calculated by subtracting NH_3 -N average concentration from TKN. The organic percent was then calculated by dividing organic N by TKN. For Plots 1, 2, and 3, the organic N fraction in the runoff was 94%, 93%, and 91%, respectively.

The soluble organic percent (SKN/TKN) lost in runoff was 82% from Plot 2, compared to 42% and 27%, respectively, from Plots 3 and 1. Because fertilizers are largely soluble ammonia and soluble inorganic N species, excess fertilizer may not be the direct source of the high soluble organic concentration of Plot 2 runoff. The addition of fertilizer may have caused an increase in the release of soluble organic matter from the compost in Plot 2, as the excess insoluble N may have reacted with the organic matter.

Insoluble organic N, calculated as 100% less the organic percent, was 73% for Plot 1, 58% for Plot 3, and 18% from Plot 2. Thus, the insoluble organic N fraction was exported more readily from the unamended Plot 1. This corresponds to the high TSS concentration and export from Plot 1.

Any organic N exported in runoff may be converted to NO_3^- -N under aerobic conditions in its receiving waters. NO_3^- -N concentrations in drinking water must be kept below 10 mg/L to preclude toxicity problems for newborns.

The OXN concentration of Plot 2 was 3.5 times that of Plot 1 and 2.7 times that of Plot 3. Because nitrite and nitrate are inorganic N species, this observation may indicate an excess of inorganic nitrogen in Plot 2 from the application of both fertilizer and compost.

It should be noted that the terms ammonia and ammonium

are used interchangeably throughout this report. The ammonium ion actually was the dominant form found in the runoff because the soils were between 5.7-7.5 . Below pH 8.0, the ammonium ion dominates (above 99%).

The concentration of $\text{NH}_4\text{-N}$ in the runoff was relatively small. Biggar and Corey (1969) found that the ammonium ion was normally dissolved and carried into the soil instead of discharged in runoff. For soluble inorganic nitrogen, they reported that the nitrate concentration in the runoff was usually less than the average nitrate content in rain. This was not the case in this study, where the OXN in runoff ranged from 0.01 mg/L to 77 mg/L, compared to an average nitrate rain concentration of 0.69 mg/L (Biggar and Corey, 1969).

The median loads and yields, shown graphically in Figures 51 and 52, followed similar patterns as those observed for flow weighted average concentrations. However, for each parameter, Plot 1 export exceeded Plot 3 export. This may be attributed to the lack of water infiltration and retention in Plot 1. Plots 2 and 3 remained relatively similar with the exception of TKN, where Plot 3 export dropped in comparison to Plots 1 and 2.

The box plots in Figures 21 through 24 are useful in interpreting this data. Similar distribution patterns were observed for TKN and NH_3 . The median value for Plot 1 was

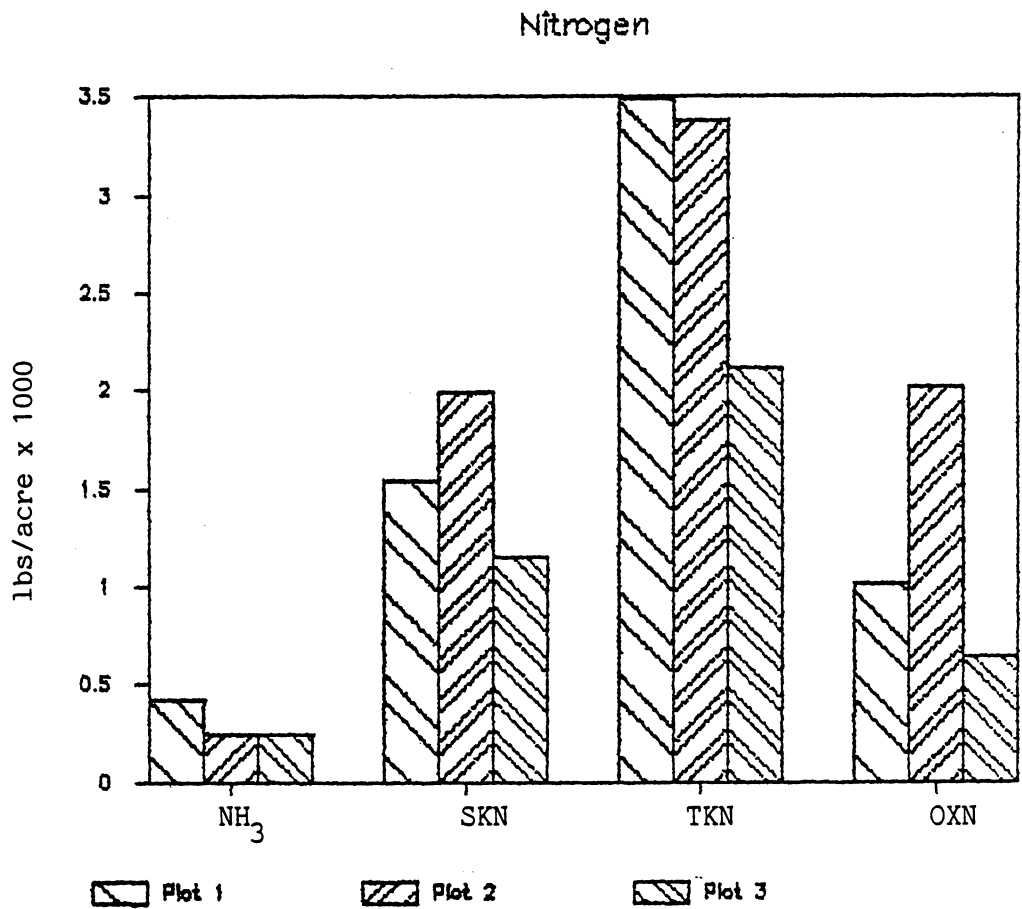


Figure 51: Median Load of the Nitrogen Species in Runoff

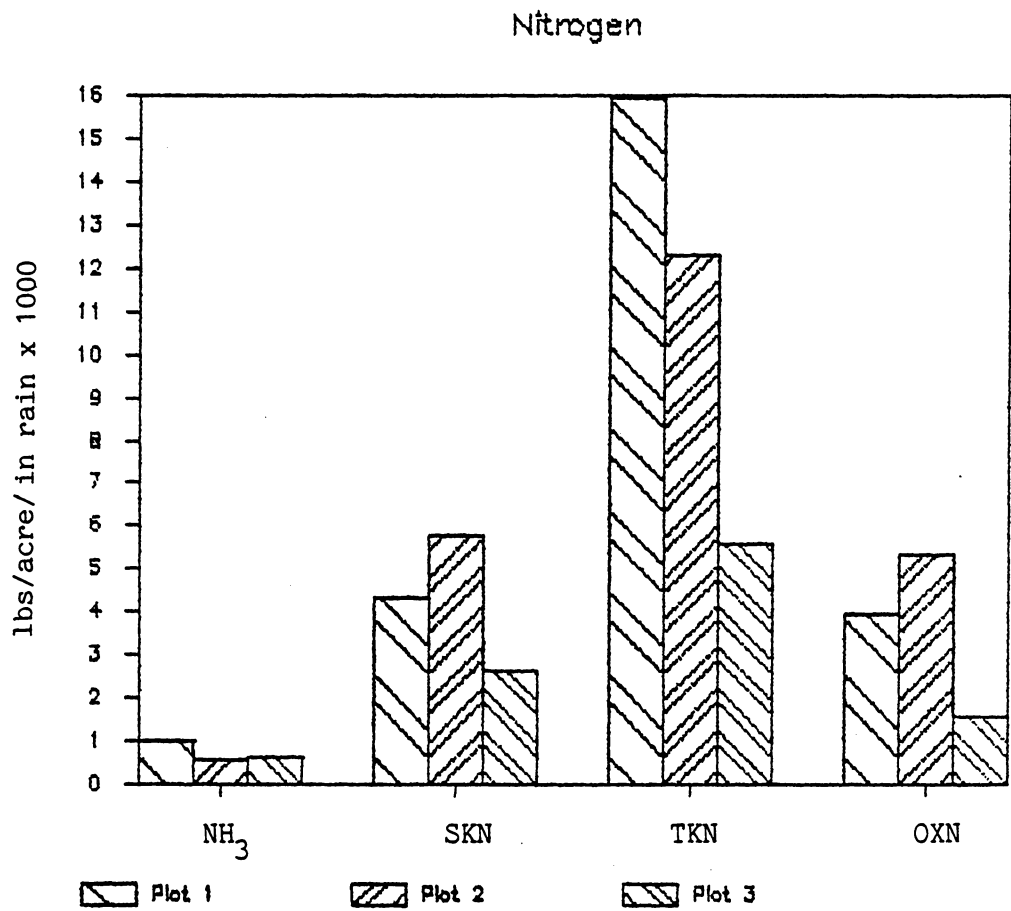


Figure 52: Median Yield of the Nitrogen Species in Runoff

higher than those for Plots 2 and 3. The distribution patterns for SKN and OXN were also similar. The median values for Plot 2 were slightly higher than Plot 1. Plot 3 median SKN and OXN loads and yields were lowest. The higher median values for SKN and OXN from Plot 2 follow the pattern noted for flow weighted average concentrations, although the median values were not drastically higher than Plot 1 medians.

The high OXN export from Plot 2 did not appear to be caused by the compost amendment since Plot 3 export was relatively low. Instead, it appears that the high OXN export from Plot 2 was due to excess inorganic N from the fertilizer. The capacity of soils to adsorb anions, such as nitrite and nitrate, increases as the pH decreases. At pH values above 7.0, anion adsorption is negligible (Bohn et al., 1979). Because the pH of compost-amended Plots 2 and 3 was above 7.0, anions such as nitrites and nitrates were not likely adsorbed by the soil and thus were probably soluble and available for runoff. However, OXN export from Plot 3 (compost only) was substantially lower than Plots 1 and 2 which were fertilized. In Plot 1, the pH was below 7.0, and thus conditions existed where anion adsorption may have occurred more readily than in Plots 2 and 3 which had higher pHs. Lower OXN export would therefore be expected from Plot 1. However, OXN export from Plot 1 was significantly higher

than that from Plot 3, and was within 25% of Plot 2 export. It appears that anion release (OXN export) was due to excess inorganic N from the fertilizer, not the compost.

Reduced Pollutant Export Due to Compost Amendment

In order to compare the amount of nutrient applied with the amount discharged in runoff, the normalized storm loads shown in Table 10 were multiplied by the amount of total rainfall. Total rainfall was measured from the time of nutrient application to the last monitored event which equalled approximately 16 inches. The total pollutant export in lbs/acre is estimated in Table 11. None of the nutrient loads exported were significant compared to the amounts applied. Likewise, for the other constituents applied (metals primarily) to Plots 2 and 3 from the compost, presented in Table 12, there was no significant loss of these constituents to the runoff. It is interesting to note that Plot 1, which had no compost and thus no source of applied metals, had the highest metals content in its runoff. As discussed in a previous section of this report, the CEC, pH, and organic matter content of the soils may have affected the metal export. Plot 1 soil, which did not receive compost, had a substantially lower CEC, pH, and organic matter content than did Plots 2 and 3, which received compost application.

Table 11

Estimated Total Export from Time of Application to Last Monitored Event
Based on 16 inches of Total Rainfall from April 9 - Nov 2
and Median Normalized Storm Loads

Parameter	Units	Plot 1	Plot 2	Plot 3
OP	lbs/acre	0.01	0.01	0.004
TSP	lbs/acre	0.01	0.02	0.01
TP	lbs/acre	0.05	0.04	0.02
NH3	lbs/acre	0.02	0.01	0.01
SKN	lbs/acre	0.07	0.09	0.04
TKN	lbs/acre	0.30	0.20	0.09
OXN	lbs/acre	0.06	0.09	0.02
TSS	lbs/acre	40	7	5
COD	lbs/acre	25	4	7
Cd	lbs/acre (x1000)	0.40	0.10	0.10
Cu	lbs/acre (x1000)	2.5	2.0	0.80
Pb	lbs/acre (x1000)	4.5	4.0	1.5
Ni	lbs/acre (x1000)	2.5	1.0	0.80
Zn	lbs/acre (x1000)	3.5	1.5	0.80
Cr	lbs/acre (x1000)	6.5	2.0	2.5
Fe	lbs/acre (x1000)	710	NA	80

Table 12
Amount of Constituents Applied to Plots 2 and 3 from Compost

Constituent	lbs/plot	lbs/acre

Organic N*	1.1	81
NH ₃ -N	0.32	25
Total P**	5.8	450
K	0.70	55
Ca	200	15500
Cd	0.02	2 ***
Cu	0.35	27
Pb	0.14	11
Ni	0.03	2
Zn	0.48	37
Cr	0.10	7

* 10% available N is assumed (Hornick et al., 1983)

** 40% available P is assumed (Hornick et al., 1983)

*** The cadmium in the compost used for this project is not representative of UOSA compost. Average compost Cd concentration was 3.9 mg/kg, or 0.0033 lbs/plot, 0.26 lbs/acre.

Table 13 lists the contributions of various constituents from rain, reported in the NURP study for the Washington, D.C. Metropolitan area (NVPDC, 1983), in comparison to the amount found in the stormwater runoff from each Plot. The ratios of the quantity of a constituent contributed by rain, according to the literature, to the concentration found in the runoff in this study are also presented. For the ratios which are less than 1 (nutrients, COD, Cu), it can be stated that the runoff was the major source of these constituents, not the rainfall. The size of the ratios indicated that the rainfall input was actually insignificant for these constituents. The ratios for lead and zinc, however, were greater than 1 which indicates that the rain may significantly contribute to their contribution in runoff. Because rain was not analyzed in this study, and actual rain contributions cannot be estimated, no conclusions can be made regarding rain contributions in this study.

Though the nutrients in the runoff contributed by the application of fertilizer and/or compost seem low in comparison to the amount applied, their concentrations are above those known to stimulate excessive algal growth and contribute to eutrophication. Table 14 illustrates the estimated percent reduction in pollutant export effected by using compost. Referring to column (5), representing the

Table 13: Quantity of Constituent in Rain vs. Runoff
mg/L

Constituent	Rainfall Contribution "RC"	Plot 1	Plot 2	Plot 3	Ratio RC:Plot 1	Ratio RC:Plot 2	Ratio RC:Plot 3
COD	9	360	175	485	0.03	0.05	0.02
TP	0.02	2.7	1.5	1.7	0.01	0.01	0.01
TKN	0.5	9.4	8.6	8.6	0.05	0.06	0.06
OXN	0.5	1.8	6.3	2.3	0.28	0.08	0.22
Cu	0.03	0.12	0.07	0.07	0.23	0.42	0.39
Pb	0.12	0.11	0.11	0.09	1.10	1.10	1.36
Zn	0.10	0.18	0.09	0.11	0.54	1.12	0.86

Source for rain contribution: NURP data for Washington, D.C.
Metropolitan Area, reported by NVPDC (1983).

Table 14

Estimated Percent Reduction* in Pollutant Export
Due to the Use of Compost as a Soil Amendment

Parameter	Units	(1) Plot 1	(2) Plot 2	(3) % Reduction Col (1)-(2)/(1)	(4) Plot 3	(5) % Reduction Col (1)-(4)/(1)
OP	lbs/acre	0.01	0.01	3%	0.004	67%
TSP	lbs/acre	0.01	0.02	-40%	0.01	48%
TP	lbs/acre	0.05	0.04	18%	0.02	65%
NH3	lbs/acre	0.02	0.01	44%	0.01	36%
SKN	lbs/acre	0.07	0.09	-33%	0.04	39%
TKN	lbs/acre	0.30	0.20	35%	0.09	70%
OXN	lbs/acre	0.06	0.09	-35%	0.02	61%
TSS	lbs/acre	40	7	82%	5	88%
COD	lbs/acre	25	4	83%	7	74%
Cd	lbs/acre (x1000)	0.40	0.10	75%	0.10	75%
Cu	lbs/acre (x1000)	2.5	2.0	21%	0.80	69%
Pb	lbs/acre (x1000)	4.5	4.0	11%	1.5	67%
Ni	lbs/acre (x1000)	2.5	1.0	59%	0.80	68%
Zn	lbs/acre (x1000)	3.5	1.5	57%	0.80	77%
Cr	lbs/acre (x1000)	6.5	2.0	69%	2.5	62%
Fe	lbs/acre (x1000)	710	NA	NA	80	89%

* Negative percentages indicate Plot 2 export was higher than Plot 1 export.

Estimated Export from Plots 1, 2, and 3 is based on median normalized storm load multiplied by total rainfall during study period, approx. 16".

Column (3) represents the % reduction in export due to use of combination fertilizer + compost as compared to using fertilizer only.

Column (5) represents the % reduction in export due to use of compost as compared to using fertilizer only.

percent reduction due to using compost only, pollutant export was reduced from 36%-89%, and averaged 66%. Sediment export, represented by TSS, was reduced 88% by using compost as a soil amendment. A corresponding reduction in particulate phosphorus and nitrogen of over 70% was also observed. Fertilized soils may export over 8 times the sediment discharged from compost-amended soils. The chemical oxygen demand that may be exported from fertilized soils would be close to 4 times that exported from compost-amended soils. Compost amendment was observed to reduce COD export by over 70%. Metals reduction in runoff that may be attributed to the use of compost was between 62% and 89%. Phosphorus may be reduced in runoff up to 65% by using compost. Fertilized soils export approximately 3 times more total phosphorus than compost-amended soils. The soluble $\text{NH}_3\text{-N}$ and SKN exported may each be reduced by approximately 40% by amending soils with compost. The TKN and OXN exported from fertilized soils were approximately 3 times that exported from composted soils. Compost was observed to reduce the export of TKN by 70%, and oxidized nitrogen by over 60%. These significant reductions indicate that compost-amended soils may substantially reduce nonpoint pollution generated by normal practices for lawn establishment and maintenance.

The effects of the combined use of fertilizer and

compost are represented by the percent reductions in column (3) of Table 14. All but four constituents were substantially reduced by using a combination of fertilizer and compost instead of fertilizer only. Reductions ranged from 11% to 83%, and averaged 50%. Sediment reduction was nearly as high as that from compost alone, at 82%. COD reduction was observed to be slightly higher than from compost alone, at 83%. All analyzed metals were reduced by using a combination amendment of fertilizer and compost compared to fertilizer only. Similar metals reductions were observed for Plots 2 and 3, except for copper and lead which were exported in higher quantities from Plot 2 as compared to Plot 3. This study showed increased export of TSP, SKN, and OXN from Plot 2 which was treated with combination fertilizer and compost; export of OP from Plots 1 and 2 was approximately equal. The source of the excess appeared to be the fertilizer.

Soil Productivity and Quality of the Fescue

The qualitative results of the turfgrass grown in compost-amended soil were impressive. The crop grown, falcon fescue, was advertised to be drought resistant. During the study period from April to November, 1986, the rainfall was well below average. Despite the lack of rain, the compost amended plots grew, thickened, and developed a

rich green color. The unamended plot, in contrast, did not grow as well, was sparse, and had a pale yellow-green color. Because of exceedingly dry conditions June through September, weekly watering became necessary. Potable water from a Fairfax County Water Authority hydrant was used to water all three plots. The unamended Plot 1 recovered somewhat, but never developed the thickness or color observed for compost-amended Plots 2 and 3.

Sikora et al. (1980) reported that combined use of compost and fertilizer produced higher fescue yields, which indicated that compost increased the plant efficiency in the use of the commercial fertilizer. Though crop yield studies were not performed, the author and others who had watched the plots over the course of the study did not see a difference between the quality of the fescue grown in Plot 2 and Plot 3. For this reason, and because excess fertilizer was shown to have increased pollutant export in some instances, it does not appear that it would be necessary to use conventional fertilizer or a combination of fertilizer and compost for turfgrass establishment. Compost alone was observed to be sufficient to provide the required nutrients and micronutrients to produce a healthy fescue crop in this study. The improved quality and higher (observable) crop yield in the compost-amended Plots supports previous research reported by Barbarika et al.(1980), Parr et

al.(1978), and Utschig et al.(1986).

Moisture Retention for Improved Plant Uptake and Reduced Pollutant Export

The results illustrate that moisture is retained in the compost-amended soil more than in unamended soil as shown previously in Figure 14. Plot 1 runoff for the various constituents ranged from approximately 4 to 12.5 times the runoff from Plots 2 and 3 which were amended with compost. The amended Plots exhibited increased water infiltration and greater water storage capacity thus minimizing pollutant export and improving plant growth. This confirmed research performed by Parr et al.(1978). The crop growth in Plots 2 and 3 through extended dry periods confirmed Epstein et al.(1975) and Taylor et al.(1978) findings that compost-amended soils reduced water stress in plants during the growing season.

Difficulties and Errors

Several difficulties occurred during the field study. The most critical problem in conducting this study was the dependence on the weather. Dry weather forced the use of simulated rainfall. Had this study been performed during a year with average rainfall, several more runoff events, with perhaps more size variation, could have been monitored. A

larger sample population would have been more amenable to statistical analysis and could have provided a higher level of confidence in the data. Although the sample population was small (15 events), the data appear to be consistent.

For large runoff events, the sample collection containers overflowed and were flooded. On several occasions, a wet vacuum had to be used to dry out the manhole in order to allow the sample collection container to rest properly. On two occasions, the hydrostatic pressure built up under the manhole and pushed it from the ground. This was solved by constructing a plywood box, similar to sheeting and shoring, in which the manhole for each Plot could be placed. Though these boxes were flooded, the hydrostatic pressure never disturbed them or the manholes and sample containers.

Directing the runoff into the sample collection containers was difficult. Heavy plastic which lined the Plots was taped to the funnels from behind in order to reduce contamination from the runoff passing over the tape. The plastic on Plot 2 developed a leak late in the study, and despite efforts to patch it, no valid samples were collected after October 16, 1986 for Plot 2.

Measuring the volume of runoff in the field was a likely source of error. This involved reading the depth of the runoff collected and later comparing it to the carboy

calibration curve. Sample collection was often at night or while it was still raining, making it difficult to see the markings on the ruler and the fluid level. The preferred method to measure the volume was to collect all of the runoff and measure it in the Lab. This was not possible for the larger runoff volumes (over 5 liters).

Error may have been introduced by the fact that only one soil type was tested. In this respect, the results may be specific only to silty clay soil. However, the literature indicates that the results can be applied to a variety of soil types.

The analysis itself may have been a source of additional error. For the metals, the concentrations often were at or below the detection limits of atomic adsorption spectrophotometry. The detection limits were reported as the concentration whenever this occurred, thereby reducing this error in the data. Significant error was avoided by the Lab staff in their judgement to not analyze questionable samples for the organic constituents due to sample age. The strict adherence to a successful QA program also eliminated other laboratory errors.

V. Conclusions

The differences in pollutant export in stormwater runoff from identical land areas treated with fertilizer and/or compost were evaluated. Three plots were constructed with a Glenelg silty clay soil and seeded with Falcon fescue (Festuca 'Falcon'): Plot 1 received conventional 10-20-20 fertilizer, Plot 2 received a combination of conventional fertilizer and domestic wastewater sludge compost, and Plot 3 received only compost. The observable quality and yield of the crops grown in the three treatments were also evaluated.

The use of compost as a soil amendment proved to be very beneficial compared to conventional fertilizer. The following is a list of conclusions derived from this study:

- (1) The potential for a significant nonpoint pollution impact to receiving waters was greater for soils treated with fertilizer alone.
- (2) Compost amendment reduced the export of all monitored pollutants, and therefore soils amended with compost would have a reduced nonpoint impact on receiving waters.
- (3) Soils treated with a combination of compost and fertilizer were observed to have reduced export of all

but four monitored pollutants. The increased export of soluble orthophosphate, total soluble phosphorus, and oxidized nitrogen reflected an excess apparently due to the fertilizer application. The increased export of soluble Kjeldahl nitrogen may have been caused by excess insoluble N from the fertilizer application, which may have reacted with the organic matter, forming soluble organic nitrogen.

(4) Compost improved the water retention capability of the soil which reduced stormwater runoff volume and subsequently reduced pollutant export.

(5) Soil erosion, measured by total suspended solids export, was reduced by using compost as a soil amendment. Reduced total suspended solids export in the compost-amended soils correlated to the reduced export of insoluble phosphorus and nitrogen.

(6) Soils treated with compost alone were sufficient to establish and maintain high quality Falcon Fescue turfgrass. There were no observable differences between the quality of the turfgrass grown in the combination fertilizer/compost and in the compost alone. Therefore, fertilizer addition may not be necessary for Falcon Fescue establishment.

(7) Plant growth was supported during extended dry periods in compost-amended soils apparently because of

the stored water.

(8) Compost increased the cation exchange capacity (CEC) of the soil.

(9) Compost increased soil pH and enabled the soil to sustain an elevated pH level for up to one year.

(10) Compost amendment may be considered a Best Management Practice (BMP) and used instead of fertilizer for turfgrass production. Compost amendment could be considered in lieu of conventional fertilizer for turfgrass establishment and maintenance in residential, commercial, and public areas.

VI. Summary

The primary objective of this study was to compare the stormwater-borne pollutant export from identical land areas treated with fertilizer and/or composted domestic wastewater sludge (compost). Interest for the study was generated by a request to use the test compost as a soil amendment in a large new development located in the Occoquan drainage basin. The Occoquan watershed drains into the Occoquan Reservoir which provides drinking water for over 850,000 customers. To determine the effects on runoff from soils treated with compost, three plots were constructed in April, 1986, as follows: Plot 1 received conventional 10-20-20 fertilizer; Plot 2 received a combination of compost and reduced conventional fertilizer; and Plot 3 received only compost. Each plot was prepared with a Glenelg silty clay soil and seeded with Falcon fescue (Festuca 'Falcon') grass; the soil and seed type, and fertilizer and compost application rates were identical to those used in the development in a designated pilot area.

Runoff was collected for events occurring between May and November, 1986. Because of extremely dry weather, two simulated rainfall events were conducted in October to generate runoff for sample collection. Runoff was analyzed for the following pollutants: soluble orthophosphate as P,

total soluble phosphorus as P, total phosphorus as P, soluble ammonia as N, soluble Kjeldahl nitrogen as N, total Kjeldahl nitrogen as N, nitrite plus nitrate as N, total suspended solids, chemical oxygen demand, cadmium, copper, lead, nickel, zinc, chromium, and iron.

The export of all monitored pollutants was reduced by the use of compost. Compost was also found to substantially reduce stormwater runoff volume, reduce soil erosion, improve moisture retention in the soil, sustain plant growth during excessive dry periods, improve the quality of the crop, increase the cation exchange capacity of the soil, increase soil pH and sustain elevated soil pH. The use of fertilizer in combination with the compost did not provide any observable benefit. Instead, the fertilizer applied to compost-amended soil provided excessive soluble orthophosphate, total soluble phosphorus, and oxidized nitrogen which was subsequently exported from the test plot. Higher exports of soluble Kjeldahl nitrogen from the combination test plot may have been caused by excess insoluble nitrogen from the fertilizer, which may have reacted with organic matter, forming soluble organic nitrogen.

The use of compost as a soil amendment significantly reduced the potential for a nonpoint pollution impact to receiving waters. Compost amendment could be

considered in lieu of conventional fertilizer for turfgrass establishment and maintenance on residential, commercial, and public areas. Compost amendment may be considered a Best Management Practice (BMP) because it substantially reduces stormwater runoff volume and nonpoint pollutant export compared to the alternative traditional use of conventional fertilizer.

It should be noted that this study did not address the following issues:

- (1) the effect on pollutant export due to compost amendment in soils unlike the Glenelg variety, common in the study area.
- (2) the effect of compost-amended soils on humans in situations where the possibility of human exposure is greater (i.e., in recreational areas);
- (3) pathogens that may be found in compost, their disposition during amendment, and any related problems;
- (4) quantifiable plant uptake of metals, phosphorus, or nitrogen;
- (5) quantifiable crop yield from each treatment;
- (6) conditions for regulated uses of compost (i.e., potential problems with homeowners using compost in their vegetable gardens without regard to maintaining the pH above 6.5 to control plant metal uptake.

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APPENDIX A

Appendix A contains the raw data collected from this study:

Plot #

Lab ID #

Date of Event

Total Rain

Volume Collected

Concentrations for OP, TSP, TP, NH₃, SKN, TKN, OXN, COD, Cd, Cu, Pb, Ni, Zn, Cr, and Fe.

It also contains the author's log of field monitoring activity and raw survey data used to determine plot slopes and sizes.

Plot No.	Lab ID#	Date of Event	Total Rain (inches)	Average Intensity (in/hr)	Volume Collected (liters)	OP (mg/l)	TSP (mg/l)	TP (mg/l)	NH3 (mg/l)	SKN (mg/l)	TKN (mg/l)	OXN (mg/l)	TSS (mg/l)	COD (mg/l)	Cd (ug/l)	Cu (ug/l)	Pb (ug/l)	Ni (ug/l)	Zn (ug/l)	Cr (ug/l)	Fe (ug/l)
1	6494	5/20/86	0.49	0.23	3.19	0.08	0.09	1.47	2.02	2.59	8.75	1.78	1010	138	NA	NA	NA	NA	NA	NA	NA
2	6495	5/20/86	0.49	0.23	1.00	0.44	0.68	1.34	0.90	7.06	9.77	17.02	215	231	NA	NA	NA	NA	NA	NA	NA
3	6496	5/20/86	0.49	0.23	1.55	0.03	0.13	0.61	0.24	4.34	5.05	13.45	218	134	NA	NA	NA	NA	NA	NA	NA
1	6597	5/21/86	0.03	NA	1.05	NA	0.07	0.24	NA	5.02	6.40	NA	NA	359	6	12	50	21	21	NA	NA
2	6598	5/21/86	0.03	NA	0.39	NA	1.32	1.80	NA	13.99	19.69	NA	NA	359	9	113	160	36	31	NA	NA
3	6599	5/21/86	0.03	NA	0.74	NA	0.42	0.60	NA	9.19	9.69	NA	NA	270	6	45	56	21	32	NA	NA
1	6712	6/27/86	0.38	NA	1.15	0.10	0.16	1.79	2.15	6.36	10.38	1.55	1276	NA	6	18	139	61	182	NA	NA
2	6713	6/27/86	0.38	NA	0.32	0.66	0.85	1.80	4.51	15.21	21.70	42.30	NA	NA	11	125	113	21	78	NA	NA
3	6714	6/27/86	0.38	NA	0.32	0.82	1.00	2.40	4.43	9.90	18.22	1.05	NA	NA	23	34	50	21	72	NA	NA
1	6715	7/01/86	0.10	NA	1.44	0.12	0.17	0.81	2.92	5.79	8.44	4.41	776	NA	6	80	108	62	123	NA	NA
2	6716	7/01/86	0.10	NA	1.77	0.55	0.86	1.32	2.48	13.89	16.91	33.45	163	NA	9	116	78	54	81	NA	NA
3	6717	7/01/86	0.10	NA	1.98	0.17	0.19	0.53	0.95	2.99	4.50	5.19	150	NA	6	123	50	23	35	NA	NA
1	6726	7/02/86	0.70	NA	NA	0.09	NA	1.34	2.05	NA	5.56	5.21	1101	NA	6	94	147	68	140	NA	NA
2	6727	7/02/86	0.70	NA	NA	0.48	NA	1.50	0.73	NA	9.39	13.21	159	NA	6	48	65	27	43	NA	NA
3	6728	7/02/86	0.70	NA	NA	0.13	NA	0.61	0.48	NA	5.29	24.76	114	NA	6	29	65	31	32	NA	NA
1	6887	7/20/86	0.84	0.79	17.50	0.22	NA	1.17	NA	NA	5.07	4.13	838	NA	NA	NA	NA	NA	NA	NA	NA
2	6888	7/20/86	0.84	0.79	8.00	NA	NA	1.12	NA	NA	5.28	2.76	191	NA	NA	NA	NA	NA	NA	NA	NA
3	6889	7/20/86	0.84	0.79	14	NA	NA	0.57	NA	NA	5.19	2.72	136	NA	NA	NA	NA	NA	NA	NA	NA
1	6935	7/29/86	0.69	NA	4.00	0.08	0.10	2.70	0.98	3.05	11.55	3.94	2310	265	6	53	69	41	74	NA	NA
2	6936	7/29/86	0.69	NA	1.00	1.20	1.48	2.65	2.20	12.14	12.76	3.42	269	230	6	59	50	21	61	NA	NA
3	6937	7/29/86	0.69	NA	2.00	0.54	0.64	1.26	1.49	5.04	9.73	1.61	161	NA	6	18	182	21	47	NA	NA
1	7081	8/17/86	0.18	NA	2.36	0.45	0.45	2.70	0.23	1.88	8.70	1.76	2411	228	6	132	121	89	218	NA	NA
1	7083	8/19/86	0.37	NA	9.00	0.14	0.15	2.61	0.09	1.03	7.34	1.82	2947	198	6	189	304	120	295	NA	NA
2	7082	8/19/86	0.37	NA	3.10	0.55	0.77	3.28	0.14	4.47	10.67	6.51	1183	NA	6	113	278	48	174	NA	NA
3	7084	8/19/86	0.37	NA	3.00	0.87	0.94	1.70	0.68	6.07	8.95	3.93	1136	201	6	66	108	37	131	NA	NA
1	7112	8/20/86	0.72	NA	NA	0.20	0.16	0.54	0.05	0.75	1.59	0.27	281	44.3	6	23	50	21	51	NA	NA
2	7113	8/20/86	0.72	NA	NA	0.59	0.63	1.40	0.16	2.12	4.04	0.47	302	122	6	41	50	176	51	NA	NA
3	7114	8/20/86	0.72	NA	NA	0.19	0.24	0.54	0.04	2.69	4.20	1.93	216	123	6	25	50	176	40	NA	NA
1	7115	8/20/86	0.72	NA	NA	0.18	0.17	0.65	0.07	0.59	1.79	0.15	385	48	6	28	50	133	80	NA	NA
1	7208	8/28/86	0.37	NA	NA	NA	NA	0.96	NA	NA	2.97	NA	928	NA	8	48	50	250	100	NA	NA
2	7209	8/28/86	0.37	NA	NA	NA	NA	4.27	NA	NA	18.54	NA	829	NA	10	80	50	282	113	NA	NA
3	7210	8/28/86	0.37	NA	NA	NA	NA	0.48	NA	NA	5.71	NA	98	NA	8	26	50	229	54	NA	NA
1	7382	10/07/86	0.57	3.41	83.00	1.08	1.08	7.61	2.01	7.22	25.34	5.61	2718	412	32	216	180	70	340	154	NA
2	7380	10/07/86	0.57	3.41	5.20	0.63	0.76	2.00	0.61	3.65	9.37	0.91	2000	181.5	23	76	159	52	155	88	NA
3	7381	10/07/86	0.57	3.41	3.79	0.98	1.21	4.63	1.35	6.20	19.06	3.30	4162.5	494.5	37	185	204	89	341	142	NA
1	7419	10/14/86	0.31	NA	7.00	0.23	0.28	0.73	0.03	1.23	2.44	0.27	244	78.4	6	29	59	21	35	NA	NA
3	7421	10/14/86	0.31	NA	0.71	0.25	0.32	0.63	0.09	2.80	4.26	4.57	219	119	6	31	62	22	15	NA	NA
1	7422	10/16/86	0.28	1.31	25.70	0.22	0.22	0.22	0.03	1.01	1.01	0.51	633	95.4	6	49	51	21	63	26	NA
2	7424	10/16/86	0.28	1.59	1.25	1.26	2.03	3.04	0.05	9.40	15.94	0.01	579	313	6	80	73	37	115	29	NA
1	7426	10/16/86	0.10	0.03	2.00	0.27	0.47	0.74	0.09	2.02	3.17	0.37	235	104	6	45	64	31	62	111	NA
2	7427	10/16/86	0.10	0.03	12.00	0.59	1.17	1.17	0.23	5.05	6.87	0.85	171	148	6	32	50	34	34	20	NA
3	7428	10/16/86	0.38	0.03	5.00	0.47	0.75	2.25	0.02	NA	12.32	0.88	1234	226	6	61	71	34	115	54	NA
1	7504	10/25/86	0.39	NA	4.00	0.25	0.32	0.76	1.12	2.26	4.28	0.22	159	988	6	35	50	38	13	NA	12440
3	7505	10/25/86	0.39	NA	1.00	0.50	0.51	1.06	3.19	11.97	12.89	1.79	86	947	6	45	50	41	49	NA	650
1	7506	10/27/86	0.61	NA	190.00	0.70	0.72	1.34	0.09	0.90	5.08	0.28	1710	386	6	93	78	73	133	NA	28420
2	7507	10/27/86	0.61	NA	NA	0.45	NA	NA	0.74	2.07	8.82	0.35	1178	249	6	68	54	52	100	NA	8400
3	7508	10/27/86	0.61	NA	11.34	0.32	0.40	3.01	0.75	1.49	10.90	0.41	2172	493	6	59	58	60	98	NA	9300
1	7509	11/01/86	0.47	NA	14.00	0.16	0.26	0.60	0.05	0.75	1.47	0.11	266	360	6	31	50	44	37	NA	8600
2	7510	11/02/86	0.47	NA	NA	0.91	0.91	1.71	0.24	2.01	6.29	0.37	109	422	6	31	50	34	22	NA	837
3	7511	11/02/86	0.47	NA	5.00	0.19	0.30	0.55	0.12	1.46	7.50	0.29	166	988	6	28	50	29	27	NA	2771
1	7767	11/20/86	0.56	NA	NA	0.15	0.17	0.30	0.15	1.23	1.54	0.06	141	79.9	6	19	NA	21	9	NA	NA
2	7768	11/20/86	0.56	NA	NA	0.62	0.65	0.79	0.17	1.68	2.21	0.08	54	80	6	24	NA	21	6	NA	NA
3	7769	11/20/86	0.56	NA	NA	0.18	0.20	0.40	0.11	1.45	2.11	0.18	153	88.3	6	28	NA	21	15	NA	NA

Note: Rain amounts are approximated based on the rain gauge from the plot site. Intensities and more accurate rainfall data will be obtained from UOSA's records.

April

4-09-86 Finish seeding/dressing. Manholes in place, plots ready;

4-10-86 Angelotti, Byrd, Grizzard, Weand met on-site to discuss sampling set-up.

4-11-86 Light rain all day. Negligible amount. No runoff, no samples.

4-13-86 Light rain all day. Negligible amount. No runoff, no samples.

4-15-86 Big storm, approx. 1" rain. No samples(carboys not in place)

4-16-86 Light rain all day. Picked up carboys at OWML. Decided to buy calibrated carboys which were ordered and received on 4-21-86. No runoff, no samples.

4-17-86 Big storm, manholes popped out of the ground at plots 1 & 3 due to groundwater/hydrostatic pressure. Plot 2 manhole caught runoff-plastic at center front directed runoff properly. No carboys were in the ground, however, to catch samples. 1-1.2" rain.

4-18-86 Met Ron Choffrey (Fairfax County Wastewater Treatment Division) on-site to enlist his help with the floating manholes.

4-20-86 Light rain, on/off. Negligible amount. No samples.

4-21-86 Light rain, distinct storm event, approx. 0.2"/hr. Byrd and Fx.Co. staff work on manholes; cut holes in bottom, sides. Install funnel and carboys in plots 1 & 2; plot 3 manhole is found to be too shallow to install carboy. Fx.Co. staff will dig out manhole. Picked up and acid-cleaned new carboys.

4-22-86 Light rain, on/off.

May

5-06-86 Thunderstorm @ 8-8:30 pm. 0.1" rain. No runoff, no samples.

5-14-86 Rain 0.2", no runoff, no samples. Grass about 3-4" high, but sparse; ready for mowing.

5-15-86 Misting rain, negligible. No runoff, no samples.

5-20-86 - Heavy rain, 0.49". Collected samples;
Volume runoff: 1 @ 3.19L, 2 @ 1.0L, 3 @ 1.55L. *1*

5-20-86 Grass cut this afternoon by Fairfax County staff.
Thunderstorm 5-21-86 5-21-86, rain approximately 0.03".
Collected samples. Volume runoff: 1 @ 1.05L, 2 @ 0.30L, 3 @ 0.74L. *2*

5-26-86 - Light rain, approx 0.1", no runoff, no samples.
5-27-86

5-27-86 - Light rain, less than 0.1", no runoff, no samples.
5-28-86

June

6-11-86 Light rain, approx 0.1", no runoff, no samples.

6-17-86 Watered plots, .284" rain equivalent.

6-24-86 Rain 0.3", negligible runoff from plots 2 & 3; 0.71 L runoff from plot 1. *3*

6-27-86 Watered plots, 0.284" . Later in the day it rained 0.1", collected samples. Volume runoff: 1 @ 1.15 L, 2 @ 0.32 L, 3 @ 0.32 L. *4*

July

7-01-86 Rain 0.10", collected samples. Volume runoff: 1 @ 1.44 L, 2 @ 1.77 L, 3 @ 1.98 L. *5*

7-08-86 Watered plots, 0.568".

7-11-86 Watered plots, 0.284" and cut grass.

7-17-86 Watered plots, 0.284". Later received 0.25" rain. Runoff but not able to collect samples.

7-18-86 Rain 0.05", no runoff, no samples.

7-20-86 Rain 0.84". Collected samples. Volume runoff: 1 @ 17.5 L, 2 @ 8 L, 3 @ 14 L. *6*

7-29-86 Watered 0.284" and cut grass. Rain 0.41" @ 8 pm, collected samples. Volume runoff: 1 @ 4 L, 2 @ <1 L,

3 @ 2 L. *7*

August

8-02-86 Rain 0.1" day and 0.05" overnight; no runoff, no samples.

8-05-86 Watered 0.568", runoff only from plot 1; no sample collected.

8-06-86 Heavy rain, 3.66". Carboys overflowed into manholes which filled up.

8-11-86 Rain 0.18", runoff but no samples collected since plots still down from previous 8-06-86 rain.

8-13-86 Plots ready for business again thanks to Fx.Co. staff.

8-16-86 Rain 0.01"; no runoff, no samples.

8-17-86 Rain 0.18"; runoff only from plot 1, collected sample. *8*

8-18-86 Rain 0.05"; no runoff, no samples.

8-19-86 Rain 0.37" between 4-8 pm, still raining when samples were collected. Volumes runoff: 1 @ 9 L, 2 @ 3.1 L, 3 @ 2.5-3 L (lost one container. *9*

8-20-86 - Rain 0.72", collected samples. Plot 1 overflow, took 2 grabs.

8-21-86 Volume of 2 & 3 ?

8-25-86 Cut grass.

8-28-86 Rain .37", collected samples. Volumes ? *11*

September

9-16-86 Cut grass, raked grass, watered 0.284", limed plots, 29 lbs each, as per Hazel Peterson @ Fair Lakes.

9-18-86 Seeded plots 1,2,3 with 3 lbs Falcon Fescue/plot; topped with straw. Fertilized plots 1 & 2 with 1.5 lbs 10-10-10, all per Hazel Peterson @ Fair Lakes. Watered 0.284" all plots.

9-18-86 - Light rain, no runoff, no samples.

9-19-86

October

10-01-86 Rain 0.05"; no runoff, no samples.

10-02-86 Watered 0.284", cut grass; rain overnight, no samples.

10-07-86 Artificial rain, watered 0.568" in 10 minutes. Volumes runoff: Plot 1 overflowed carboy, 83 liters total; plot 2, 5.2 liters; plot 1, 3.79 liters. *12*

10-13-86 Rain overnight 0.25"; no runoff, no samples.

10-14-86 Rain overnight and still raining at 8:30 am when samples were collected, 0.31" rain. Volume runoff: 1 @ 7 L, 2 @ ?, 3 @ .71 L. Note that there was a hole in the plastic at plot 2 where the runoff is to be directed into the carboy; instead the runoff went into the manhole. *17*

10-16-86 Artificial rain. *13* Plot 1: 0.284" rain in 13 minutes, 1.31"/hr. Runoff 25.7 L ; Added 0.095" rain in 3:26 minutes and got 2L additional runoff. Plot 2: 0.284" rain in 10.75 minutes, 1.585"/hr. Runoff 1.25 L. Added 0.095" rain in 3:48 minutes and got 12 L additional runoff. Plot 3: 0.284" rain in 9.5 minutes, 1.794"/hr. Runoff < 1L, not enough to analyze. Added 0.095" rain in 3:19 minutes and got 5 L total volume after 0.38" rain total.

10-23-86 Cut grass.

10-25-86 Rain 0.39", runoff collected for plots 1 & 3 (hole in plastic of plot 2 broke through again causing leakage. Approx. volume runoff: 1 @ 4 L, 3 @ 1 L. *14*

10-27-86 Rain 0.61", plot 1 overflowed. Approx volume runoff: *15* 1 @ 190 liters, 2 @ 8 liters (some leakage suspected), 3 @ 11.36 L.

November

11-02-86 Rain 0.47", runoff collected. Volume runoff: 1 @ 14 L, 2 @ 1 L, 3 @ 5 L. Suspected leak in Plot 2 liner. *16*

11-20-86 Rain 0.56" rain, runoff collected. Volume runoff not recorded.

SURVEY DATA
PLOT SIZES AND SLOPES

Plot 1: Seed and Fertilizer

AB: 23' 8.5"= 23.708 ft CD: 23' 7.5"= 23.625 ft
BD: 23'11.0"= 23.917 ft AC: 23'11.5"= 23.958 ft

AREA = 0.5(ABxBD)+0.5(CDxAC) = 566.52 sf

Raw survey data subtracted
from elevation 100.00:

1)	96.26	1) - 7)	4.93%
2)	95.70	2) - 8)	5.01%
3)	96.29	3) - 9)	4.89%
4)	95.74	1) - 2)	4.72%
5)	95.20	3) - 2)	4.98%
6)	95.85	4) - 5)	4.56%
7)	95.08	6) - 5)	5.49%
8)	94.50	7) - 8)	4.91%
9)	95.12	9) - 8)	5.25%

Plot 3: Seed and Compost

AB: 23' 9.0"= 23.750 ft CD: 23' 8.5"= 23.708 ft
BD: 23'11.0"= 23.917 ft AC: 23'11.0"= 23.917 ft

AREA = 0.5(ABxBD)+0.5(CDxAC) = 567.52 sf

Plot 2: Seed, Fertilizer, and Compost

AB: 23' 9.0"= 23.750 ft CD: 23' 8.0"= 23.667 ft
BD: 23'11.0"= 23.917 ft AC: 23'10.5"= 23.875 ft

AREA = 0.5(ABxBD)+0.5(CDxAC) = 566.53 sf

Raw survey data subtracted
from elevation 100.00:

1)	96.56	1) - 7)	4.77%
2)	95.93	2) - 8)	4.27%
3)	96.66	3) - 9)	4.85%
4)	96.34	1) - 2)	5.31%
5)	95.59	3) - 2)	6.15%
6)	96.13	4) - 5)	6.33%
7)	95.42	6) - 5)	4.56%
8)	94.91	7) - 8)	4.31%
9)	95.50	9) - 8)	4.99%

Raw survey data subtracted
from elevation 100.00:

			Slopes
1)	96.99	1) - 7)	5.18%
2)	96.52	2) - 8)	5.85%
3)	96.97	3) - 9)	4.64%
4)	96.52	1) - 2)	3.96%
5)	95.99	3) - 2)	3.79%
6)	96.58	4) - 5)	4.47%
7)	95.75	6) - 5)	4.97%
8)	95.12	7) - 8)	5.31%
9)	95.86	9) - 8)	6.24%

APPENDIX B

Appendix B contains the tabulated data and calculations, including:

Weighted Average Concentration

Storm Load

Normalized Storm Yield (listed under "lbs/acre/in rain")

OP-Soluble Orthophosphate

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)
05/20/86	0.49	0.08	3.19	0.26	0.09	0.44	1.00	0.44	0.15	0.03	1.55	0.05	0.02
06/27/86	0.38	0.10	1.15	0.12	0.05	0.66	0.32	0.21	0.10	0.82	0.32	0.26	0.12
07/01/86	0.10	0.12	1.44	0.17	0.30	0.55	1.77	0.97	1.68	0.17	1.98	0.34	0.58
07/29/86	0.69	0.08	4.00	0.32	0.08	1.20	1.00	1.20	0.30	0.54	2.00	1.08	0.27
08/17/86	0.18	0.45	2.36	1.06	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/86	0.37	0.14	9.00	1.26	0.59	0.55	3.10	1.71	0.80	0.87	3.00	2.61	1.22
10/07/86	0.57	1.08	83.00	89.64	27.13	0.63	5.20	3.28	0.99	0.98	3.79	3.71	1.12
10/16/86	0.28	0.22	25.70	5.65	3.48	1.26	1.25	1.58	0.97	0.00	0.00	0.00	0.00
10/16/86	0.10	0.27	2.00	0.54	0.93	0.59	12.00	7.08	12.22	0.47	5.00	2.35	4.05
10/25/86	0.39	0.25	4.00	1.00	0.44					0.50	1.00	0.50	0.22
10/27/86	0.61	0.20	190.00	38.00	10.75					0.32	11.36	3.64	1.03
11/02/86	0.47	0.16	14.00	2.24	0.82					0.19	5.00	0.95	0.35
10/14/86	0.31	0.23	7.00	1.61	0.90					0.25	0.71	0.18	0.10

Wtd Avg Conc(mg/L) 0.41

0.64

0.44

lbs/in runoff (x 1000) 1.21

1.89

1.30

Average thru 10/16/86*

... load, mg 11.00

1.83

1.16

... lbs/acre/in rainfall (x 1000) 3.74

1.91

0.82

Average, all events, plots 1 & 3

... load, mg 10.91

1.83

1.20

... lbs/acre/in rainfall (x 1000) 3.58

1.91

0.70

*Note loads for 10/14/86 are not included since volume is not known

inches of runoff 0.26

0.02

0.03

Sum of Vol., L 346.84

25.64

35.71

Volume through 10-16-86 131.84

25.64

17.64

TSP-Total Soluble Phosphorus

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)
05/20/86	0.49	0.09	3.19	0.29	0.10	0.68	1.00	0.68	0.24	0.13	1.55	0.20	0.07
05/21/86	0.03	0.07	1.05	0.07	0.42	1.32	0.39	0.51	2.96	0.42	0.74	0.31	1.75
06/27/86	0.38	0.16	1.15	0.18	0.08	0.85	0.32	0.27	0.12	1.00	0.32	0.32	0.14
07/01/86	0.10	0.17	1.44	0.24	0.42	0.86	1.77	1.52	2.63	0.19	1.98	0.38	0.64
07/29/86	0.69	0.10	4.00	0.40	0.10	1.48	1.00	1.48	0.37	0.64	2.00	1.28	0.31
08/17/86	0.18	0.45	2.36	1.06	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/86	0.37	0.15	9.00	1.35	0.63	0.77	3.10	2.39	1.11	0.94	3.00	2.82	1.29
10/07/86	0.57	1.08	83.00	89.64	27.13	0.76	5.20	3.93	1.19	1.21	3.79	4.57	1.36
10/16/86	0.28	0.22	25.70	5.65	3.48	2.03	1.25	2.54	1.56	0.00	0.00	0.00	0.00
10/16/86	0.10	0.47	2.00	0.94	1.62	1.17	12.00	14.04	24.22	0.75	5.00	3.75	6.35
10/25/86	0.39	0.32	4.00	1.28	0.57					0.51	1.00	0.51	0.22
10/27/86	0.61	0.22	190.00	41.80	11.82					0.40	11.36	4.54	1.26
11/02/86	0.47	0.26	14.00	3.64	1.34					0.30	5.00	1.50	0.54
10/14/86	0.31	0.28	7.00	1.96	1.09					0.32	0.71	0.23	0.12
Wtd Avg Conc(mg/L)		0.43				1.02				0.55			
lbs/in runoff (x 1000)			1.26				3.02				1.64		
Average thru 10/16/86*													
... load, mg				11.06				2.96				1.49	
... lbs/acre/in rainfall (x 1000)					3.88				3.80				1.32
Average,all events,plots 1 & 3													
... load, mg				11.40				2.96				1.55	
... lbs/acre/in rainfall (x 1000)					3.83				3.80				1.08
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.26				0.02				0.03		
Sum of Vol., L			347.89				26.03				36.45		
Volume through 10-16-86			132.89				26.03				18.38		

TP-Total Phosphorus

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)
05/20/86	0.49	1.47	3.19	4.69	1.65	1.34	1.00	1.34	0.47	0.61	1.55	0.95	0.33
05/21/86	0.03	0.24	1.05	0.25	1.45	1.80	0.39	0.70	4.04	0.60	0.74	0.44	2.50
06/27/86	0.38	1.79	1.15	2.06	0.93	1.80	0.32	0.58	0.26	2.40	0.32	0.77	0.34
07/01/86	0.10	0.81	1.44	1.17	2.01	1.32	1.77	2.34	4.03	0.53	1.98	1.05	1.78
07/20/86	0.84	1.17	17.50	20.48	4.21	1.12	8.00	8.96	1.84	0.57	14.00	7.98	1.61
07/29/86	0.69	2.70	4.00	10.80	2.70	2.65	1.00	2.65	0.66	1.26	2.00	2.52	0.62
08/17/86	0.18	2.70	2.36	6.37	6.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/86	0.37	2.61	9.00	23.49	10.95	3.28	3.10	10.17	4.74	1.70	3.00	5.10	2.33
10/07/86	0.57	7.61	83.00	631.63	191.19	2.00	5.20	10.37	3.14	4.63	3.79	17.55	5.21
10/16/86	0.28	0.22	25.70	5.65	3.48	3.04	1.25	3.80	2.34	0.00	0.00	0.00	0.00
10/16/86	0.10	0.74	2.00	1.48	2.55	1.17	12.00	14.04	24.22	2.25	5.00	11.25	19.04
10/25/86	0.39	0.76	4.00	3.04	1.34					1.06	1.00	1.06	0.46
10/27/86	0.61	1.34	190.00	254.60	72.01					3.01	11.36	34.19	9.49
11/02/86	0.47	0.60	14.00	8.40	3.08					0.55	5.00	2.75	0.99
10/14/86	0.31	0.73	7.00	5.11	2.84					0.63	0.71	0.45	0.24
Wtd Avg Conc(mg/L)		2.66				1.54				1.66			
lbs/in runoff (x 1000)			7.90				4.76				5.04		
Average thru 10/16/86*													
... load, mg				64.37				5.00				4.33	
... lbs/acre/in rainfall (x 1000)					20.66				4.16				3.07
Average,all events,plots 1 & 3													
... load, mg				65.28				5.00				5.74	
... lbs/acre/in rainfall (x 1000)					20.44				4.16				3.00
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.27				0.03				0.04		
Sum of Vol., L			365.39				34.03				50.45		
Volume through 10-16-86			150.39				34.03				32.38		

NH3- Soluble Reactive Ammonia													
Date	Rainfall inches	conc mg/L	Plot 1			Plot 2				conc mg/L	Plot 3		
			volume L	load mg	lbs/acre/ in rain (x 10E3)	volume L	load mg	lbs/acre/ in rain (x 10E3)	volume L		load mg	lbs/acre/ in rain (x 10E3)	
05/20/86	0.49	2.02	3.19	6.44	2.27	0.90	1.00	0.90	0.32	0.24	1.55	0.37	0.13
06/27/86	0.38	2.15	1.15	2.47	1.12	4.51	0.32	1.44	0.66	4.43	0.32	1.42	0.63
07/01/86	0.10	2.92	1.44	4.20	7.25	2.48	1.77	4.39	7.57	0.95	1.98	1.88	3.18
07/29/86	0.69	0.98	4.00	3.92	0.98	2.20	1.00	2.20	0.55	1.49	2.00	2.98	0.73
08/17/86	0.18	0.23	2.36	0.54	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/86	0.37	0.09	9.00	0.81	0.38	0.14	3.10	0.43	0.20	0.68	3.00	2.04	0.93
10/07/86	0.57	2.01	83.00	166.83	50.50	0.61	5.20	3.15	0.95	1.35	3.79	5.10	1.51
10/16/86	0.28	0.03	25.70	0.77	0.48	0.05	1.25	0.06	0.04	0.00	0.00	0.00	0.00
10/16/86	0.10	0.09	2.00	0.18	0.31	0.23	12.00	2.76	4.76	0.02	5.00	0.10	0.17
10/25/86	0.39	1.12	4.00	4.48	1.98					3.19	1.00	3.19	1.38
10/27/86	0.61	0.09	190.00	17.10	4.84					0.75	11.36	8.52	2.36
11/02/86	0.47	0.05	14.00	0.70	0.26					0.12	5.00	0.60	0.22
10/14/86	0.31	0.03	7.00	0.21	0.12					0.09	0.71	0.06	0.03
Wtd Avg Conc(mg/L)		0.60				0.60				0.74			
lbs/in runoff (x 1000)			1.77				1.76				2.17		
Average thru 10/16/86*													
... load, mg				20.69				1.70				1.54	
... lbs/acre/in rainfall (x 1000)					7.09		1.67					0.81	
Average,all events,plots 1 & 3													
... load, mg				16.05				1.70				2.02	
... lbs/acre/in rainfall (x 1000)					5.46		1.67					0.87	
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.26				0.02				0.03		
Sum of Vol., L			346.84				25.64				35.71		

SKN-Soluble Kjeldahl Nitrogen

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acr in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)
05/20/86	0.49	2.59	3.19	8.26	2.91	7.06	1.00	7.06	2.49	4.34	1.55	6.73	2.32
05/21/86	0.03	5.02	1.05	5.27	30.31	13.99	0.39	5.46	31.38	9.19	0.74	6.80	38.37
06/27/86	0.38	6.36	1.15	7.31	3.32	15.21	0.32	4.87	2.21	9.90	0.32	3.17	1.41
07/01/86	0.10	5.79	1.44	8.34	14.39	13.89	1.77	24.59	42.42	2.99	1.98	5.92	10.02
07/29/86	0.69	3.05	4.00	12.20	3.05	12.14	1.00	12.14	3.04	5.04	2.00	10.08	2.47
08/17/86	0.18	1.88	2.36	4.44	4.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/86	0.37	1.03	9.00	9.27	4.32	4.47	3.10	13.86	6.46	6.07	3.00	18.21	8.33
10/07/86	0.57	7.22	83.00	599.26	181.39	3.65	5.20	18.98	5.75	6.20	3.79	23.48	6.97
10/16/86	0.28	1.01	25.70	25.96	15.99	9.40	1.25	11.75	7.24	0.00	0.00	0.00	0.00
10/25/86	0.39	2.26	4.00	9.04	4.00					11.97	1.00	11.97	5.19
10/27/86	0.61	0.90	190.00	171.00	48.37					1.49	11.36	16.93	4.70
11/02/86	0.47	0.75	14.00	10.50	3.85					1.46	5.00	7.30	2.63
10/14/86	0.31	1.23	7.00	8.61	4.79					2.80	0.71	1.99	1.09

Wtd Avg Conc(mg/L) 2.54

7.03

3.58

lbs/in runoff (x 1000) 7.50

20.74

10.57

Average thru 10/16/86*

... load, mg 75.59

10.97

8.26

... lbs/acre/in rainfall (x 1000) 28.88

11.22

7.77

Average, all events, plots 1 & 3

... load, mg 67.65

10.97

8.66

... lbs/acre/in rainfall (x 1000) 24.69

11.22

6.42

*Note loads for 10/14/86 are not included since volume is not known

inches of runoff 0.26

0.01

0.02

Sum of Vol., L 345.89

14.03

31.45

TKN-Total Kjeldahl Nitrogen

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)
05/20/86	0.49	8.75	3.19	27.91	9.83	9.77	1.00	9.77	3.44	5.05	1.55	7.83	2.70
05/21/86	0.03	6.40	1.05	6.72	38.65	19.69	0.39	7.68	44.16	9.69	0.74	7.17	40.45
06/27/86	0.38	10.38	1.15	11.94	5.42	21.70	0.32	6.94	3.15	18.22	0.32	5.83	2.60
07/01/86	0.10	8.44	1.44	12.15	20.97	16.91	1.77	29.93	51.64	4.50	1.98	8.91	15.08
07/20/86	0.84	5.07	17.50	88.73	18.22	5.28	8.00	42.24	8.68	5.19	14.00	72.66	14.64
07/29/86	0.69	11.55	4.00	46.20	11.55	12.76	1.00	12.76	3.19	9.73	2.00	19.46	4.77
08/17/86	0.18	8.70	2.36	20.53	19.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/86	0.37	7.34	9.00	66.06	30.80	10.67	3.10	33.08	15.42	8.95	3.00	26.85	12.28
10/07/86	0.57	25.34	83.00	2103.22	636.63	9.37	5.20	48.72	14.75	19.06	3.79	72.24	21.45
10/16/86	0.28	1.01	25.70	25.96	15.99	15.94	1.25	19.93	12.28	0.00	0.00	0.00	0.00
10/16/86	0.10	3.17	2.00	6.34	10.94	6.87	12.00	82.44	142.24	12.32	5.00	61.60	104.26
10/25/86	0.39	4.28	4.00	17.12	7.57					12.89	1.00	12.89	5.59
10/27/86	0.61	5.08	190.00	965.20	273.00					10.90	11.36	123.82	34.36
11/02/86	0.47	1.47	14.00	20.58	7.55					2.50	5.00	12.50	4.50
10/14/86	0.31	2.44	7.00	17.08	9.51					4.26	0.71	3.02	1.65
Weighted Avg Conc		9.40				8.62				8.62			
lbs/in runoff (x 1000)			27.72				25.42				25.45		
Average thru 10/16/86*													
... load, mg				219.61				26.68				25.69	
... lbs/acre/in rainfall (x 1000)					74.43				27.18				19.84
Average, all events, plots 1 & 3													
... load, mg				229.05				26.68				28.99	
... lbs/acre/in rainfall (x 1000)					74.42				27.18				17.62
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.27				0.03				0.04		
Sum of Vol., L			365.39				34.03				50.45		

OXN- Nitrite + Nitrate

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)
05/20/86	0.49	1.78	3.19	5.68	2.00	77.02	1.00	77.02	27.12	13.45	1.55	20.85	7.20
06/27/86	0.38	1.55	1.15	1.78	0.81	42.30	0.32	13.54	6.15	1.05	0.32	0.34	0.15
07/01/86	0.10	4.41	1.44	6.35	10.96	33.45	1.77	59.21	102.15	5.19	1.98	10.28	17.39
07/20/86	0.84	4.13	17.50	72.28	14.85	2.76	8.00	22.08	4.54	2.72	14.00	38.08	7.67
07/29/86	0.69	3.94	4.00	15.76	3.94	3.42	1.00	3.42	0.86	1.61	2.00	3.22	0.79
08/17/86	0.18	1.76	2.36	4.15	3.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/86	0.37	1.82	9.00	16.38	7.64	6.51	3.10	20.18	9.41	3.93	3.00	11.79	5.39
10/07/86	0.57	5.61	83.00	465.63	140.94	0.91	5.20	4.73	1.43	3.30	3.79	12.49	3.71
10/16/86	0.28	0.51	25.70	13.11	8.08	0.01	1.25	0.01	0.01	0.00	0.00	0.00	0.00
10/16/86	0.10	0.37	2.00	0.74	1.28	0.85	12.00	10.20	17.60	0.88	5.00	4.40	7.45
10/25/86	0.39	0.22	4.00	0.88	0.39					1.79	1.00	1.79	0.78
10/27/86	0.61	0.28	190.00	53.20	15.05					0.41	11.36	4.66	1.29
11/02/86	0.47	0.11	14.00	1.54	0.57					0.29	5.00	1.45	0.52
10/14/86	0.31	0.27	7.00	1.89	1.05					4.57	0.71	3.24	1.77
Weighted Avg Conc		1.81				6.25				2.26			
lbs/in runoff (x 1000)			5.33				18.44				6.69		
Average thru 10/16/86*													
... load, mg				60.19			21.04				10.14		
... lbs/acre/in rainfall (x 1000)					19.45				16.93				4.73
Average,all events,plots 1 & 3													
... load, mg				47.10			21.04				7.06		
... lbs/acre/in rainfall (x 1000)					15.11				16.93				3.61
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.27				0.03				0.04		
Sum of Vol., L			364.34				33.64				49.71		

TSS-Total Suspended Solids

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)
05/20/86	0.49	1010	3.19	3222	1134	215	1.00	215	76	218	1.55	338	117
07/01/86	0.1	776	1.44	1117	1928	163	1.77	289	498	150	1.98	297	503
07/20/86	0.84	838	17.50	14665	3012	191	8.00	1528	314	136	14.00	1904	384
07/29/86	0.69	2310	4.00	9240	2310	269	1.00	269	67	161	2.00	322	79
08/17/86	0.18	2411	2.36	5690	5454	0	0.00	0	0	0	0.00	0	0
08/19/86	0.37	2947	9.00	26523	12368	1183	3.10	3667	1710	1136	3.00	3408	1559
10/07/86	0.57	2718	83.00	225594	68286	2000	5.20	10400	3148	4162.5	3.79	15776	4684
10/16/86	0.28	633	25.70	16268	10024	579	1.25	724	446	0	0.00	0	0
10/16/86	0.1	235	2.00	470	811	171	12.00	2052	3540	1234	5.00	6170	10443
10/25/86	0.39	159	4.00	636	281					86	1.00	86	37
10/27/86	0.61	1710	190.00	324900	91896					2172	11.36	24674	6846
11/02/86	0.47	266	14.00	3724	1367					166	5.00	830	299
10/14/86	0.31	244	7.00	1708	951					219	0.71	155	85
Weighted Avg Conc		1745				575				1093			
lbs/in runoff (x 1000)			5144				1694				3226		
Average thru 10/16/86*													
... load, mg				33643				2127				3135	
... lbs/acre/in rainfall (x 1000)					11703				1089				1974
Average, all events, plots 1 & 3													
... load, mg				48751				2127				4151	
... lbs/acre/in rainfall (x 1000)					15371				1089				1926
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.27				0.02				0.04		
Sum of Vol., L			363.19				33.32				49.39		

COD-Chemical Oxygen Demand

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)	conc mg/L	volume L	load mg	lbs/acre/ in rain (x 10E3)
05/20/86	0.49	138	3.19	440	155	231	1.00	231	81	134	1.55	208	72
05/21/86	0.03	359	1.05	377	2168	359	0.39	140	805	270	0.74	200	1127
08/17/86	0.18	228	2.36	538	516	0	0.00	0	0	0	0.00	0	0
10/07/86	0.57	412	83.00	34196	10351	182	5.20	944	286	495	3.79	1874	556
10/16/86	0.28	95	25.70	2452	1511	313	1.25	391	241	0	0.00	0	0
10/16/86	0.1	104	2.00	208	359	148	12.00	1776	3064	226	5.00	1130	1913
10/25/86	0.39	988	4.00	3952	1748					947	1.00	947	411
10/27/86	0.61	386	190.00	73340	20744	249				493	11.36	5600	1554
11/02/86	0.47	360	14.00	5040	1850	422				988	5.00	4940	1779
10/14/86	0.31	78	7.00	549	305					119	0.71	84	46
08/19/86	0.37	198	9.00	1782	831					201	3.00	603	276
Weighted Avg Conc		360				176				485			
lbs/in runoff (x 1000)			1061				517				1432		
Average thru 10/16/86*													
... load, mg				6369				580				569	
... lbs/acre/in rainfall (x 1000)					2510				746				611
Average,all events,plots 1 & 3													
... load, mg				11170				580				1417	
... lbs/acre/in rainfall (x 1000)					3685				746				703
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.26				0.01				0.02		
Sum of Vol., L			341.30				19.84				32.15		

Cd-Cadmium

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)
05/21/86	0.03	6	1.05	6	36	9	0.39	4	20	6	0.74	4	25
06/27/86	0.38	6	1.15	7	3	11	0.32	4	2	23	0.32	7	3
07/01/86	0.10	6	1.44	9	15	9	1.77	16	27	6	1.98	12	20
07/29/86	0.69	6	4.00	24	6	6	1.00	6	2	6	2.00	12	3
08/17/86	0.18	6	2.36	14	14	0	0.00	0	0	0	0.00	0	0
08/19/86	0.37	6	9.00	54	25	6	3.10	19	9	6	3.00	18	8
10/07/86	0.57	32	83.00	2656	804	22.5	5.20	117	35	37	3.79	140	42
10/16/86	0.28	6	25.70	154	95	6	1.25	8	5	0	0.00	0	0
10/16/86	0.10	6	2.00	12	21	6	12.00	72	124	6	5.00	30	51
10/25/86	0.39	6	4.00	24	11					6	1.00	6	3
10/27/86	0.61	6	190.00	1140	322					6	11.36	68	19
11/02/86	0.47	6	14.00	84	31					6	5.00	30	11
10/14/86	0.31	6	7.00	42	23					6	0.71	4	2
Wtd Avg Conc(ug/L)		12				10				10			
lbs/in runoff (x 1000)		0.036				0.029				0.028			
Average thru 10/16/86*													
... load, ug				326				27				25	
... lbs/acre/in rainfall (x 1000)					0.11				0.02				0.02
Average,all events,plots 1 & 3													
... load, ug				325								26	
... lbs/acre/in rainfall (x 1000)					0.11								0.01
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.26				0.02				0.03		
Sum of Vol., L			344.70				25.03				34.90		

Cu- Copper

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)
05/21/86	0.03	12	1.05	12.60	72	113	0.39	44.07	253	45	0.74	33.30	188
06/27/86	0.38	18	1.15	20.70	9	125	0.32	40.00	18	34	0.32	10.88	5
07/01/86	0.10	80	1.44	115.20	199	116	1.77	205.32	354	123	1.98	243.54	412
07/29/86	0.69	53	4.00	212.00	53	59	1.00	59.00	15	18	2.00	36.00	9
08/17/86	0.18	132	2.36	311.52	299	0	0.00	0.00	0	0	0.00	0.00	0
08/19/86	0.37	189	9.00	1701.0	793	113	3.10	350.30	163	66	3.00	198.00	91
10/07/86	0.57	216	83.00	17928.0	5427	76	5.20	395.20	120	184.5	3.79	699.26	208
10/16/86	0.28	49	25.70	1259.3	776	80	1.25	100.00	62	0	0.00	0.00	0
10/16/86	0.10	45	2.00	90.0	155	32	12.00	384.00	663	61	5.00	305.00	516
10/25/86	0.39	35	4.00	140.0	62					45	1.00	45.00	20
10/27/86	0.61	93	190.00	17670	4998					59	11.36	670.24	186
11/02/86	0.47	31	14.00	434	159					28	5.00	140.00	50
10/14/86	0.31	29	7.00	203.0	113					31	0.71	22.01	12
Wtd Avg Conc(ug/L)		116				63				69			
lbs/in runoff (x 1000)		0.34				0.19				0.20			
Average thru 10/16/86*													
... load, ug		2406				175				170			
... lbs/acre/in rainfall (x 1000)		0.86				0.18				0.16			
Average,all events,plots 1 & 3													
... load, ug		3084				175				185			
... lbs/acre/in rainfall (x 1000)		1.01				0.18				0.13			
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff		0.26				0.02				0.03			
Sum of Vol., L		344.70				25.03				34.90			

Pb-Lead

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc ug/L	volume L	load ug	lbs/acre/ in rain (x10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x10E6)
05/21/86	0.03	50	1.05	53	302	160	0.39	62	359	56	0.74	41	234
06/27/86	0.38	139	1.15	160	73	113	0.32	36	16	50	0.32	16	7
07/01/86	0.10	108	1.44	156	268	78	1.77	138	238	50	1.98	99	168
07/29/86	0.69	69	4.00	276	69	50	1.00	50	13	182	2.00	364	89
08/17/86	0.18	121	2.36	286	274	0	0.00	0	0	0	0.00	0	0
08/19/86	0.37	304	9.00	2736	1276	278	3.10	862	402	108	3.00	324	148
10/07/86	0.57	180	83.00	14940	4522	159	5.20	824	249	203.5	3.79	771	229
10/16/86	0.28	51	25.70	1311	808	73	1.25	91	56	0	0.00	0	0
10/16/86	0.10	64	2.00	128	221	50	12.00	600	1035	71	5.00	355	601
10/25/86	0.39	50	4.00	200	88					50	1.00	50	22
10/27/86	0.61	78	190.00	14820	4192					58	11.36	659	183
11/02/86	0.47	50	14.00	700	257					50	5.00	250	90
10/14/86	0.31	59	7.00	413	230					62	0.71	44	24
Wtd Avg Conc(ug/L)		105				106				85			
lbs/in runoff (x 1000)		0.31				0.31				0.25			
Average thru 10/16/86*													
... load, ug		2227				296				219			
... lbs/acre/in rainfall (x 1000)		0.87				0.26				0.16			
Average,all events,plots 1 & 3													
... load, ug		2783				296				229			
... lbs/acre/in rainfall (x 1000)		0.97				0.26				0.14			
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff		0.26				0.02				0.03			
Sum of Vol., L		344.70				25.03				34.90			

Ni-Nickel

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)
05/21/86	0.03	21	1.05	22	127	36	0.39	14	81	21	0.74	16	88
06/27/86	0.38	61	1.15	70	32	21	0.32	7	3	21	0.32	7	3
07/01/86	0.10	62	1.44	89	154	54	1.77	96	165	23	1.98	46	77
07/29/86	0.69	41	4.00	164	41	21	1.00	21	5	21	2.00	42	10
08/17/86	0.18	89	2.36	210	201	0	0.00	0	0	0	0.00	0	0
08/19/86	0.37	120	9.00	1080	504	48	3.10	149	69	37	3.00	111	51
10/07/86	0.57	70	83.00	5810	1759	52	5.20	268	81	89	3.79	337	100
10/16/86	0.28	21	25.70	540	333	37	1.25	46	28	0	0.00	0	0
10/16/86	0.10	31	2.00	62	107	34	12.00	408	704	34	5.00	170	288
10/25/86	0.39	38	4.00	152	67					41	1.00	41	18
10/27/86	0.61	73	190.00	13870	3923					60	11.36	682	189
11/02/86	0.47	44	14.00	616	226					29	5.00	145	52
10/14/86	0.31	21	7.00	147	82					22	0.71	16	9

Wtd Avg Conc(ug/L) 66

40

46

lbs/in runoff (x 1000) 0.20

0.12

0.14

Average thru 10/16/86*

... load, ug 894

112

81

... lbs/acre/in rainfall (x 1000) 0.36

0.13

0.07

Average,all events,plots 1 & 3

... load, ug 1756

112

124

... lbs/acre/in rainfall (x 1000) 0.58

0.13

0.07

*Note loads for 10/14/86 are not included since volume is not known

inches of runoff 0.26

0.02

0.03

Sum of Vol., L 344.70

25.03

34.90

Zn-Zinc

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)
05/21/86	0.03	21	1.05	22	127	31	0.39	12	70	32	0.74	24	134
06/27/86	0.38	182	1.15	209	95	78	0.32	25	11	72	0.32	23	10
07/01/86	0.10	123	1.44	177	306	81	1.77	143	247	35	1.98	69	117
07/29/86	0.69	74	4.00	296	74	61	1.00	61	15	47	2.00	94	23
08/17/86	0.18	218	2.36	514	493	0	0.00	0	0	0	0.00	0	0
08/19/86	0.37	295	9.00	2655	1238	174	3.10	539	252	131	3.00	393	180
10/07/86	0.57	340	83.00	28220	8542	155	5.20	806	244	341	3.79	1292	384
10/16/86	0.28	63	25.70	1619	998	115	1.25	144	89	0	0.00	0	0
10/16/86	0.10	62	2.00	124	214	34	12.00	408	704	115	5.00	575	973
10/25/86	0.39	13	4.00	52	23					49	1.00	49	21
10/27/86	0.61	133	190.00	25270	7147					98	11.36	1113	309
11/02/86	0.47	37	14.00	518	190					27	5.00	135	49
10/14/86	0.31	35	7.00	245	136					15	0.71	11	6

Wtd Avg Conc(ug/L) 174

85

108

lbs/in runoff (x 1000) 0.51

0.25

0.32

Average thru 10/16/86*

... load, ug 3760

238

274

... lbs/acre/in rainfall (x 1000) 1.34

0.18

0.20

Average, all events, plots 1 & 3

... load, ug 4609

238

291

... lbs/acre/in rainfall (x 1000) 1.51

0.18

0.17

*Note loads for 10/14/86 are not included since volume is not known

inches of runoff 0.26

0.02

0.03

Sum of Vol., L 344.70

25.03

34.90

Cr-Chromium

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)
10/07/86	0.57	154	83.00	12782	3869	88	5.20	458	139	142	3.79	538	160
10/16/86	0.28	26	25.70	668	412	29	1.25	36	22	0	0.00	0	0
10/16/86	0.1	111	2.00	222	383	20	12.00	240	414	54	5.00	270	457
Wtd Avg Conc(ug/L)		124				40				92			
lbs/in runoff (x 1000)			0.36				0.12				0.27		
Average thru 10/16/86*													
... load, ug				4557				245				269	
... lbs/acre/in rainfall (x 1000)					1.55				0.19				0.21
Average,all events,plots 1 & 3													
... load, ug				4557				245				269	
... lbs/acre/in rainfall (x 1000)					1.55				0.19				0.21
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.08				0.01				0.01		
Sum of Vol., L			110.70				18.45				8.79		

Fe-Iron

Date	Rainfall inches	Plot 1				Plot 2				Plot 3			
		conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E3)	conc ug/L	volume L	load ug	lbs/acre/ in rain (x 10E6)
10/25/86	0.39	12440	4.00	49760	22014					650	1.00	650	282
10/27/86	0.61	28420	190.00	5399800	1527304					9300	11.36	105648	29313
11/02/86	0.47	8600	14.00	120400	44198					2771	5.00	13855	4989
Wtd Avg Conc(ug/L)		26779				NA				6921			
lbs/in runoff (x 1000)			79				NA					20	
Average thru 10/16/86*													
... load, ug				NA				NA				NA	
... lbs/acre/in rainfall (x 1000)					NA				NA				NA
Average,all events,plots 1 & 3													
... load, ug				1856653								40051	
... lbs/acre/in rainfall (x 1000)					531.17								11.53
*Note loads for 10/14/86 are not included since volume is not known													
inches of runoff			0.16									0.01	
Sum of Vol., L			208.00									17.36	

APPENDIX C

Soil CEC and Individual Cation Contributions before and after the study for the test soil. Net change after study completion.

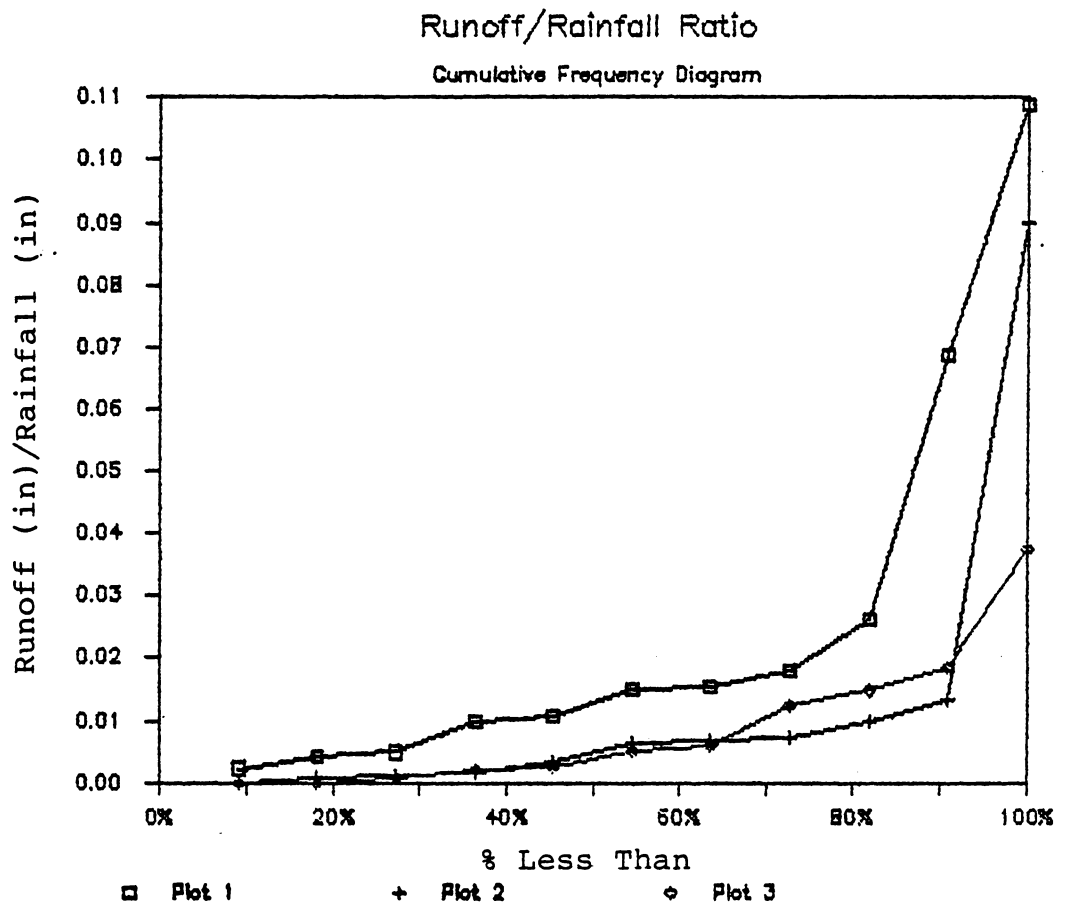
Soil CEC and Individual Cation Contributions

	Cations mg/100 g				
	Ca++	Mg++	K+	Na+	CEC
Prior to Fertilizer and/or Compost	-----				
Plot 1	182.6	37.2	15.5	1.7	237.0
Plot 2	174.6	28.4	15.8	1.5	220.3
Plot 3	165.4	27.4	15.8	1.4	210.0
After Fertilizer and/or Compost Application					
Plot 1	174.6	27.4	12.5	1.6	216.1
Plot 2	530.0	41.2	21.2	1.2	593.6
Plot 3	486.0	35.0	7.9	1.8	530.7
Net Change After 1 Year Since Fertilizer and/or Compost Application					
Plot 1	(8.0)	(9.8)	(3.0)	(0.1)	(20.9)
Plot 2	355.4	12.8	5.4	(0.3)	373.3
Plot 3	320.6	7.6	(7.9)	0.4	320.7

Note: CEC analyses were performed by the Fairfax County Environmental Laboratory in April 1987.

APPENDIX D

Cumulative Frequency Diagram of Runoff/Rainfall Ratio



Cumulative Frequency Diagram of Runoff/Rainfall Ratio

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